Journal of Applied Geophysics 135 (2016) 281–287

Contents lists available at ScienceDirect

Journal of Applied Geophysics

journal homepage: www.elsevier.com/locate/jappgeo

Improving the Curie depth estimation through optimizing the spectral block dimensions of the aeromagnetic data in the Sabalan geothermal field

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ARTICLE INFO

Article history:
Received 7 August 2016
Received in revised form 24 October 2016
Accepted 25 October 2016
Available online 27 October 2016

Keywords:
Aeromagnetic data
Curie point
Optimal block size
Power spectrum
Sabalan

ABSTRACT

The Curie point depth is of great importance in characterizing geothermal resources. In this study, the Curie isodepth map was provided using the well-known method of dividing the aeromagnetic dataset into overlapping blocks and analyzing the power spectral density of each block separately. Determining the optimum block dimension is vital in improving the resolution and accuracy of estimating Curie point depth. To investigate the relation between the optimal block size and power spectral density, a forward magnetic modeling was implemented on an artificial prismatic body with specified characteristics. The top, centroid, and bottom depths of the body were estimated by the spectral analysis method for different block dimensions. The result showed that the optimal block size could be considered as the smallest possible block size whose corresponding power spectrum represents an absolute maximum in small wavenumbers. The Curie depth map of the Sabalan geothermal field and its surrounding areas, in the northwestern Iran, was produced using a grid of 37 blocks with different dimensions from 10 × 10 to 50 × 50 km^2, which showed at least 50% overlapping with adjacent blocks. The Curie point depth was estimated in the range of 5 to 21 km. The promising areas with the Curie point depths less than 8.5 km are located around Mountain Sabalan encompassing more than 90% of known geothermal resources in the study area. Moreover, the Curie point depth estimated by the improved spectral analysis is in good agreement with the depth calculated from the thermal gradient data measured in one of the exploratory wells in the region.

1. Introduction

The rocky formations in the Earth's crust lose their magnetic properties below a certain depth known as the Curie point depth. Estimating the Curie point depth and recognizing the shallow geothermal basins are central issues in utilizing geothermal resources. The Curie point depth depends, to a large degree, on geological settings. Normally, it is less than 10 km in volcanic and geothermal regions, equal to 5 to 15 km in island arcs and ridges, more than 20 km in plateaus, and more than 30 km in trenches (Tanaka et al., 1999).

Several studies have been conducted in various geothermal regions to determine the Curie point depth. Bhattacharyya and Leu (1975) modeled the Curie point isothermal level to identify geothermal resources in Yellowstone National Park, and estimated a depth of about 6 km below sea level for the Curie point. Shuey et al. (1977) and Bouligand et al. (2009) modeled the depth of the Curie temperature in the western part of the United States using spectral analysis and fractal spectral analysis, respectively. In a study by Connard et al. (1983), they estimated the Curie point depth at about 9 km in the Central Eragon Prptansyl region, using spectral methods. Blakely (1988) implemented the estimation of the Curie point depth in Nevada, using statistical specifications of magnetic anomalies, with other regional geological and geophysical data for tectonically interpretation of the region. Tanaka et al. (1999) estimated the maximum depth of the magnetic crust in a vast area in East and South-East Asia using spectral analysis of the residual magnetic anomalies. Dolmaz et al. (2005) estimated the depth of the Curie point in the western Antalya using 53 overlapping blocks of 90 × 90 km, and showed that the minimum depth of the Curie point is related to the existing graben structures in the region. Hsieh et al. (2014) estimated the magnetic anomaly maps and the Curie point isotherm in Taiwan and surrounding areas by converting the spatial data into the frequency domain and using two-dimensional power spectrum. Khojamli et al. (in press, 2016) investigated the depth of the magnetic sources in Ardabil province, in northwest of Iran, using the centroid depth method and the forward modeling of the spectral peak method. The results of their studies showed a Curie point map varies from 10 to 18.6 km in depth.

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http://dx.doi.org/10.1016/j.jappgeo.2016.10.018
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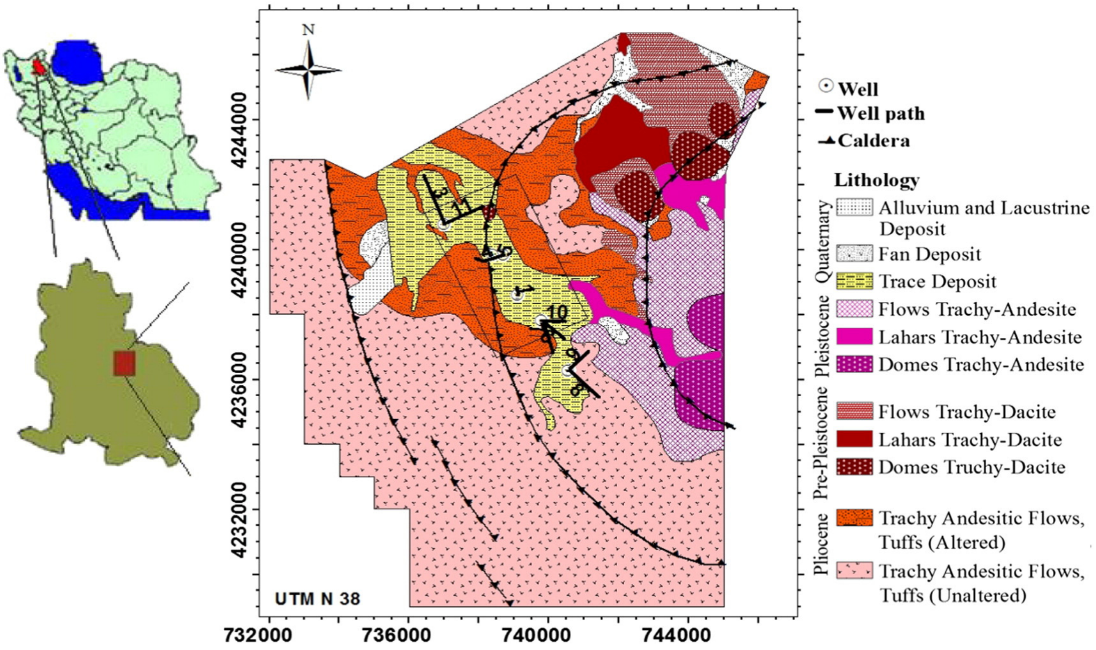

Fig. 1. Location and geological map of Sabalan geothermal field (adopted from Morrison, 1999).

In this study, the Curie point depth is estimated using the well-known method of power spectral analysis of aeromagnetic data enhanced by calculating the power spectra for optimized block sizes.

2. Geological setting

The study area encompasses the Sabalan geothermal field and its surroundings, located in Ardabil province in northwest Iran (Fig. 1). The geological setting in the Sabalan area has been discussed in detail by Bogie et al. (2000). Mt. Sabalan is a large stratovolcano, consisting of an extensive central edifice uilt on a probable tectonic horst of underlying intrusive and effusive volcanic rocks. Enormous amounts of discharged magma caused the formation of a collapsed caldera about 12 km in diameter, and a depression of about 400 m (Morrison, 1999). As shown in Fig. 1, three arcuate ring structures are identified, including the inner and outer caldera structures and the strongly developed arcuate structure interpreted to be a decollement fault that is very obvious in the field, occurring as a curved scarp, up to 100–200 m high. The lava flows in the Sabalan are mostly trachy-andesite and dacite with alternating explosive phases. The four major units used for the original geologic study and mapping of Northwest Sabalan are Quaternary alluvium, fan and terrace deposits; Pleistocene post-caldera trachy-andesitic flows; Pleistocene syn-caldera trachy-dacitic to trachy-andesitic domes and Pliocene pre-caldera trachy-andesitic lavas, tuffs and pyroclastic (SKM, 2005).

3. Theoretical development

3.1. Governing equations

Bhattacharyya and Leu (1975) presented a method to determine the centroid depth of parallel prismatic hypothetical magnetic resources to investigate the Curie point depth in Yellowstone Park. If it is assumed that the two-dimensional magnetic masses are magnetized quite randomly and independently, the radially averaged power spectral density of the total magnetic field, $P(k)$, can be simplified as follow (Blakely, 1995; Stampolidis et al., 2005):

$$P(k) = A_1\,exp(-2|k|Z_t)(1-exp(-|k|(Z_b-Z_t)))^2 \tag{1}$$

where, A_1 is a constant number, Z_t and Z_b are depth to the top and bottom of the magnetic source, respectively, and k shows the wavenumber of the magnetic field.

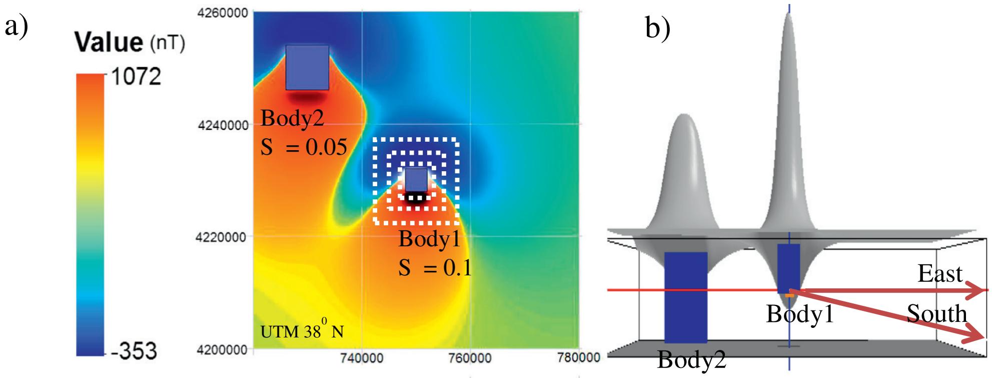

Fig. 2. a) Calculated magnetic field using forward modeling (Dashed white lines represent the different block dimensions); b) 3-D geometry of the synthetic magnetic bodies.