Interpretation and modeling of airborne and ground magnetometry data for a geothermal reservoir in the Abgarm region, Mahallat-Iran

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SUMMARY

Abgarm of Mahallat is a well-known geothermal region in Iran. So far lots of geophysical surveys have been conducted to evaluate the reservoir beneath the area. This study has taken the opportunity to analyze the region by using magnetic and aeromagnetic methods, simultaneously, to estimate the profound expansion of the leading geothermal anomaly and its sub-branches. The form of the anomaly was determined from aeromagnetic and ground magnetic grids, and in order to investigate the anomalies thoroughly, a 3D inverse modeling has been utilized. Using several methods to estimate the depth of anomaly lead us to the actual values. Hence, Euler's depth estimation and power spectrum depth estimation are applied to the aeromagnetic and magnetic data. The interpretation of the entire methods afforded the consonant and comprehensive interpretation that perfectly accommodates previous studies in this region.

Keywords: Geothermal, Mahallat, Magnetometry, Aeromagnetic, 3D inversion

INTRODUCTION

The earth is an extreme thermal energy resource that its heat is directed to the ground surface by volcano eruptions and underground waters. The heat continuously flows from the core to the out of it and transfers to the upper levels. While there is enough temperature and pressure together, the rocks melt and form the lava; According to the lava's density, it rises towards the crust slowly. Sometimes the lava reaches the surface and flows on the ground; however, usually, it remains subsurface and makes the rocks and infiltrated waters hot. These hot waters come to the surface through the fractures and porosities and emerge as hot water springs and geysers. Most of these waters are trapped in porous rocks and crustal fractures and provide the natural warm water resources, known as geothermal resources (Huenges et al 2010). By studying geothermal anomalies, it turns out that superficial and groundwaters carry heat to the surface or shallower areas by penetrating to the deeper layers; this heat circulation is caused by the specific gravity of the cold and hot subsurface fluid (Dickson et al 1995). Mahallat is one of the essential geothermal areas in central Iran. Some of the geological evidence to back up this claim are numerous hot springs, intrusive granite, granodiorite on sedimentary beds, and obvious alterations (Oskooi et al. 2016; Darijani et al 2014; Geological specifications of Mahallat 2008; Kahak and Golpayegan geological maps, 1995). Oskooi et al. (2016) have indicated that a structure with a 1.82 structure index shows a vertical cylinder; it is a geothermal spring formed by a significant mass of mafic or ultramafic intrusive igneous rocks. Oskooi and Darijani (2013) also confirm that the top of the cylinder anomaly is cone-shaped. In this study, Mahallat hot springs were explored using magnetic and aeromagnetic methods simultaneously. In general, magnetic studies can help us study the geothermal sources. Mafic intrusive bodies are closely associated with magnetic rocks, which are highly susceptible. This article tried to find the location of the geothermal heat source by interpreting the magnetic and aeromagnetic data together.

Methodology

By using standard Euler deconvolution, we can estimate the position of the target body. This approach utilizes three orthogonal gradients of potential quantities. Three-dimensional Euler's equation is shown as below (Reid et al 1990):

$$(x_i - x_0)\frac{\partial \Delta T_i}{\partial x} + (y_i - y_0)\frac{\partial \Delta T_i}{\partial y} + (z_i - z_0)\frac{\partial \Delta T_i}{\partial z} = -N\Delta T_i \qquad (1)$$

$x_0, y_0, and\ z_0$ Are the coordinates of magnetic source, T is the total magnetic anomaly and $\frac{\partial}{\partial x}, \frac{\partial}{\partial y}, and\ \frac{\partial}{\partial z}$ are derivatives in directions of x, y, and z, respectively. N belongs to the structural index (SI) that has been explained in the following. Using deconvolution can obtain the source anomaly specifications; because it is a procedure that uses the output to gain input.

Spectral analysis is a proper approach for estimating the average depth of large-scale magnetic or gravity anomalies that concentrates on statistical specifications of sources. By taking the natural logarithm of both sides of azimuthally averaged power spectral equation, obtains:

$$\ln(\Phi|k|) = \ln(A) - 2|k|d + 2\ln(1 - e^{-|k|t}) \qquad (2)$$

A is a constant value that depends on magnetization direction and regional magnetic fields, and k is wave number. Equation (3) in the high wave-number mediums, belongs to straight-line with -2d coefficient. approximately. Thus, we can obtain half of angle coefficient, which is estimation of (d) by fitting a straight line on the mediocre and high wavenumber section of logarithm power spectral curvature (Blakely 1995).

Li and Oldenburg (1996, 1998) provided algorithms for inverse modeling of the magnetic and gravity data. Because of the comprehensiveness of recommended method, it is one of the useful and classical methods for this purpose. The following Equation 3 (the general form of $Ax = B$), is principle of magnetic and gravity inversion modeling as has been used in this paper (Li and Oldenburg 1994, 1996, 1998):

$$(G^T W_d^T W_d G + \beta W_m^T W_m)m = G^T W_d^T W_d d^{obs} + \beta W_m^T W_m m_0 \qquad (3)$$

G is $N \times M$ matrix known as data kernel, $d^{obs} = [d_1 d_2 d_3 \dots d_N]^T$ is observed data (magnetic or gravity), $m = [m_1 m_2 m_3 \dots\ m_M]^T$ is model parameter, W_d is weighted data matrix as diagonal matrix $W_d = diag[{}^1/_{\sigma_1} \dots\ {}^1/_{\sigma_N}]$ that σ_i is ith data standard deviation, m_0 is geological reference model, and W_m is a matrix for weight factor for calculating m length.

Geological Setting

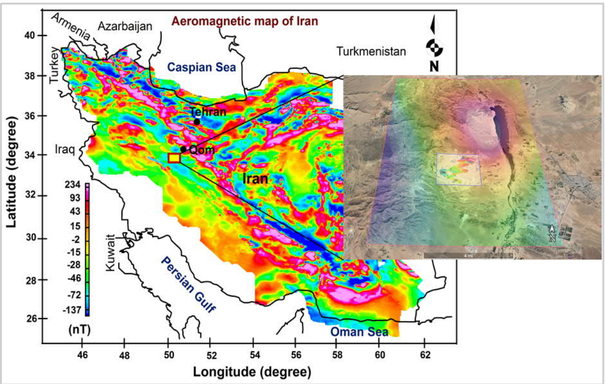
Based on the geological classification of Iran, Mahallat is located in the central volcanic zone of Iran. This zone has been active through the centuries and looks like a triangle in central Iran. The western boundary of Mahallat is limited to The Sanandaj-Sirjan metamorphic zone. The central zone of Iran is restricted to Alborz and Makran zone from Northern and southern boundaries, respectively, and in the eastern border of the mentioned zone can observe the Lut block. Minor superficial-shearing erosion of the zone is noticeable. Due to the extension of dolomite and limestone units and their fractures, the zone illustrates a good permeability. As mentioned, The Eocene sediments consist of conglomerates that emerge in the southern section of the zone as hills. The most critical fault in the area is the Mahallat fault with an east-west extension. This fault near Dilijan finds northeast-southwest, then north-south direction. The outcropped formations of the area are as follows: Shemshak formation (with Jurassic shale and limestone lithology), cretaceous Orbitolina limestone, Qom formation (with Marly - Limestone lithology), and igneous granodiorite has formed in the vicinity of sedimentary rocks (Hosseini et al 2020). Travertine alluvial sediments settled near faults over the ages and were significantly thick. Tile et al., 1995 in Golpaygan geological map report, mingled the thicknesses to 500 meters (Golpayegan Geological report 1995). It is worth noting that the area possesses abundant alterations. Argillitization-sericitization is the most alteration in the region. Also, the kaolinization-alunitization alteration is considerable. This type of alteration, especially the first one, occurs at significant temperatures and is closely related to hydrothermal fluids activity.

Results

In order to investigate the Mahallat geothermal zone generally, which is a large-scale area, aeromagnetic data of the mentioned area have been utilized. The altitude of the flight is 400 to 500 meters with a flight spacing of 7.5 kilometers. The dimension of the region is 18800 × 15500 m^2 and the residual magnetic map's minimum and maximum magnetic intensity are 18.8 and 525.8 nT, respectively. The lack of a negative value for the magnetic intensity states that the bottom part of the anomaly could be profound; therefore, the surveying cannot detect the negative pole of the anomaly. The RTP filter (Figure 1) was exerted to simplify the interpretation and increase the resemblance of the map and the actual shape of the anomaly. The shape of the anomaly in the RTP filter is very similar to the shape of the mass in inverse modeling, shown in the following. In order to investigate the sub-branches of the main anomaly discussed in the aeromagnetic section, a ground magnetic survey has been acquired. The dimension of the surveyed zone is 4660*2600 square meters, and 10000 stations have been used. Figure 1 indicates the residual aeromagnetic map of Iran (with 7.5 KM flight spacing) and the studying area. The red and blue rectangular in the zoom box picture illustrates the geographical locations of the aeromagnetic and ground magnetometry. In order to illuminate the main anomaly and sub-branches anomalies positions, the aeromagnetic and ground magnetometry RTP grids have been overlayed on the geographical projection of the surveying zone.

The minimum magnetic field intensity is 47391.3, and the maximum is 48988.1 nT. The inclination and declination angles are 52.4 and 4.4 degrees, respectively. It is worth noting that the main intrusive anomaly of the Mahallat, which has been investigated in the aeromagnetic section, is in the northeast of the Abgarm area (ground magnetic grid).

Figure 1. The residual aeromagnetic grid of Iran



(the aeromagnetic and ground magnetometry surveying zones and their RTP grids have been superimposed)

Spectral analysis depth estimation is applicable for large-scale anomalies (Blakely 1995). Figure 2 shows the power spectrum function of Mahallat aeromagnetic data.

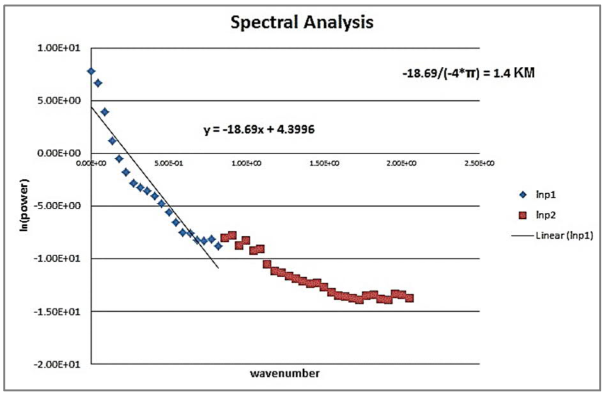
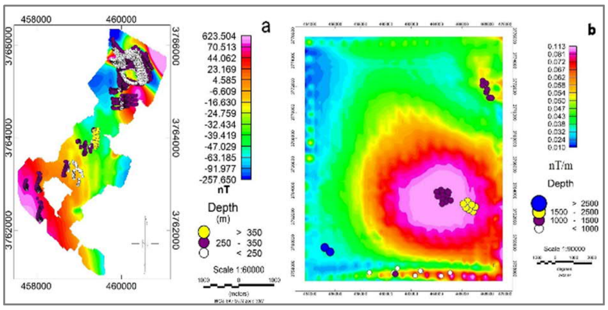


Figure 2. Depth estimation by power spectrum function.

As shown in Figure 2, the depth of the top of the anomaly is 1.4 km. This value fits well with previous studies that have suggested a depth of 1280 meters. (Oskooi et al., 2014). Figure 3a illustrates the located Euler depth estimation for structure index of 2 (cylinder). Conquerors of the solutions demonstrate the depth of 1000 to 1500 meters and 1500 to 2500 meters. In order to estimate the basement depth, the standard Euler was acquired. Euler's method depends on the shape of the anomaly that interferes with the differential equation as the structural index. Due to the area dimension and the anomaly expansion,400 × 400 m^2 window was considered for depth estimation in its center. According to the obtained inverse modeling from ground magnetometry data in the following, a structural index of 1 was presumed. Due to the Figure 3b, three depth ranges have been considered. White circles indicate 250 meters depths and lesser, purple circles are related to 250 to 350 meters, and yellow points are more than 350 meters depths representative.

Figure 3. (a) Standard Euler's depth estimation for



structural index 1 (ground magnetic data), (b) located Euler depth estimation for structure index 2 (aeromagnetic data).

Figure 4a indicates 3D inverse modeling, which has been obtained from the Li-Oldenburg algorithm for Mahallat aeromagnetic data. The minimum and maximum of the susceptibility value are 0 and 0.03, respectively. The upper section of the anomaly has cone-shape geometry, and prior studies in this region have provided the same shape in their modeling, which confirms the inverse modeling accuracy (Oskooi et al. 2016). Li-Oldenburg inversion modeling algorithm also has been utilized for ground magnetometry survey of Abgarm region. Figure 4b views the ultimate inverse modeling obtained from the Li-Oldenburg algorithm. The Minimum and Maximum values of the susceptibility are 0 and 0.1, respectively. In order to present the model nicely, a depth of 2000 meters has been considered.

Discussion

This study continues the previous studies in the Mahallat geothermal region that simultaneously benefits from a multi-method interpretation. The proliferation of the studies in this zone facilitates validation by matching the outcomes with prior ones. As mentioned before, first, the aeromagnetic data was investigated. Due to the Mahallat geothermal expansion, exploitation of the long flight spacing aeromagnetic data would be passable. Afterward, the power spectrum depth estimation and Euler's depth estimation have been utilized to obtain the aeromagnetic data anomaly upper depth. The upper depth of the anomaly in 3D inversion modeling is 1500 meters approximately in the power spectrum, depth estimation is 1.4 kilometers, and Euler's depth estimation is 1000 to 1500 meters. In the following, the Abgarm zone of the Mahallat ground magnetometry has been used. The ground magnetometry surveying was supplementary data through the main Mahallat geothermal zone. First, we applied Euler depth estimation on the data, and the upper sector depth of the anomaly is about 250 meters. In order to study the Abgarm-Mahallat area perfectly, 3D inverse modeling has been employed. The upper depth of the modeling shows 250 meters, which matches Euler's depth estimation.

CONCLUSIONS

This study utilizes aeromagnetic and ground magnetic data and their inverse modeling as verification implements, and the results indicate perfect analogy with previous studies in the region. The obtained depths to anomalies have accordance with prior studies for instance with Hosseini (2020) in which according to the 2D inverse modeling of MT data, the depths of 250 to 1500 meters are proposed as granodiorites lavas. In addition, the cooling volcanic mass (heat source) has been set in the depth of 3 to 4 kilometers as a common results.

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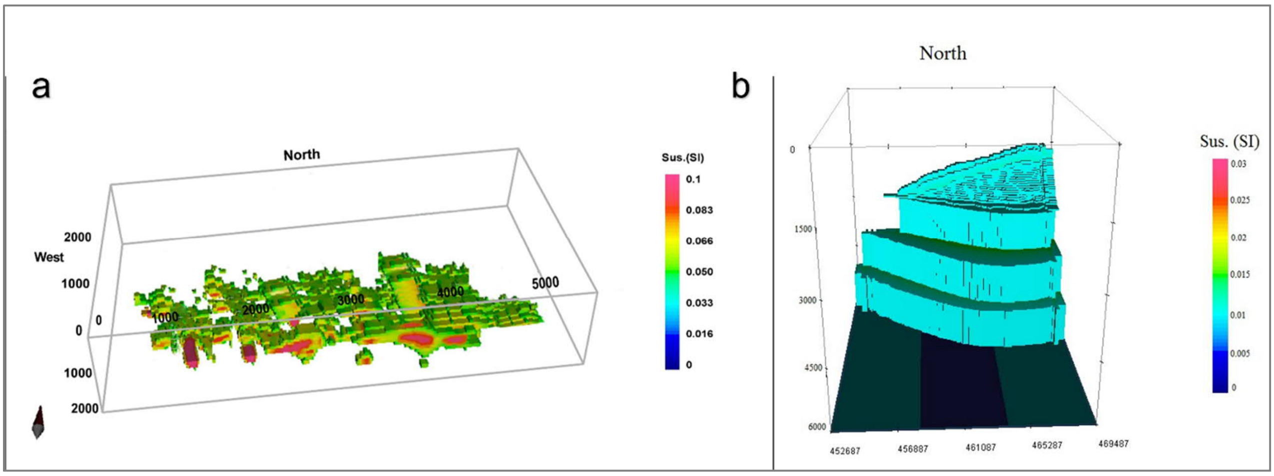

Figure 4. Inversion model of (a) Abgarm magnetometry data, (b) and Mahallat aeromagnetic data.