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ScienceDirect

Russian Geology and Geophysics 56 (2015) 1791–1800

RUSSIAN GEOLOGY AND GEOPHYSICS

www.elsevier.com/locate/rgg

Investigation of density contrasts and geologic structures of hot springs in the Markazi Province of Iran using the gravity method

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Received 26 December 2014; accepted 28 May 2015

Abstract

In 2012, the renewable energy organization of Iran (SUNA) performed a gravity survey around hot springs of the Mahallat geothermal field in the Markazi Province of Central Iran, as part of the explorations and developments of geothermal energy investigation program in the region. The Mahallat region has the greatest geothermal field in Iran. This work presents interpretation results of various gravity maps and a calculated 3D inversion model. The residual gravity map shows three negative gravity anomaly zones (A1, A2, and A3) associated with the geothermal reservoirs in the region. The horizontal gradient maps reveal a complex fault system. In order to attain more information about the Khorhe geothermal reservoir, a 3D density contrast model was calculated using the Li–Oldenburg method. The attained 3D model provides an in-depth image of the evolution, showing the density contrast and the A1 zone having a high potential for the geothermal reservoir in the region. The results also show that the rocks which exist between 1000 and 3000 meters under the Earth's surface in the A1 zone are the most suitable aquifers for utilization of geothermal energy.

Keywords: gravity; geothermal system; Bouguer anomaly; Euler; inversion; Mahallat

Introduction

In geothermal exploration, gravity method generally is used to delineate subsurface structures that control the geothermal system. Basically, a given geothermal reservoir and its fluid content cause density differences between geothermal reservoir and the surrounding rocks. The basis of gravity method is density contrast in the rocks. Gravity studies in different regions of the world have yielded useful results for geothermal exploration, such as: investigation of topography of basement in a geothermal field (Salem et al., 2005; Soengkono, 2011), magma chambers and intrusive body related to the heat source of the geothermal system (Represas et al., 2013) and delineation of faults and fractured zones corresponding to the reservoir of geothermal system (Abiye and Haile, 2008; Gottsmann et al., 2008; Montesinos et al., 2003; Represas et al., 2013; Salem et al., 2005; Schiavone and Loddo, 2007). Therefore, gravity method is one of the most economic geophysical methods for modeling of a geothermal system.

The Mahallat geothermal field of the Markazi Province in Iran is a popular tourist destination due to the occurrence of hot springs and one of the richest geothermal fields in Iran. According to the available scientific data about Abgarm geothermal region, it is found that in the NW of Mahallat city has favorable conditions for the exploitation of geothermal energy. The local heat flow and the temperature maxima in the Mahallat geothermal field originate from strong convectional heat transport mainly in the igneous basement.

In the current study area, several studies have been conducted by the renewable energy organization of Iran (SUNA) and other research institutes. Using a ground magnetic study Oskooi at al. (accepted for publication) and Mirzaei et al. (2013) showed that heat source of the Mahallat geothermal system originates from a hot igneous intrusive mass which exists at the depth of more than 1.5 km at the east of the Mahallat hot springs. Based on geological and

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http://dx.doi.org/10.1016/j.rgg.2015.11.011

geochemical studies, it was revealed that the hydrothermal fluids cycle in the area was controlled mainly by N–S faults (Porkhial et al., 2013). Using a Magnetotelluric (MT) survey along the 8 km-long profile over the Mahallat hot springs, Oskooi et al. (2013) and Oskooi and Darijani (2013) it is determined that Mahallat geothermal system included a cap rock (from 100 to 600 m), a reservoir (from 500 to 2000 m) and a source (from 1000 m to the deepest reachable point). However, these results can't illustrate the lateral extent of the structures of the Mahallat geothermal system, because their interpretation was two-dimensional, and the amount of data was insufficient.

Gravity survey which is presented in this paper is the most important geophysical study conducted in the Mahallat geothermal region that allows us to generate a comprehensive overview of the area. The only other performed geophysical and geological surveys are too local and incomplete to be of any use for this purpose. In the current study, a total of 380 gravity observations along several regular profiles were recorded, covering nearly 200 km^2.

It should be mentioned that so far no wells have been drilled in the Mahallat geothermal region. Therefore all the data about this region are based on the surface studies.

Geologic setting

In the Markazi Province of Iran (Fig. 1), the geologic structures are characterized by a dextral rotational movement, which has formed by northward under-thrusting of the Arabian plate beneath Central Iran (McKenzie, 1972). The Cenozoic geologic history and the stratigraphy of this region are complex, due to its tectonic framework. As a result, the stratigraphic record of the area is made up of units with different structural characteristics. During the Eocene, igneous activities took place in this area, causing accumulation of volcanic rocks over the Mesozoic and Paleozoic sediments. Subsequently, these rocks were thermally metamorphosed by an Early Miocene monzonitic batholith, elongated in a NW–SE direction.

Being the most important thermal water sources of the area, Abgarm hot springs are located 15 km northeast of Mahallat city in the Markazi Province. They are considered as a small part of the Central Iran zone, which is located in the Urumieh–Dokhtar volcanic belt. The geologic setting of this area and the distribution of hot springs are presented in Fig. 1. The study area is characterized by sedimentary deposits from the Permian to the Quaternary, with the existence of magmatic and volcanic outcrops. Notable formations cropped out in the study area include the Shemshak Formation (shale and sandstone), Cretaceous Orbitolina bearing limestones, marly limestones of the Qom Formation and volcanic rocks (granodiorite, tuff and lava). The hot springs (depicted as orange hexagons in the geological map in Fig. 1) caused deposition of travertine sediments with considerable thickness of about 500 m. In this area, faults and fracture zones played an important role in the circulation of water from the surface down to the deep levels. Some important alterations have also been documented for the area.

Some major faults have been identified in the region. Generally, they have two main directions, NW–SE and NE–SW. The main geological feature present in the current study area is the segment of the NNE–SSW Mahallat–Abgarm fault (MAf) zone (Nouraliee and Shahhosseini, 2012). This structure stretches for 50 km, from southeast of Mahallat city to the north of Abgarm. All of the Abgarm hot springs is directly connected to this fault zone.

Geothermal surface manifestations

The area of the Abgarm region is composed of young volcanic rocks, hydrothermally altered zones, wide travertine outcrops and intrusive bodies as well. All of the hot springs are genetically related to tectonic activities and concentrated along the MAf zone. Due to the hot spring activity, a lot of travertine deposits have been accumulated in the Mahallat region. Travertine is a chemically-precipitated continental limestone formed around seepages, hot springs and along streams and rivers. It consists of calcite or aragonite, of low to moderate inter-crystalline porosity and often high mouldic or framework porosity within a vadose or occasionally shallow phreatic environment. Precipitation results primarily through transfer (evasion or invasion) of carbon dioxide from or to a groundwater source leading to calcium carbonate super-saturation, with nucleation/crystal growth occurring upon a submerged surface (Pentecost, 2005). Travertine deposits usually formed around hot springs can be a useful sign of geothermal activity in a region, either active or fossil one. Irregular fault movements can be responsible for spring migration leading to the deposition of a range of travertines at different levels (Soligo et al., 2002).

Before gravity studies, geological and geochemical studies were conducted in the area. In geological investigations, a very accurate 1:25,000 scale geological map of the Mahallat geothermal area was generated (Nouraliee and Shahhosseini, 2012). All faults and lithological units were studied in detail. Moreover, hydrothermally altered areas were recognized by Aster satellite images. They were also visited and sampled in order to perform mineralogical analysis.

Based on the Aster satellite images studies, checking outcrops and petrography studies, several altered zones were found in the study area. The most important of alteration types include argillitization-sericitization and kaolinitization-alunitization. Argillitization-sericitization alteration is detected in a close relationship with hydrothermal fluid activities. This type of alteration is representative of high-temperature geothermal systems. Previous studies suggest that the heat source of hot springs is due to the cooling processes of the molten magma (Oskooi et al., accepted for publication). Hot springs are charged by meteoric waters mixed with magmatic fluids (Beitollahi, 1996; Oskooi and Darijan, 2013). The hydrology and geothermometry studies (Rezaie et al., 2009) showed the average temperature of the hot springs to be about 46 °C and their pH to range from acidic to neutral. The water of hot