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Inspecting the Mahallat Geothermal Field (at the Center of Iran) Through Geological and Geochemical Analysis

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ABSTRACT

The Mahallat Geothermal Filed is known as one of the largest national prospects located in the Markazi Province at the center of Iran. Detailed geological and geochemical analysis have been performed to know this region deeper. To achieve this aim, a 1: 20000 geological map of studied area has been prepared and also all geothermal surface manifestations have been identified and marked in the map. Hot springs and pervasive travertine deposits can be addressed as the most important surface manifestations, so that one of the largest travertine outcrops in the world is formed and deposited through existing hot springs. Geochemical sampling and analysis have been carried out on 5 hot springs with temperature range from 35 to 47°C. Results of geothermometry studies revealed the existence of a low temperature geothermal reservoir (about 100°C) in this area. Regarding to the tectonic studies, major faults of this area have played the most important role in the formation of the Mahallat geothermal reservoir, and this prospect falls into the convective fracture controlled geothermal system with deep circulating water.

1. INTRODUCTION

Most of the geothermal prospects are discovered by clear surface manifestations as hot springs. But, in more complicated cases, lack of surface manifestations prevent finding invaluable resources. These cases strictly need to be explored by applying geological, geochemical and geophysical approaches (Huenges and Ledru, 2011). A geothermal exploration program can address the location of the reservoir, the volume of the reservoir and the fluid temperature, the permeability of the formation, the phase of the reservoir content and the chemical nature of the fluids. The efficient routine tools to explore a geothermal prospect include: literature studies, airborne, geological, hydrologic, geochemical and geophysical surveys (Bahadori et al., 2013; Boden, 2016; Bodvarsson, 1970, Combs and Muffler, 1972; Wollenberg, 1982). A reliable exploration task directly leads to saving a huge amount of money and preventing blind drilling. Faults, volcanic units, alteration zones, stratigraphy, geothermal surface manifestations (such as natural hot/warm springs, travertine outcrops, mud volcanos, fumaroles, steam-heated lakes, geysers and mud pots) are the most considerable natural phenomena that should be minded in geologic studies. Hydrologic surveys are responsible for analyzing springs, water table of the area and meteorological data in exploration of geothermal prospects (Nicholson, 2012). Geochemical surveys shed the light on reservoir fluid temperature. It also helps to find water source, mixture and maturity (Giggenbach, 1991; Mwangi, 2013; Arnórsson, 2000). Geophysical surveys also depict an almost clear illustration of the unknown subsurface features including temperature, magnetic susceptibility, electrical conductivity (i.e. resistivity), density and gravity changes (anomalies) (Kana et al., 2015; Represas et al., 2013). Geophysics provides the widest range of exploration methods (Aretouyap et al., 2016). In this study geological and geochemical methods have been used. Mahallat geothermal field is located in the Markazi province in the central parts of Iran (Figure 1).

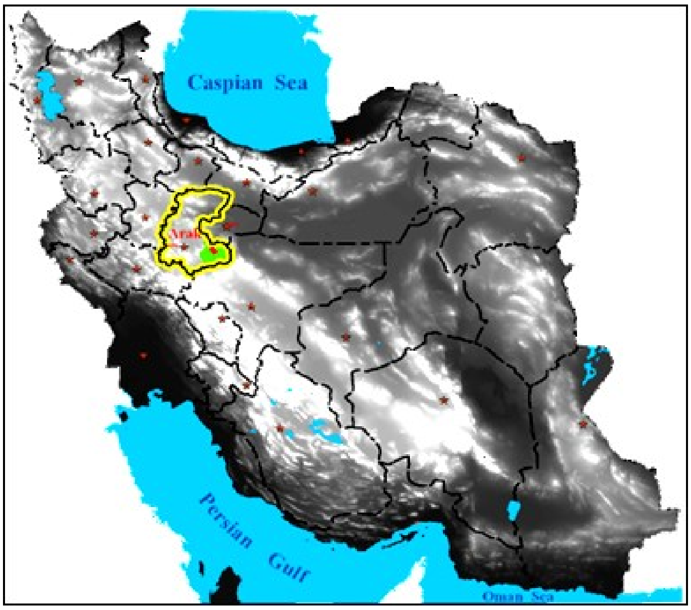

Figure 1: Location of the Mahallat geothermal field in the central part of Iran.

2. GEOLOGICAL SETTING OF STUDY AREA

Tectonic Map of Iran gathered and prepared by Stocklin and Nabavi (1973) can be addressed as the first evidence for importance of geology in Iranian territory. Regarding its tectonic, the plate is transected by numerous adjacent active, recent and mostly reverse faulting (Berberian, 1981). Besides bringing complexity for geologists, this active zone promises the existence of susceptible geothermal prospects within itself. Figure 2 depicts a general view on different segments of the Iranian Plateau and also the name and location of fourteen geothermal prospects. Abundance of faults (shown as red line) can be regarded as the first notable feature of this picture. Owing to this active tectonic history, Iran is considered to be seismically very active and is at high risk (Aghanabati, 2004). In the case of Mahallat geothermal region, host rocks are unable to raise the normal thermal gradient and generate heat source. Thermal activity detected within Sanandaj-Sirjan zone and Urumieh–Dokhtar Magmatic Assemblage can be addressed as a direct responsibility for this geothermal activity.

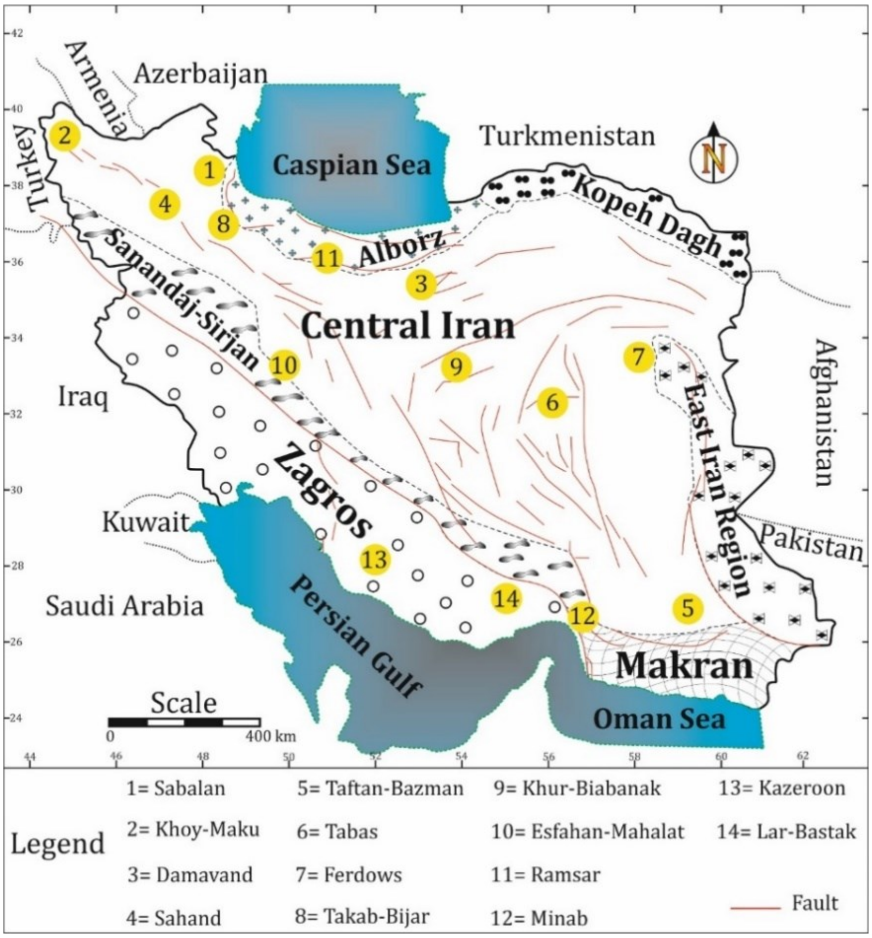

Figure 2: Geologic zonation of Iran and geothermal prospects existing within this plateau (adopted from Berberian, 1981 and Yousefi et al., 2010).

Mahallat region falls into the geologic Sanandaj-Sirjan Zone. This narrow zone is mainly composed of metamorphosed and also deformed rocks aging Mesozoic and rarely Paleozoic (Berberian, 1995; Mohajjel and Fergusson, 2000). Igneous activities took place in this area during the Eocene and causing accumulation of volcanic rocks over the Mesozoic and Paleozoic sediments. These rocks were metamorphosed by an Early Miocene monzonitic batholith, elongated in a NW– SE direction (Nouraliee et al, 2015; Moghaddam et al, 2016). There are several altered zones in this region. 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.

Figure 3 is a detailed 1:25000 geologic map provided in the study area. It provides observed formations, faults and lots of other geologic features. About the lithology of studied area, volcanic outcrops are mostly seen in north eastern and central parts of the region whereas the intrusive outcrops which are seen limitedly in some areas of the region are mainly observed in the east. As Mahallat geologic map declares, diverse set of sedimentary rocks in specific limestones, sandstones and in a lower amount, shale, conglomerate and marlstones cover the area. The lithology of the volcanic rocks varies between dacite and rhyodacite, possibly being the cause of the region's existing mineralizations and alterations. The intrusive layers with granite-granodiorite acidic mixtures are in direct contact with altered sandstone and tuff layers. The most important outcrops in this area include the Shemshak Formation (Jurassic shale and sandstone), Cretaceous limestones, marly limestones and volcanic rocks (granodiorite, tuff and lava). Mahallat geothermal prospect is formed in a convective setting and the geologic structures are characterized by a dextral rotational movement (McKenzie, 1972). The hot springs caused deposition of travertine with considerable thickness in this region.

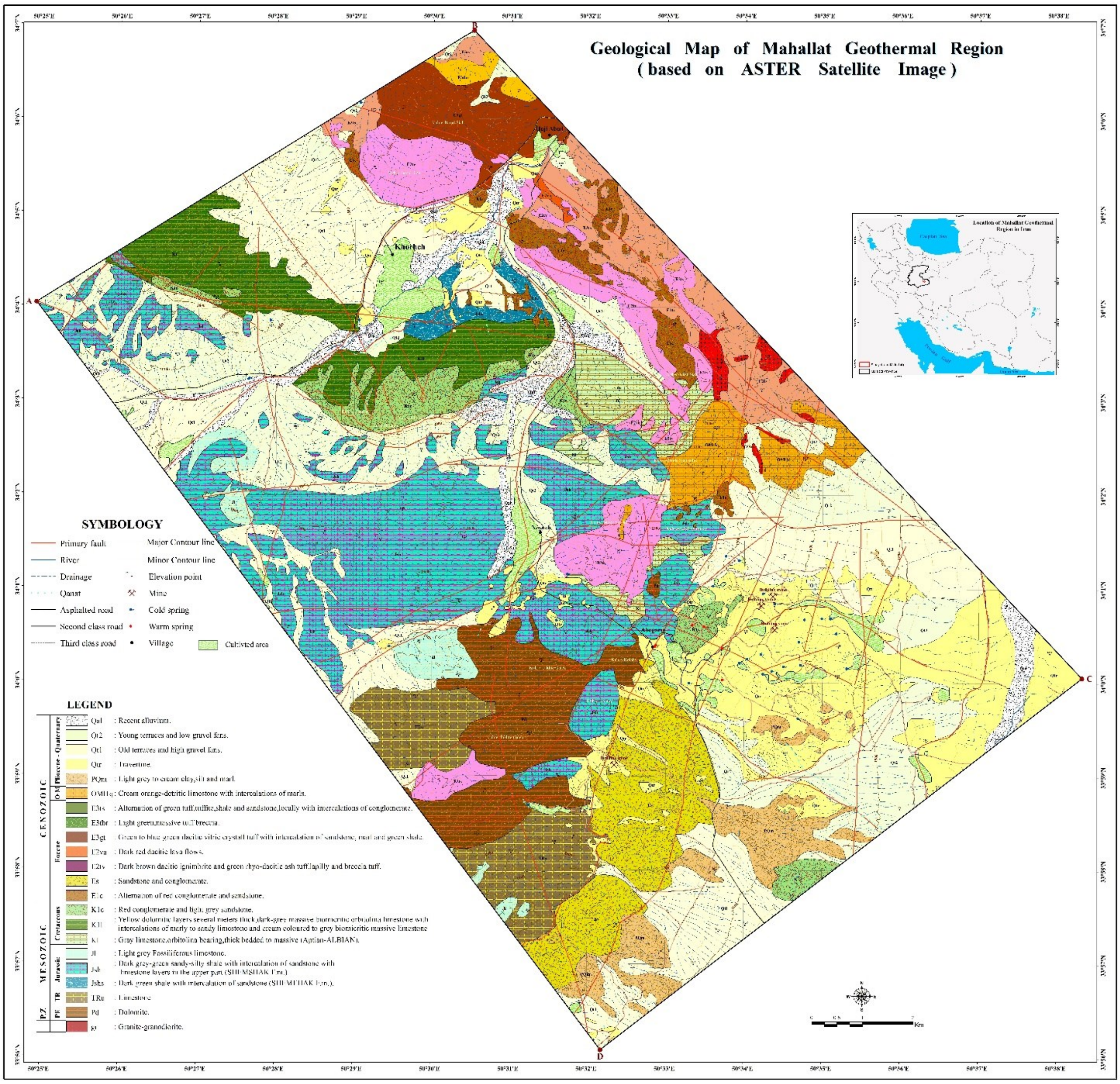

Figure 3: Geologic 1:25000 map of Mahallat Region in Iran.

3. GEOCHEMICAL ANALYSES AND INTERPRETATIONS

Geochemistry analyzes have a considerable role in identification and development of geothermal resources. Such studies yield important data about geothermal reservoirs and their hot fluids (Henley and Ellis, 1983). As Arnorsson and Fridikisson (2009) addressed, geochemistry studies are exerted to detect the chemical composition of the geothermal fluid and use it for obtaining information about the temperature, the source and the flow direction of the fluid. Meanwhile, geochemical analysis can predict the scaling and corrosion processes occurring in pipes. In addition to the mentioned applications, environmental impacts of the extracted geothermal energy can also be deciphered through these studies. To sum up, all the information gathered from geochemical studies can be used for preparing and developing a geothermal system model (Arnorsson and Fridikisson, 2009).

Geochemistry studies in the Mahallat region involved sampling, chemical analysis, fluids origin determination and geothermometry. To achieve mentioned aims, hot springs existing in the study area have been sampled. Five springs are observed in the area with a temperature ranging from 35 to 47°C. Table 1 represents the general characteristics of these springs. Sampling was performed with STM1060 standard and, CO_2 and H_2S gases were also measured simultaneously with the sampling at the site. (Figure 4 shows an overview of sampling operations).

Figure 4: Geochemical sampling equipment used in the Mahallat Region.

Table 1: General properties of five hot springs sampled for geochemistry analyzes.

Spring Name	Longitude	Latitude	Altitude	Temperature (°C)	Discharge (L/S)	PH	EC (µs/Cm)
Ab-Donbeh	459031	3763453	1848	47	1.45	6.45	9.02
Ab-Soleymanieh	459201	3763341	1826	46	8	6.55	9.8
Ab-Soda	459560	3762953	1737	46	23	6.54	10.005
Ab-Hakim	458919	3762289	1753	35	6	6.87	10.14
Shafa	458344	3762921	1870	47	8	6.61	9.85

3.1 Geochemical Analyzes

Geothermal fluids have different chemical conditions that mainly reflect their geologic origin. In addition to geology of the area, other factors such as source of input water, gases contained in the fluid coming from magma or atmospheric waters, as well as temperature and pressure also result in chemical changes of geothermal fluids. Different types of fluids are extracted from the geothermal systems, which identifying their type can provide useful information about geothermal reservoir. Therefore, determining reservoir fluid type can be regarded as an exploratory method exerted to identify geothermal sources. By providing appropriate samples from hot springs, other surface markers and geothermal wells, considerable amount of information about geochemistry of geothermal reservoir can be obtained. Results of the geochemical analyzes carried out on geothermal fluids are presented in Table 2.

Table 2: Results of geochemical analyzes performed on samples gathered from five selected hot spring in Mahallat.

Spring / Geochemical Component (Mg/L)	**Shafa**	**Ab-Soleymanieh**	**Ab-Donbeh**	**Ab-Hakim**	**Ab-Soda**
NH3	0.005>	0.005>	0.005>	0.005>	0.005>
Suspended solids	0.9	0.8	1.9	0.1	1.7
HCO3	236.4	234.1	236.4	208.6	238.8
Mg	72.7	67.8	72.7	82.4	72.7
Na	100	95	95	105	95
K	5.5	5.4	5.4	5.9	5.5
Cl	43	44	45.9	51	45.9
SO4	1126	1135	1108	1182	1102
B	N.D (<0.005)	0.1	0.03	0.08	0.08
Fe	0.7	0.2	0.65	0.02	0.76
SiO2	37.5	36	36	36	36
TDS (180˚C)	1126	1135	1108	1182	1102
Li	0.4	0.4	0.4	0.4	0.4
S2-	N.D (<0.1)	N.D (<0.1)	N.D (<0.1)	N.D (<0.1)	N.D (<0.1)
CO2	49.5	58	50	27.2	54
As	N.D (<0.1)	N.D (<0.1)	N.D (<0.1)	N.D (<0.1)	N.D (<0.1)
F-	1	1	1	1.5	1
Al	<0.02	<0.02	<0.02	<0.02	<0.02

Cl-SO_4-HCO_3 diagram

This diagram is used to classify the geothermal fluid and identify their origin (family). According to the results obtained from chemical analysis, hot springs of the Mahallat Region fall into boiling water and the vicinity of volcanic zones (Figure 5). These fluids are formed through the geothermal fluids charge into underground waters, and in high-temperature and low-temperature systems usually contain HCl and H_2S gases, respectively. Based on the available evidence, these springs fluids source cannot be related to this type of reservoirs. The main reason for concentration of such elements in these fluids can be related to the geology of the region and the presence of sedimentary layers containing them. Regarding the results of samples chemical analysis revealed the considerable concentration of sulfate ions which can be due to the presence of coal layers observed in the Shemshak Formation that acts as the cap rock of the reservoir (Figure 6).

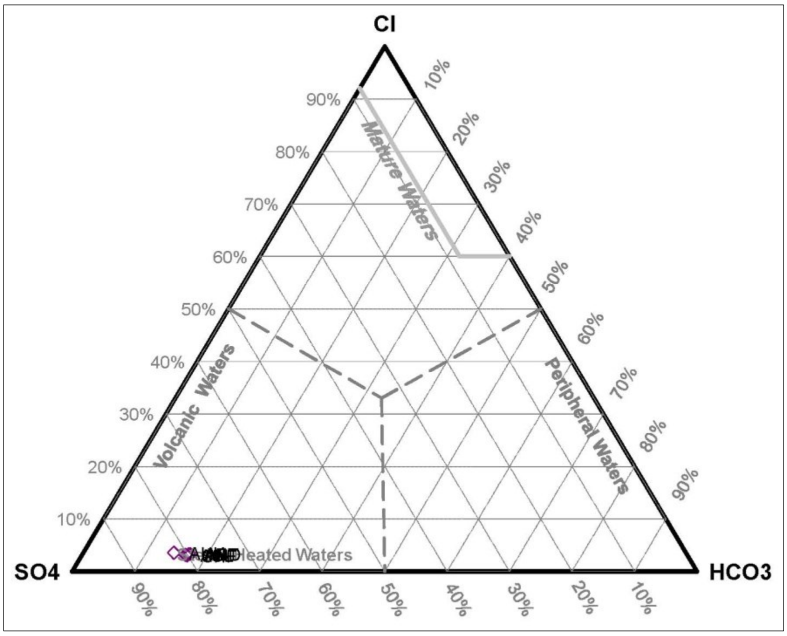

Figure 5: Cl-SO$_4$-HCO$_3$ diagram of hot springs in Hot Springs in Mahallat Region.

Figure 6: Coal rich layers of Shemshak Formation deposited in the Mahallat Geothermal region.

Na-K-Mg diagram

This diagram is used to evaluate the hot water and rock equilibrium at depths, as well as to check the reservoir temperature. As Figure 7 shows, this diagram is the result of the combination of the two geothermometers (Na-K and Mg-K) (Giggenbach, 1988) and routinely exerted to estimate the temperature of the reservoir. It contains three areas of immature, partial equilibrium and equilibrium water. Samples close to the Mg corner actually indicate the immaturity of water. Using this diagram is a suitable method to understand the degree of fluid-rock exchange. Location of hot springs is usually placed below the equilibrium curve and close to the Mg corner. It confirms that magnesium absorption in shallower cool temperatures is far more than sodium and potassium. Some bicarbonate waters achieve the partial equilibrium, while other bicarbonate and acidic waters are located close to the Mg corner, thus called immature waters. This plot is invaluable in geochemistry studies because of differentiation between appropriate and inappropriate fluids for using in geothermometry of ionic solutions, evaluating the deep equilibrium temperature and evaluating the re-equilibrium and mixture effect on lots of fluid samples.

All the samples gathered from the Mahallat Region are located close to the Mg corner. Samples on the diagram reveal that all fluids belong to boundary of immature and partial equilibrium zone. High Mg content and low temperature of reservoir reveal the short residence of fluid in geothermal reservoir and consequently lack of enough chemical equilibrium between fluid and hot rocks.

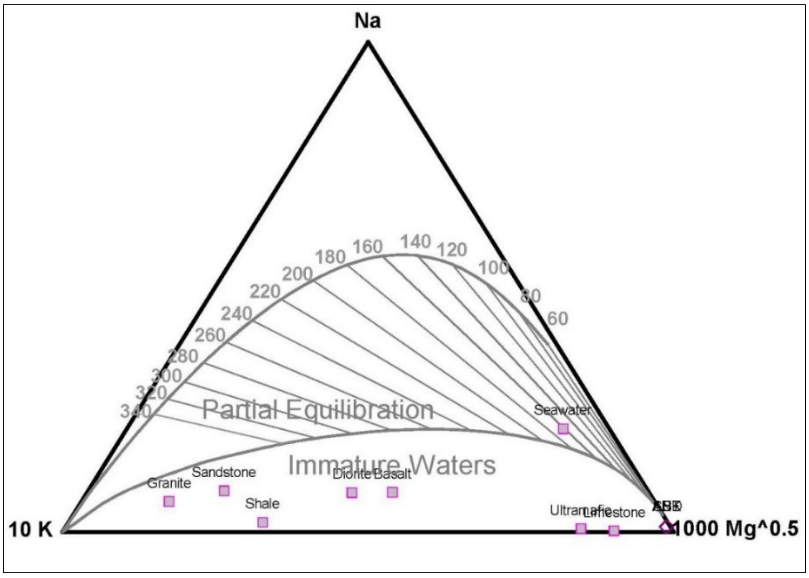

Figure 1: Na-K-Mg ternary diagram and distribution of hot springs' samples.

3.2 Geothermometry Studies

Temperature of the fluids coming out of geothermal reservoir can be assessed through chemical analyses. Obviously, accurate predictions on the reservoir temperature can provide vital information for following explorations in the area where underground drillings are absent. In the geothermometry studies based on the exiting different conditions, geothermometers yield different results. In such situations, a more complete data set including geologic and geochemical data are strictly important for selecting the most reliable geothermometers. Here, geochemical results of hot spring are applied to run the geothermometry analyses. Cation geothermometers of Powell and Cumming, 2010 software is exerted to calculate the Mahallat reservoir temperature. Outcomes are presented in the Table 3. Results of some geothermometers are not suitable, such as in the case of having a reservoir with temperatures less than 150°C, at which point their calculations would not be reliable. For springs that reach the surface quickly or are located just above the geothermal reservoir surface, silica geothermometer can provide reliable outcomes. Based on the results of performed geothermometry, the temperature of the Mahallat geothermal reservoir is estimated to be around 90°C.

Table 1: Results of different geothermometric methods in studied locations.

	Chalcedony cond	Quartz cond	Quartz adiabatic	K/Mg (Giggenbach)	Na/K (Giggenbach)	Na/K Truesdell	Na/K Fournier	Na-K-Ca
SHF	58	89	91	35	189	131	171	1
ASL	56	88	90	35	191	134	173	16
AND	56	88	90	34	191	134	173	2
AHK	56	88	90	35	190	133	172	--16
ABT	56	88	90	35	192	192	171	1

4. CONCLUSION

The Mahallat geothermal region is one of the most well-known low temperature geothermal area in Iran which is located in the central part of the country. The most important surface manifestations of geothermal energy in this area are warm springs, extensive outcrops of Travertine deposits and altered rocks. Geological studies indicate that this area was a big sedimentary basin and sediments were deposited during the Permo-Triassic (carbonate deposits) and Jurassic (shale and sandstone deposits). These sedimentary rocks act as reservoirs and cap rocks for a geothermal system. Thrust faults circulate the water from the surface toward deep levels and warm springs are formed by the emergence of heated water. The temperature of warm springs in this region is ranging from 35 to 47°C. The chemical composition of these springs is affected by the geological situation in the area. All the samples gathered from the Mahallat region are located close to the Mg corner and partial equilibrium zone in the Na-K-Mg diagram. The results of geothermometry indicate that the temperature of the Mahallat geothermal reservoir is around 90°C.

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