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Thermal Surveying of Mahallat Geothermal Prospect in Central Iran and Comparing its Results to the Mödruvellir Geothermal Field, SW Iceland

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ABSTRACT

In the present study, thermal surveying of a low temperature geothermal field which is located in the central parts of Iran (close to Mahallat City) has been carried out. Seven exploration boreholes with different depths (between 30 to 110 m) have been drilled to detect the subsurface characteristics of this area. Thermal maps of the area are prepared using the geothermal gradient method to detect location of the thermal anomaly. The Mödruvellir geothermal prospect is located in the SW of Iceland and falls into low temperature geothermal resource category. Thermal surveying of this region have been carried out by the author in 2015. This study is conducted based on the data collected from 22 gradient boreholes, and also existing two geothermal wells. Thermal maps are provided for the depths horizon of 50 meters in both regions and their geothermal gradients are calculated. In the case of Mödruvellir, 5 thermal zones are detected with thermal gradients ranging from 160 to 300 °C/km. In Mahallat geothermal region, 3 zones are detected and the geothermal gradient is estimated to be ranging from 71 to 108 °C/km. Comparison of these regions revealed that the thermal zones of Mödruvellir region has a higher temperature than the Iranian Mahallat prospect. Geothermal gradient of Mödruvellir is also higher than Mahallat region. Distinguished thermal anomalies of Mahallat prospect are known to be in close relation with the activity of large thrust faults that paved the way for circulation of water through fractures. In the case of Mödruvellir region, it is confirmed that the geothermal reservoir is associated with a graben structure sandwiched between two main normal faults.

1. INTRODUCTION

Thermal surveying by drilling gradient wells is one of the exploration methods of geothermal energy sources. This method is used in exploration of both high and low temperature geothermal areas, but its main application is in low temperature areas where there are no surface manifestations. In the low temperature areas, this technique is used to obtain the areal extent of thermal anomaly. The best results for this method are obtained in fracture controlled low temperature fields (Saemundsson, 2007).
It indicates that temperature increases with depth and heat is generated transferred through rocks and sediments to the surface (Forrest et al., 2007). Thermal gradient is calculated for any gradient well based on the gradient equation. Having a scheme of geothermal gradient spatial variation is strictly crucial for geothermal investigation and underground heat harnessing. To achieve this scheme, drilling of gradient wells is regarded as an efficient method (Corrado et al., 1988; Saemundsson, 2013; Ebrahimi 2015).

In this paper Thermal surveying of a low temperature geothermal field (Mahallat geothermal field), which is located in Iran has been carried out. We have tried to compare the results of this study to results of thermal surveying in Mödruvellir geothermal field which is located in Iceland. Mödruvellir geothermal field is a low temperature geothermal resource located in southwest Iceland. The Mödruvellir area is located about 40 km NE of Iceland's capital Reykjavik (Figure 1). Mahallat geothermal field is located in the central parts of Iran which is one of the biggest geothermal field in Iran. The Mahallat geothermal area is located in Markazi province, 15 km NE of Mahallat city (Figure 1).

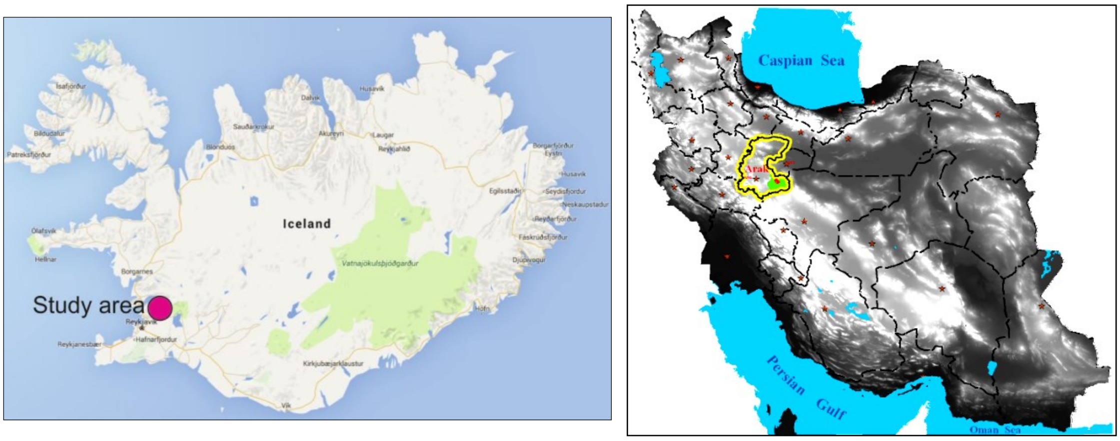

Figure 1: Locations of the studied areas. Left: Mödruvellir geothermal field in Iceland. Right: Mahallat geothermal field in Iran

2. GEOLOGY SETTING OF STUDIES AREAS

2.1. Geology setting of Mahallat region

There are variety of rock units in the Mahallat geothermal region. Most part of this region is covered by sedimentary units. These units consist mainly of limestone and sandstone. The volcanic units of the region have dacite and rhyodacite composition which can also be the origin of mineralization and alteration of the region. Intrusive bodies consist of granite and granodiorite which have a direct border with altered units and sandstone.

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). Due to the tectonic framework the stratigraphic units have different structural characteristics. Some of the major faults circulate the water from the surface toward deep levels and hot spring is formed by the emergence of heated water that reaches the surface. These springs caused deposition of travertine with considerable thickness in this region. Figure 2 is a detailed 1:25000 geologic map provided in the study area. It provides observed formations, faults and lots of other geologic features.

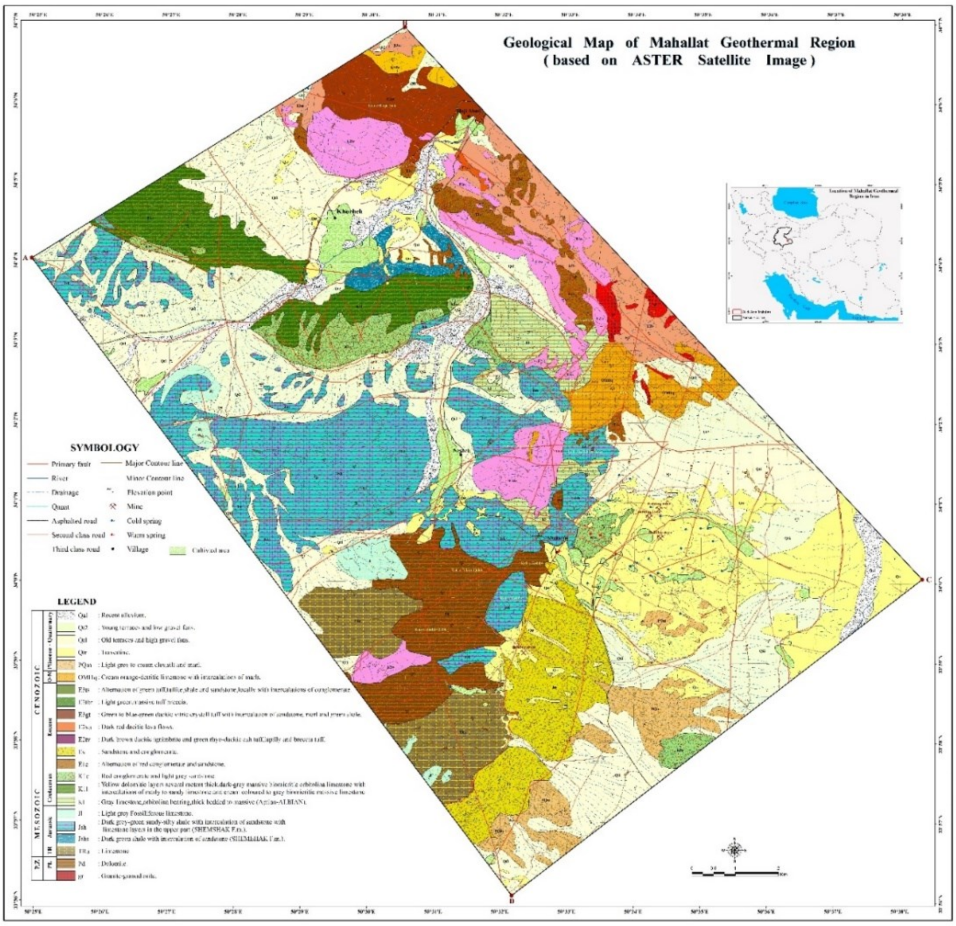

Figure 2: Geologic 1:25000 map of Mahallat Region in Iran

2.2. Geology setting of Mödruvellir region

Mödruvellir geothermal field is in the Hvalfjördur region in SW Iceland. Hvalfjördur belongs to a sequence of late Tertiary to early Quaternary flood basalts with a minor interlayer of hyaloclastites and rhyolites. Two central volcanos were active in this region for one million years and during this time, ten glaciations occurred in the region (Fridleifsson, 1973). 1:25,000 Geology map of the study area was prepared by Hjartarson and Kristinsson in 2007. This map was verified by Ebrahimi in 2015 and geothermal mapping, including mapping of the main structures like faults, fractures and dykes, was carried out in the Mödruvellir area. The study area includes the superficial deposits, lava flows, and hyaloclastite formations. Stratigraphical units in this area consist of basalt with intercalations of hyaloclastites. There are many faults and fractures in this area which most of them have a general NE-SW trend and some have ENE-WSW trends. Based on analysis of aerial photos, there are some lineaments that have WNW-ESE trends. These lineaments are located in the southern part of the study area. Most of the dykes that were measured in the field have a NE-SW trend (Figure 3).

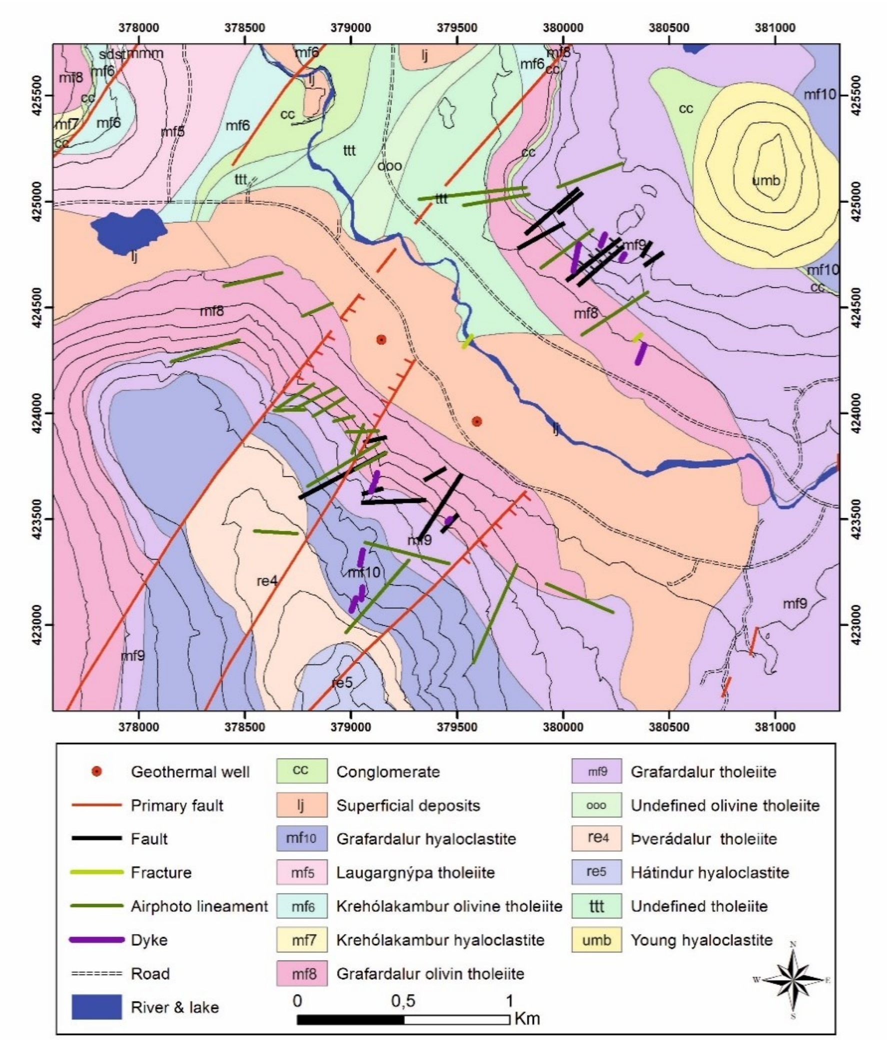

FIGURE 3: Geologic map of the Mödruvellir region in Iceland (modified by Ebrahimi 2015 from Fridleifsson, 1973; Hjartarson and Kristinsson, 2007).

3. THERMAL SURVEYING OF STUDIES AREAS

3.1. Thermal Surveying in Mahallat region

Considering all the influential factors such as the position of the hot springs, topography and the amount of tectonic activities, 15 drilling locations were suggested and then 7 gradient wells were drilled. After completing the drilling in each borehole, a special thermometer and software were used to measure the temperature in every 10 meters of depth. Measurements are presented in the Figure 4. According to this figure, among the seven wells investigated, anomalies in temperature change through depth are only observed in wells #1, #3 and #7. In other wells the change of temperature is insignificant and normal (in the range of the universal geothermal gradient of 25 °C/km) which show no sign of an existing geothermal potential. Unlike inside wells #1, #3 and #7 that the temperature is significantly increasing with depth, in well #2 the temperature is declining which it could be the effect of groundwater flows. Considering the fact that multiple hot springs and a fault line are located in the vicinity of the wells #1, #3 and #7 and the wells are in an area relatively close together, it is can be concluded that the observed sudden increase of temperature through depth in these wells are caused by elevated hydrothermal flows in the area.

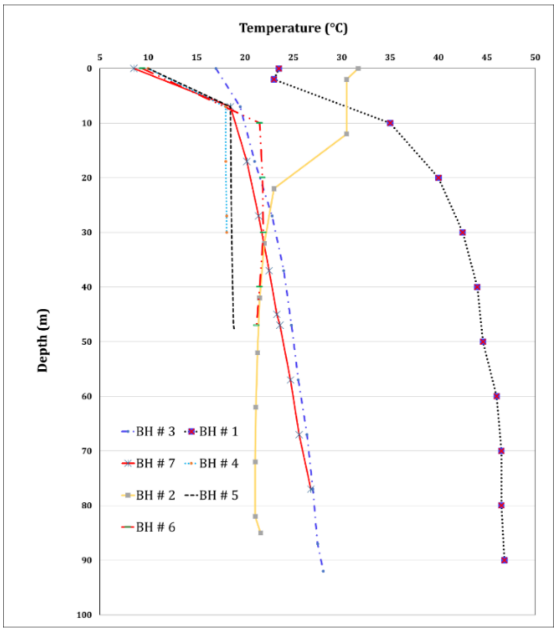

Figure 4: Temperature changes versus depth profile of seven gradient wells in Mahallat region

It should be mentioned that for calculating the geothermal gradient of the wells #1, #3 and #7 only the temperatures measured from depths below 30 meters were used. This is because of dismissing all the possible errors that occur at shallower depths and also to measure the temperatures of all wells in a similar environment (inside water). Therefore, through gradient Equation, the geothermal gradient of the three wells were measured.

$$TG = \frac{T_{depth} - T_{surface}}{Depth}$$

Thermal gradient for well #1, well #3 and well #7 are 71, 74 and 107.5 °C/km, respectively. By having the geothermal gradients besides the geological and geophysical surveys, the fault lines that help the elevation of hydrothermal fluids can be identified. The temperature profiles revealed that the locations of the wells #2, #4, #5 and #6 are not suitable for drilling a geothermal well and the best location for it will be in the vicinity of wells #1, #3 and #7. As a result of the measurements mentioned previously, temperature map for the depths of 50 m with full information about the temperature profile, thermal gradient, fault lines, elevation points and also the location of hot springs, roads and villages are provided (Figure 5). It can be concluded that the upper Ab-Garm village near well #7 would be an ideal and feasible location for geothermal heat production. Through the multiple faults that have an impact on the existence of this geothermal potential, the Ab-Garm fault located in the surrounding of the three wells with abnormal temperature gradients (#1 with 71°C/km, #3 with 74 °C/km and #7 with 107.5 °C/km) has the most role in the formation of thermal anomaly.

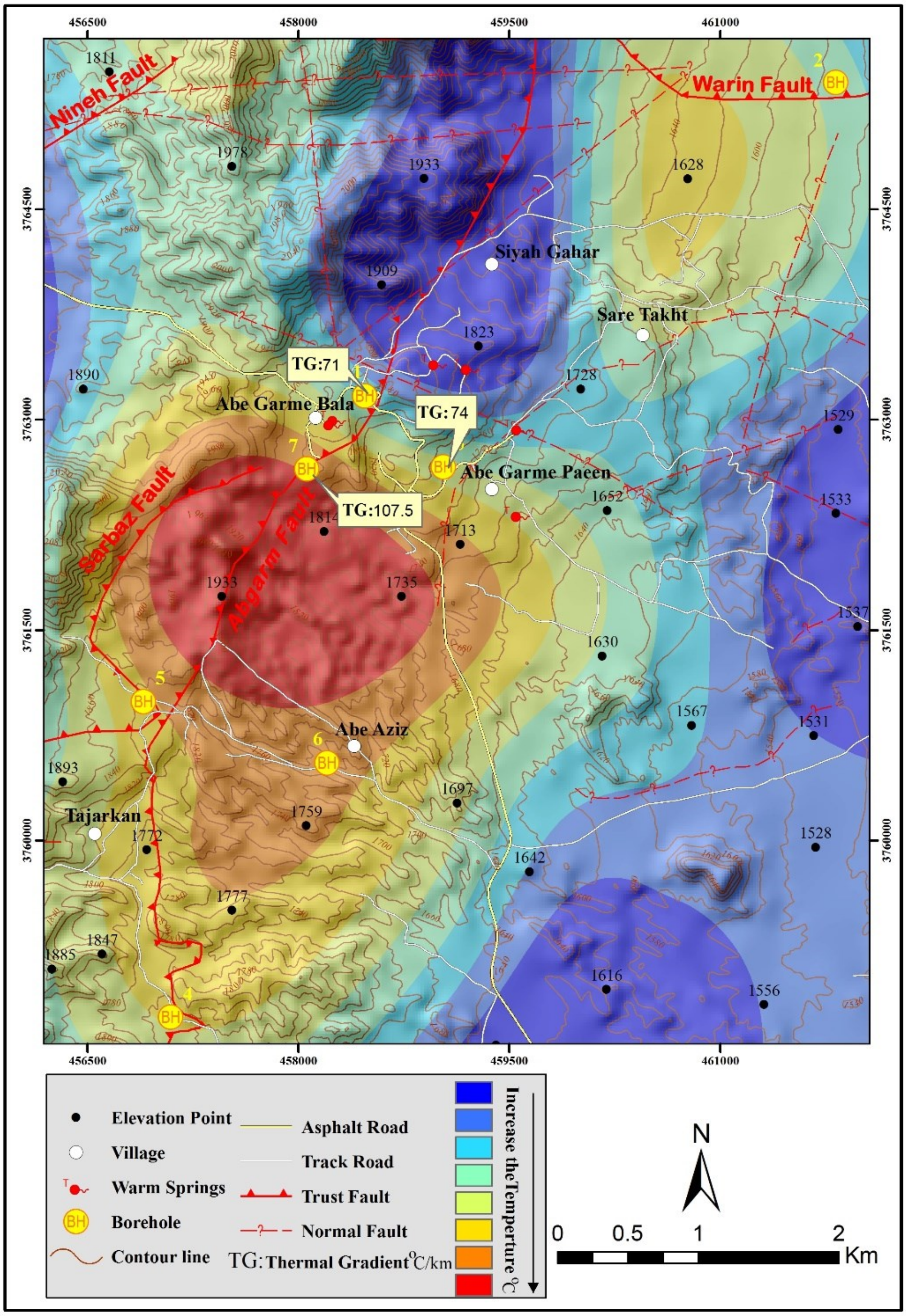

Figure 5: Temperature map of Mahallat region at 50 m depth

3.2. Thermal Surveying in Mödruvellir region

There are 22 gradient wells and 2 production wells in the Mödruvellir area in SW Iceland. Table 1 shows the characteristics of the wells. Based on the data of these wells, gradient method was applied to locate geothermal anomalies (Ebrahimi, 2015). In this study, two geothermal anomalies were defined on the basis of temperature at 50 m depth and the thermal gradient in wells. Figure 6 shows the temperature map at 50 m depth and thermal gradient map in this area. There are five different temperature zones on the map, the highest temperature gradient is >270°C/km and the lowest is <180°C/km. This map can be considered a portrayal of the subsurface temperature distribution in this region.

Table 1: characteristics of the gradient wells in Mödruvellir area

Well	Coordinate system		Temperature at 50m depth	Gradient °C/Km	Depth (m)
	x	y			
MV-6	379666	423651	14	205	75
MV-7	379848	423502	14	183	73
MV-8	379541	423856	18	265	58
MV-9	379266	424200	18	272	59
MV-10	379400	424036	17	245	59
MV-11	379187	424364	19	300	60
MV-12	378908	424435	15	190	59
MV-13	379208	424325	19	297	60
MV-14	379147	424388	19	300	54
MV-15	379051	424372	19	282	71
MV-16	379274	424393	19	275	70
MV-18	379251	424502	19	290	70
MV-20	379492	423944	17	257	69
MV-21	379388	423832	17	256	71
MV-22	379646	423781	16	230	70
MV-23	379639	423958	16	265	90
EJ-5	379792	424149	13	160	51
KM-3	379571	424698	16	210	51
KM-4	379624	424674	16	236	45
KM-5	379343	424884	12	160	64

Comparison between the temperature and gradient maps shows that the highest temperature zone on the temperature map is within the highest gradient zone. Based on Figure 6 the main temperature anomaly is located between two major faults in this area.

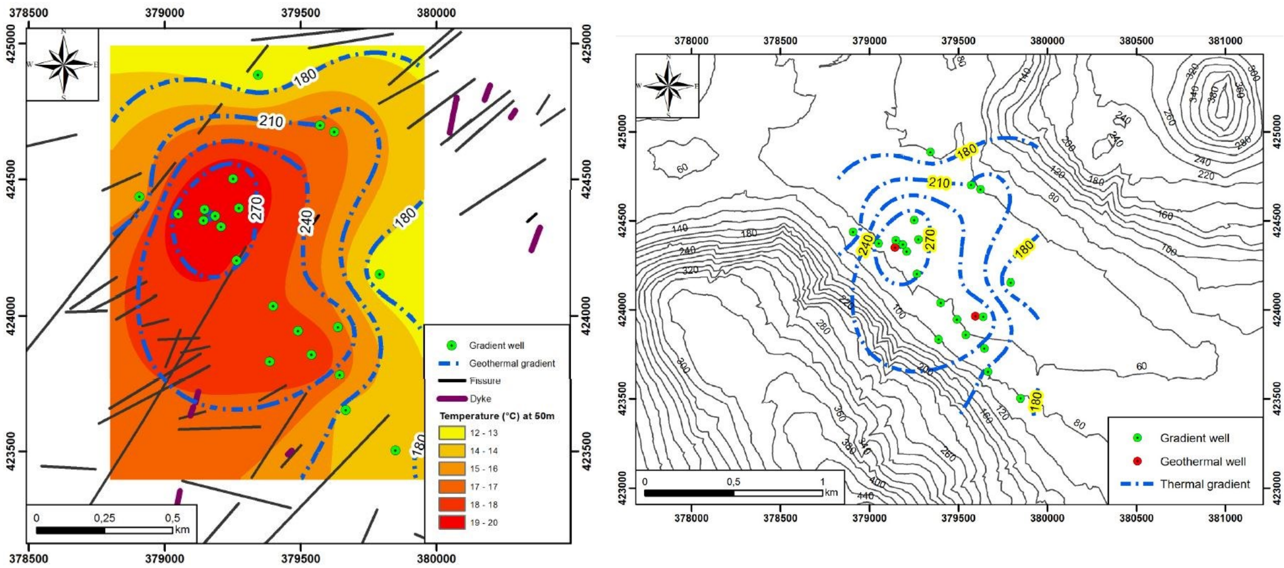

FIGURE 6: Left: Temperature map at 50 m depth in the gradient wells. Right: Thermal gradient map in Mödruvellir region (Ebrahimi, 2015)

4. COMPARING THE RESULTS OF THERMAL SURVEYING IN MAHALLAT AND MODRUVELLIR GEOTHERMAL FIELDS

As it mentioned above, thermal surveying is one of the geothermal exploration methods which is most used in low temperature geothermal areas having are few surface manifestations. This method works better in fracture controlled low temperature fields

(Saemundsson, 2007). Based on the information shown in the figures 2, 3, 5 and 6, it is indicated that geothermal reservoirs in both areas are controlled by some main faults and fractures.
Within the thermal anomaly of Mahallat geothermal field (Figure 5) there are two large thrust faults that have the most influential role in the formation of geothermal reservoirs. Numerous faults in this area are also acting as pathways for hydrothermal fluids circulation (Oskooi and Darijani, 2014; Nouraliee et al., 2015; Moghaddam et al., 2016). The deep circulation water is heated by geothermal gradient and then flows upwards to approach the surface along the faults and fractures. There are thick permeable sedimentary layers (Cretaceous limestones) which are covered by thick impermeable layers (Jurassic shale) in this area, moreover the geology of Mahallat region shows that there are no young volcanic rocks as a heat source in the area. Besides the highest temperature gradient is 107.5°C/km in well #7. Based on these evidence, the Mahallat geothermal reservoir is classified in sedimentary geothermal systems.

In the Mödruvellir geothermal filed, SW Iceland, there are two thermal anomalies. The main thermal anomaly is located between two major faults (Figure 6). Intersection of these faults is the main reason of the formation of thermal anomaly in this region. Another thermal anomaly occurs above fractures that have ENE-WSW trend. Geology structures that control the flow of the fluids upwards are observed in three main directions: NE-SW, WSW-ENE and WNW-ESE (Ebrahimi, 2015). Two major faults with different dips were formed a graben in the area that has an important role in increasing the permeability.

The Mödruvellir geothermal reservoir is classified as a convective fracture controlled system and the highest temperature gradient is >270°C/km.

5. CONCLUSION

This work presents the results of thermal surveying studies in Mahallat geothermal field in Iran and Mödruvellir geothermal field in Iceland which are done by the author. Seven gradient wells were drilled in Mahallat region and thermal surveying is based on information extracted from these wells. The highest temperature gradient in the Mahallat area is 107.5°C/km. There are two thrust faults that have an important role in the formation of thermal anomaly in the Mahallat region. In the Mödruvellir region, the data were obtain from 22 gradient well and 2 production wells. Based on the temperature map at 50 m depth, there are two temperature anomalies in this area and the highest temperature gradient is >270°C/km. The results of this study show that the Mahallat geothermal reservoir is classified in sedimentary geothermal systems and The Mödruvellir geothermal reservoir is classified in convective fracture controlled systems.

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