Proceedings World Geothermal Congress 2020+1
Reykjavik, Iceland, April - October 2021

Geochemical Characteristics of the South Khorasan Geothermal Fields, E-Iran

Mohammad Reza Rahmani

Renewable Energy and Energy Efficiency Organization, Yadegar-e Emam Highway, Pounak Bakhtari Ave., P.O.Box 14665-1169 Tehran, Iran

mrrahmani@satba.gov.ir

Keywords: South Khorasan, geothermal, geochemistry, thermal spring, Iran

ABSTRACT

South Khorasan Province hosts several low-temperature geothermal prospects include Ferdows, Lut, Dig-e Rostam, Kandegan, Morteza Ali and Gazik. Thermal springs are the most visible manifestations of geothermal systems in this province. Thermal springs have temperatures between 31.8 and 51.9 °C. The Na-K-Mg triangular diagram shows that the thermal waters plot in the area of immature waters (except for Ferdows and Lut waters that plot on the border between immature and partially equilibrated waters) with a relatively high Mg content, indicating that the geothermal waters have possibly a high proportion of cold groundwater. According to a Cl-Li-B ternary diagram, all the samples have high Cl relative to Li and B suggesting that they are from old hydrothermal systems. The Na-K-Mg-Ca diagram illustrates that all the thermal waters plotted far from the full equilibration curve indicating these waters are not fully equilibrated or high degree of mixing with cold groundwater and or re- equilibration. The Cl-SO_4-HCO_3 triangular diagram shows that the thermal waters from Kandegan and Gazik plot in the peripheral waters area, while Ferdows, Dig-e Rostam and Lut waters lie in the field marked “volcanic waters” and only Morteza Ali water plots between peripheral and volcanic waters, which might be an indication that it is combined water. Characteristics of thermal waters indicate that the common geothermometers involving Na, K, Ca, and Mg are unlikely to be applicable to these waters, therefore reservoirs temperatures have been calculated based on thermal spring samples using the chalcedony conductive and quartz conductive geothermometers as 57-89 °C, 55-86 °C, 72-102 °C, 85-114 °C, 23-55 °C and 23-55 °C for Lut, Ferdows, Dig-e Rostam, Kandegan, Gazik and Morteza Ali respectively. The temperature obtained from chalcedony geothermometer (23 °C) for both waters from Gazik and Morteza Ali is not valid as it is lower than spring’s temperature.

1. INTRODUCTION

In the early stages of geothermal exploration, geochemical studies provide information which neither geological nor geophysical methods can reveal. Geochemical studies predict subsurface temperature, identify the origin of thermal fluids, and quantify processes that control their compositions and accompanying chemical and mineralogical alterations of rocks (Arnorsson, 2000) Data sampling, analysis and interpretation play paramount importance in geochemistry studies of geothermal fluids. South Khorasan Province is one of the eastern provinces of Iran (Figure 1), which hosts several low-temperature geothermal prospects. The geothermal prospects of interest include: Ferdows, Lut, Dig-e Rostam, Kandegan, Morteza Ali and Gazik (Figure 2). All of the geothermal regions in this province are in a desert and semi-desert environment. Geothermal manifestations in this province usually consist of thermal springs. Until now, geothermal utilization in South Khorasan is simple, such as swimming pools and spa treatments .The purpose of this study is to interpret the chemical properties of thermal waters from South Khorasan and estimation of reservoir temperature using geothermometers as a part of geothermal exploration.

2. SURFACE GEOLOGY

Geological studies invariably start at the incipient reconnaissance stage which entails preliminary mapping of the lithologic units and structures, mapping of thermal surface manifestations and possibly relate to the structures and or volcanism in the prospect of interest. The characterization of tectonic structures is very important in geothermal exploration because the geothermal manifestations are often directly related to the presence of these structures. The two main active tectonic faults in South Khorasan geothermal fields are Nayband and Nehbandan faults. These two faults and their dependent faults have an important role in the formation of geothermal systems in this province. The main geological units in the geothermal prospects of South Khorasan are as follows:

Ferdows: Shale, sandstone, siltstone, limestone (Triassic), alternation of sandstone, shale, argillite and thin lenses of coaly argillite (Jurassic), limestone (Early Cretaceous), andesite, trachyte, trachyandesite, , dacite, rhyodacite, rhyolite, latite, , tuff, agglomerate, basalt, andesite -basalt (Eocene), conglomerate, marl, sandstone, sandstone and conglomerate as intercalations, partly gypsiferous with gypsum lenses (Neogene), conglomerate, terraces and old gravel fans, terraces and young gravel fans (Quaternary) (Figure 3).

Lut: Limestone (Permian), sandstone, siltstone, shale, dolomitic limestone (Triassic), granodiorite (Late Jurassic), limestone, marl, conglomerate (Late Cretaceous), sandstone, siltstone, marl, tuffite, volcaniclastic conglomerate, dacite and associated pyroclastics, olivine basalt, latite andesite, quartz latite, tuff (Eocene), limestone (Oligocene-Miocene), older terraces and alluvium deposits, younger terraces and alluvial fans, clay and silt flats and alluvium in major river (Quaternary) (Figure 4).

Figure 1: Location of South Khorasan province

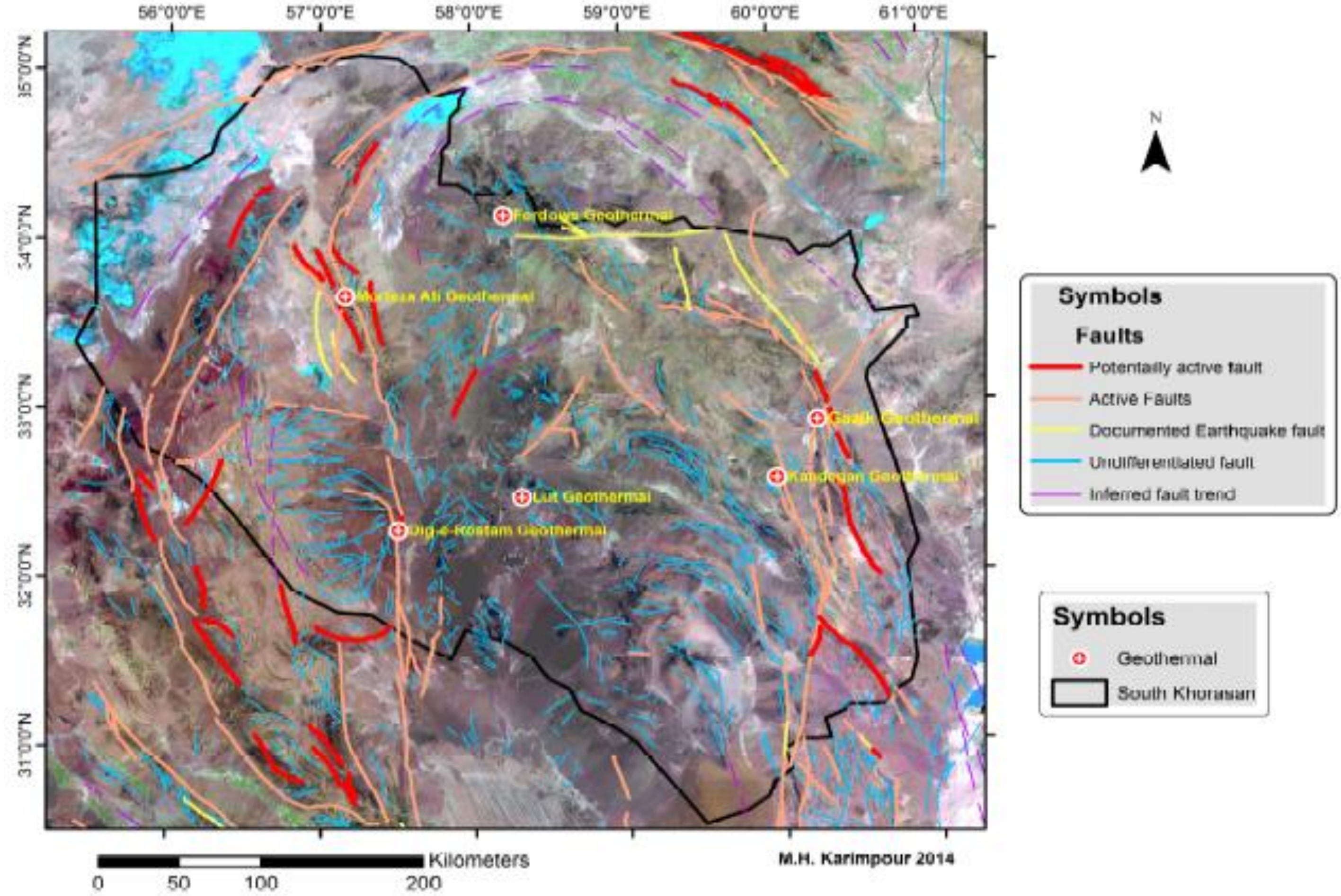

Figure 2: Location of geothermal prospects in South Khorasan (Karimpour et al., 2014)

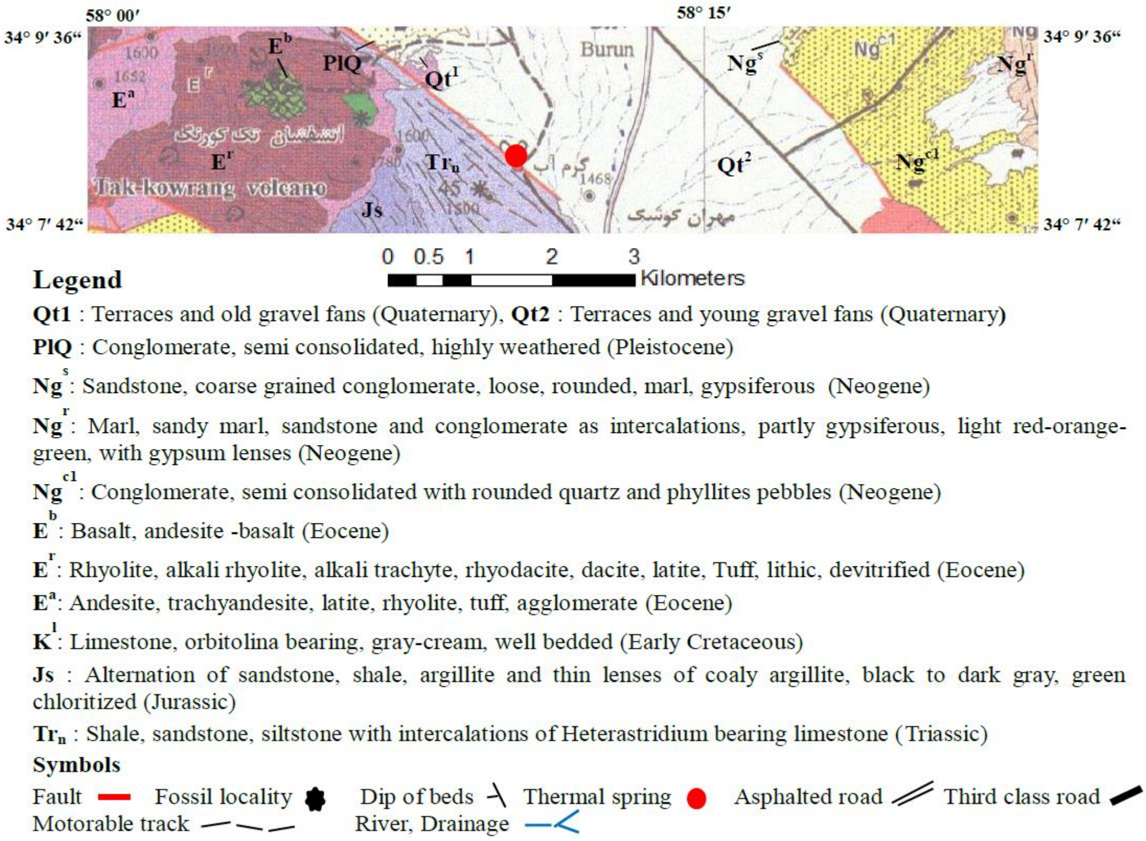

Figure 3: Geological map of Ferdows geothermal prospect (extracted from geological map of the Ferdows area of Pourlatifi (2005))

Dig-e Rostam: Hornfels, shale, sandstone, limestone, reefal limestone (Triassic), dioritic plug and dykes (Tertiary), alluvium in older, elevated terraces and gravel fans, alluvium in young terraces, alluvium in braided channels and flood plains and alluvium in major stream channels (Quaternary) (Figure 5).

Kandegan: Altered volcanic rocks, andesite, marly tuff and dacitic tuff, pyroxene andesite (Eocene) and recent alluvium (Quaternary) (Figure 6).

Morteza Ali: Sandstone, limestone, sandy limestone, shale (Devonian), shale, sandstone, limestone (Carboniferous), limestone, dolomite (Permian), gypsiferous marly shale, limestone (Jurassic), recent alluvium (Quaternary) (Figure 7).

Gazik: Ultrabasic rocks, gabbro, diabase, tuff, basalt, amphibolite, schist, andesite, shale, turbidite, flysch (mostly shale) (Cretaceous), limestone (Paleocene), marl, sandstone (Eocene), andesite, basaltic andesite (Oligocene-Miocene), conglomerate (Pliocene-Quaternary), mud flat and recent alluvium (Quaternary) (Figure 8).

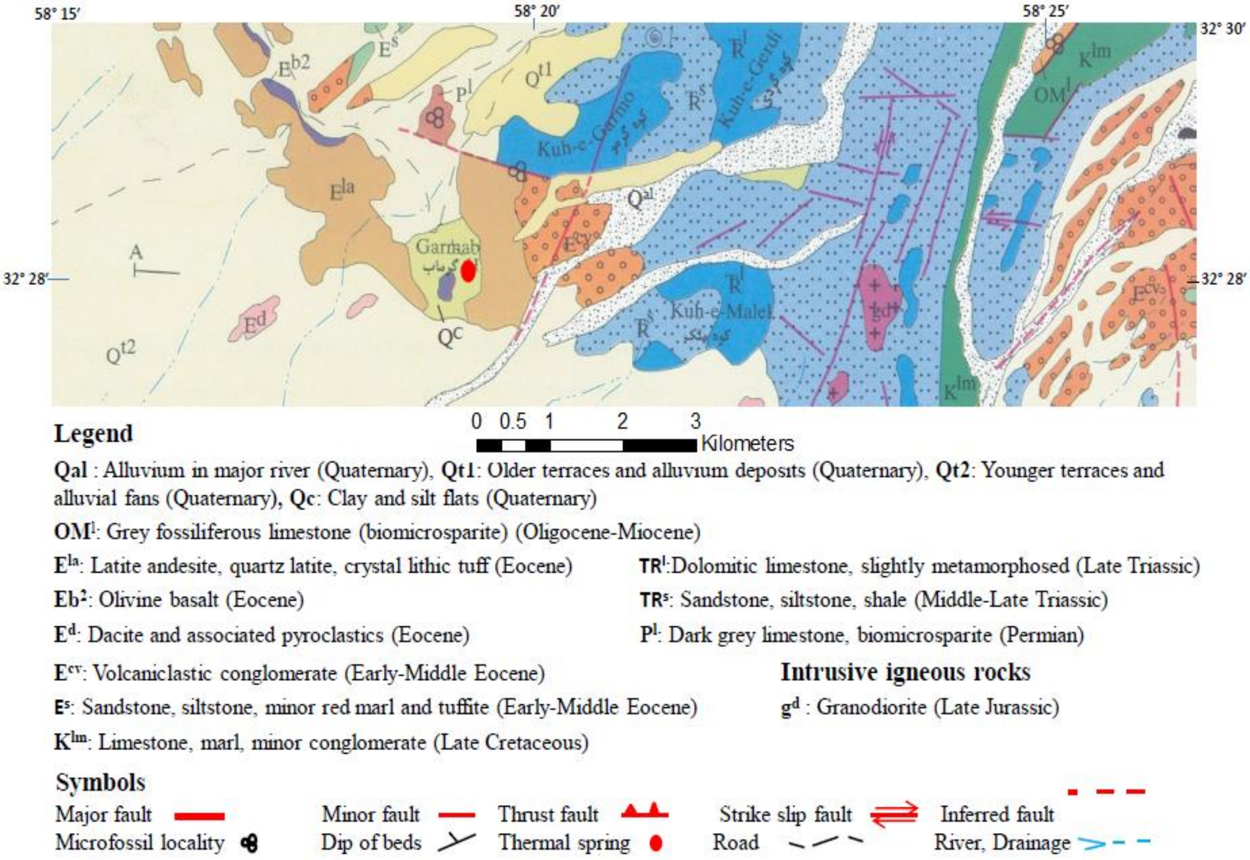

Figure 4: Geological map of Lut geothermal prospect (extracted from geological map of the Jonub-e Sehchangi area of Bolourian et al., 2004)

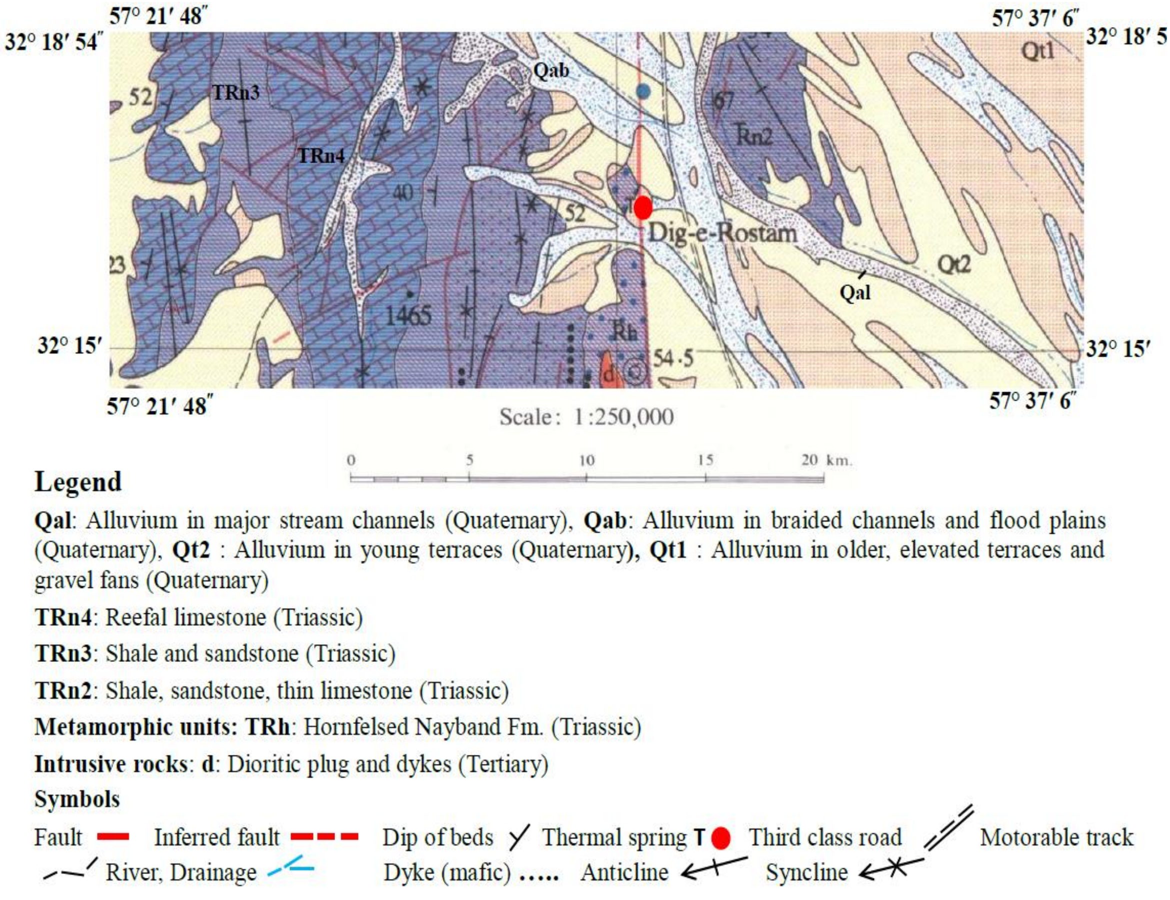

Figure 5: Geological map of Dig-e Rostam geothermal prospect (extracted from geological map of the Naybandan area of Alavi-Naini et al., 1981)

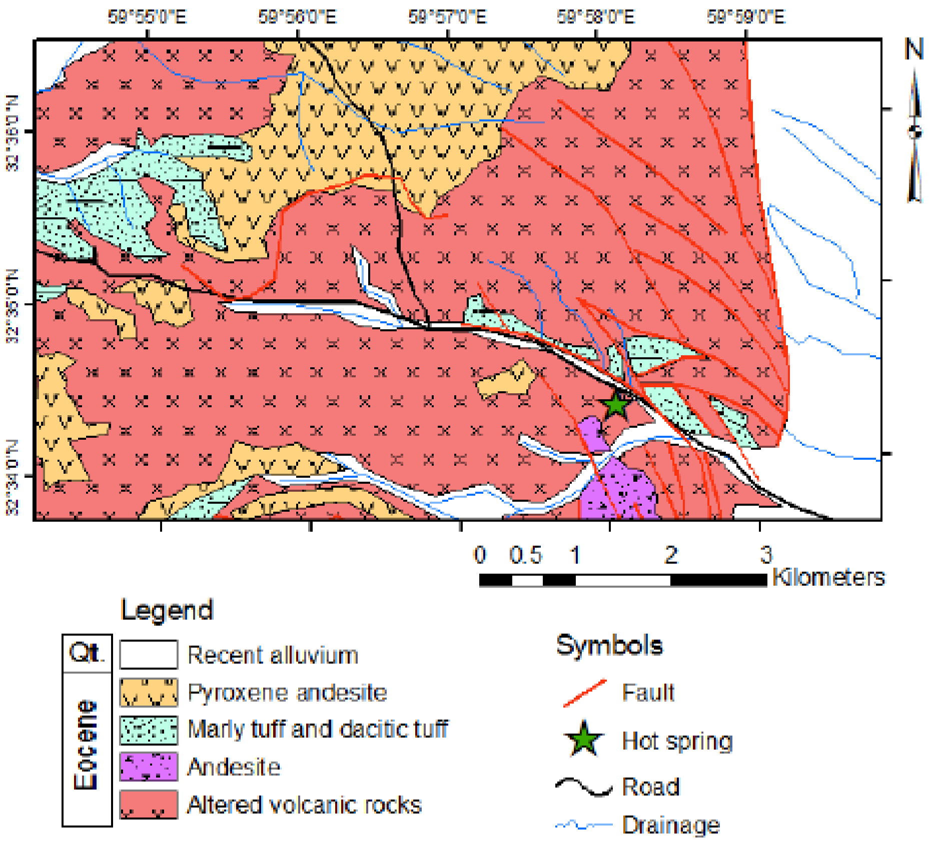

Figure 6: Geological map of Kandegan geothermal prospect (extracted from geological map of the Sarbishe area of Nazeri et al., 1999)

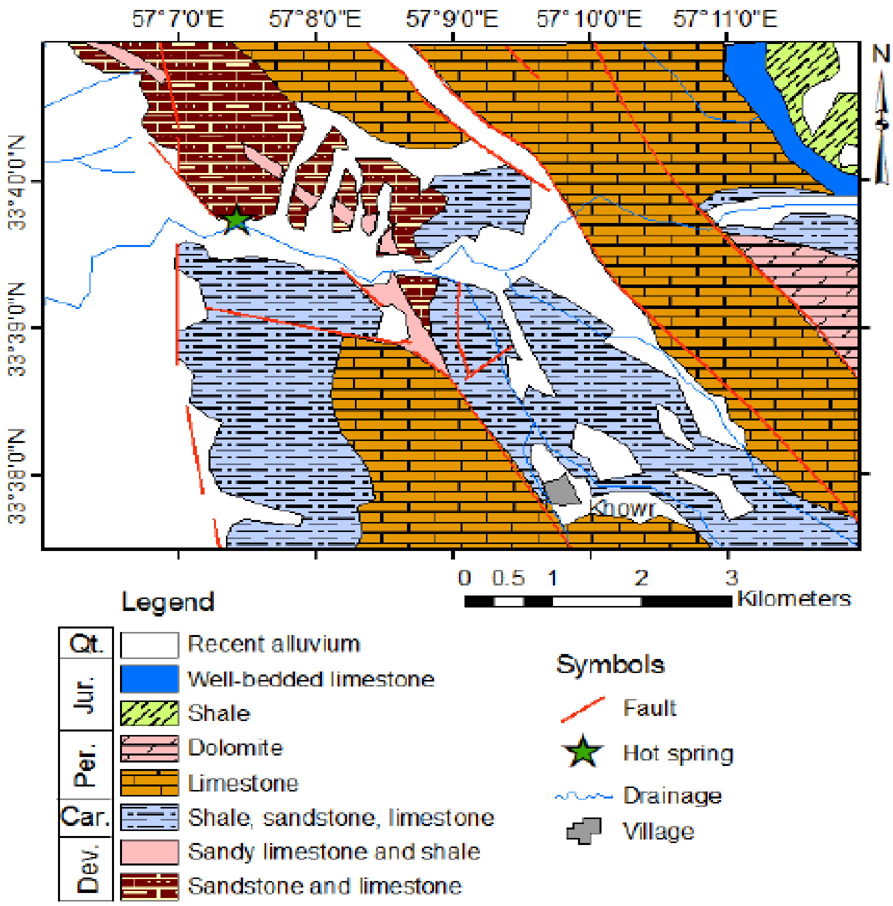

Figure 7: Geological map of Morteza Ali geothermal prospect (extracted from geological map of the Boshruyeh area of Stocklin et al., 1993)

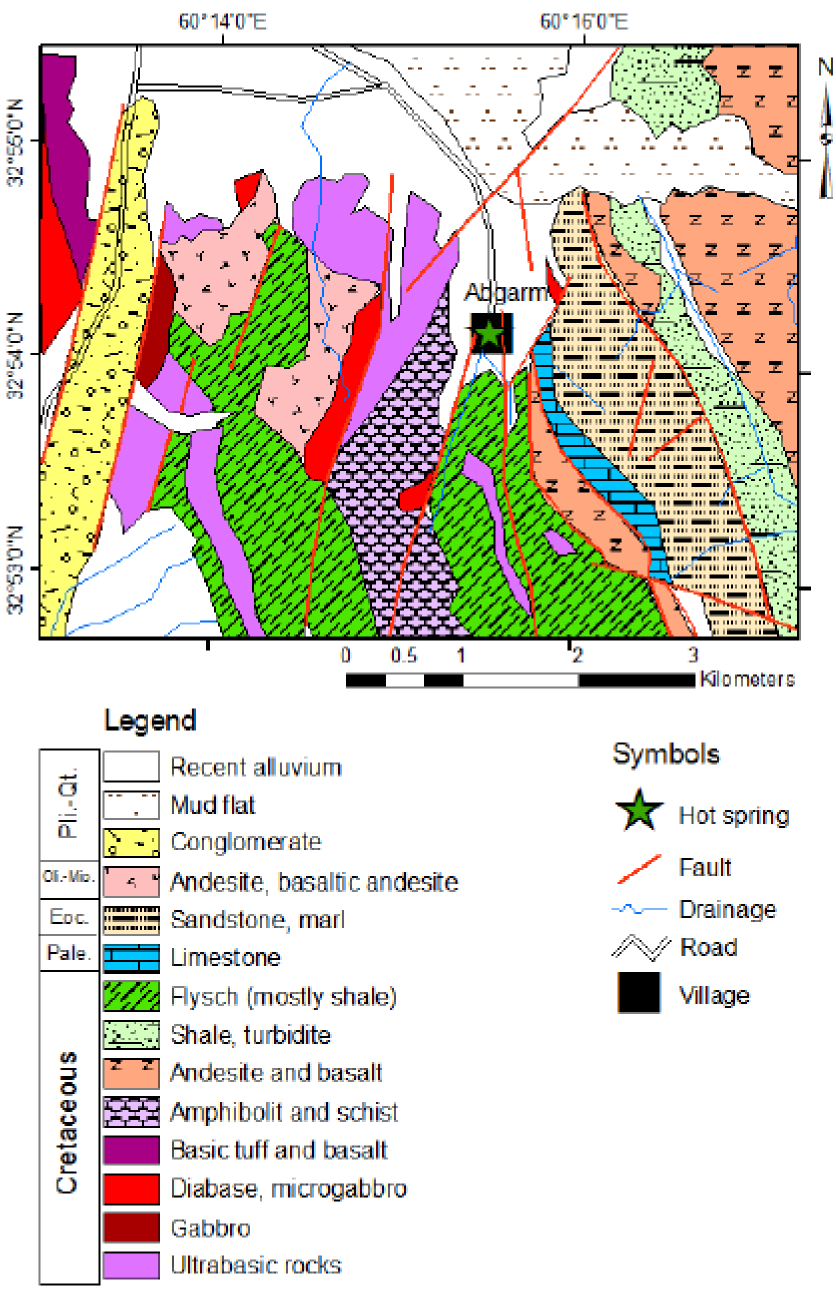

Figure 8: Geological map of Gazik geothermal prospect (extracted from geological map of the Gazik area of Alavi-Naini et al., 1981)

3. CHEMICAL PROPERTIES OF THE GEOTHERMAL WATERS

The composition of water in geothermal field have their own characteristics depending on the rock composition, the residence time of the water within the rocks, the rate of leaching of components from the rocks, the fluid flow into the system, the rate of formation of secondary minerals, pressure and temperature. The temperatures of the thermal springs vary between 31.8 and 51.9°C. The data used in this study is from 6 thermal springs of the South Khorasan. Thermal springs were sampled and analyzed and geochemical data is interpreted to estimate the reservoir temperatures and properties. The chemical composition of thermal waters from the South Khorasan geothermal fields is given in Table 1. The interpretation and evaluation of all available information regarding the geochemistry were accomplished by the methods of Cl-SO_4-HCO_3 ternary diagram, Na-K-Mg ternary diagram, Cl-Li-B ternary diagram, Na-K-Mg-Ca diagram, geothermometers and Excel spreadsheets by Powell and Cumming (2010).

3.1 Chemical evaluation of geothermal fluids using anion and cation diagrams

3.1.1 Cl-SO_4-HCO_3 diagram

The Cl-SO_4-HCO_3 ternary diagram classifies the geothermal waters on the basis of the abundance of major anions. In Figure 9, Kandegan and Gazik thermal waters plot in the HCO_3 field. This indicates that the samples from Kandegan and Gazik are possible mixed with cold groundwater or the higher HCO_3 concentration of the water is a result of the presence of carbonate rocks. The waters from Ferdows, Dig-e Rostam and Lut lie in the field marked “volcanic waters” and only Morteza Ali water plots between peripheral and volcanic waters, which might be an indication that it is combined water.

3.1.2 Na-K-Mg diagram

The Na-K-Mg diagram is used to classify waters into fully equilibrated, partially equilibrated and immature waters .It can be used to predict the equilibrium temperature. In addition, the Na-K-Mg tiangular diagram provides a tool for selecting samples that are suitable for the application of the cation geothermometer. From Figure 10, it is clear that the waters from the thermal springs plot as immature waters (except for Ferdows and Lut waters that they plot on the border between immature and partially equilibrated waters) with a relatively high magnesium concentration, suggesting a high proportion of cold groundwater and therefore according to Giggenbach (1991) the application of both the Na-K and K-Mg geothermometers becomes doubtful.

3.1.3 Na-K-Mg-Ca diagram

The Na-K-Mg-Ca diagram illustrates that all the thermal waters plotted far from the full equilibration curve indicating these waters are not fully equilibrated or high degree of mixing with cold groundwater and or re- equilibration (Figure 11).

3.1.4 Cl-Li-B diagram

A plot of the relative concentrations of Cl, Li and B is shown in Figure 12. All the thermal water samples plot near the Cl corner, showing high Cl content relative to Li and B, the area of low absorption of B/Cl steam. This may indicate that the thermal waters originate from relatively old hydrothermal systems. Water in young systems may plot near the B corner due to the high absorption of B/Cl steam from degassing fresh magma.

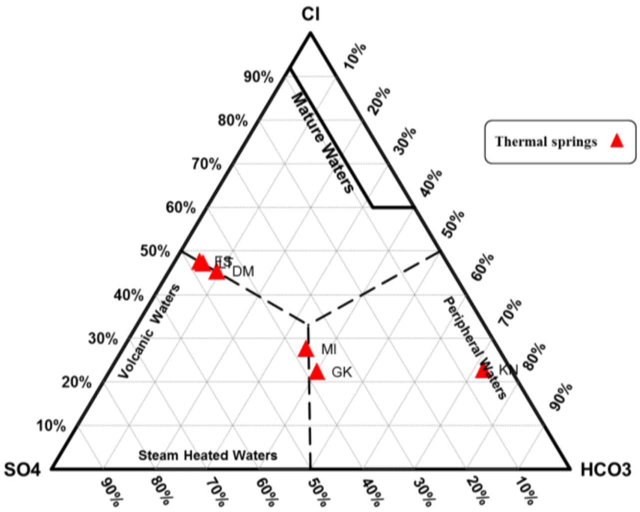

Figure 9: Cl-SO4-HCO3 diagram for the South Khorasan thermal springs

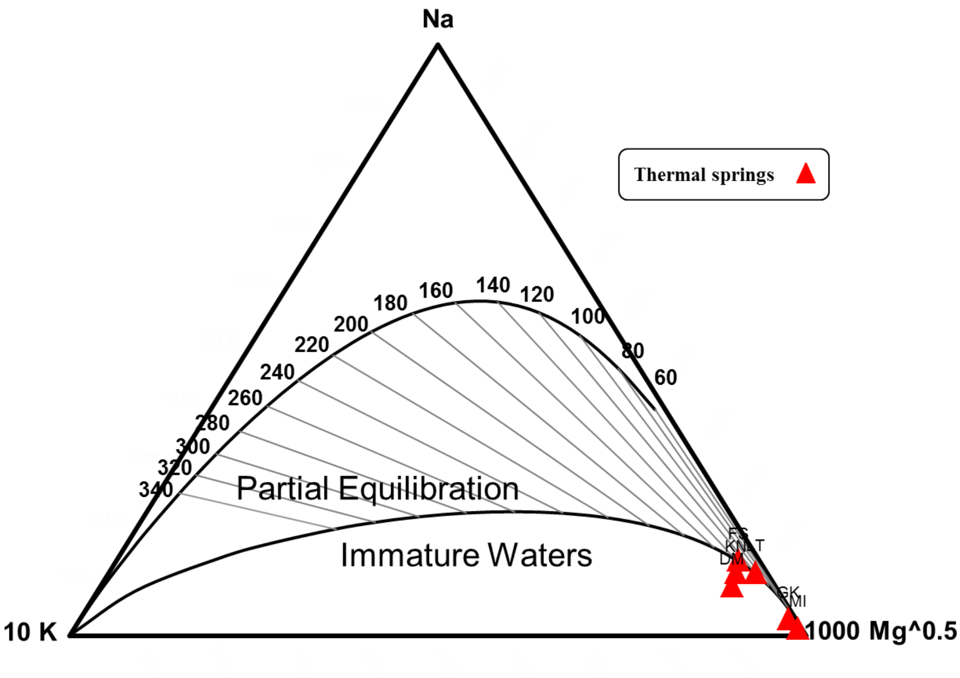

Figure 10: Na-K-Mg diagram for the South Khorasan thermal springs

Table 1: Chemical composition of water samples from thermal springs of the South Khorasan geothermal prospects (mg/kg) (Karimpour et al., 2014)

FS: Ferdows; LT: Lut; DM: Dig-e Rostam; KN: Kandegan; MI: Morteza Ali; GK: Gazik

Sample	Temp. (ºC)	pH	Li	Na	K	Ca	Mg	Fe	Cl	F	SO_4	HCO_3	B	SiO_2	As	TDS (g/l)	Ec (μ/cm)	Flow rate (l/s)
FS	43.5	6.8	0.65	1618	36.2	422.4	115.5	0.009	2800	0.4	2800	283	0.35	35	0.2	7.25	14.5	5.2
LT	38.2	7.14	0.5	1411	21	306.2	134.7	0.008	2100	0.3	2100	253.8	0.4	37	0.1	5.57	11.17	4
DM	51.9	7.45	1	658	45.4	176	44.9	0.009	1100	0.6	1100	224.5	0.5	50	0.4	3.51	6.96	0.5
KN	32.8	6.99	1	1285	52.1	35.2	106.9	0.009	908.8	0.3	210.9	2879.2	0.2	64	0.3	3.87	7.75	16
MI	32.8	7.56	0.2	105.8	4.4	61.9	66.3	0.007	156.2	0.5	210.5	200.1	0.5	16	0.2	651.7	1295	11
GK	31.8	7.64	0.2	154.5	5.5	45.8	27.8	0.005	127.8	0.4	215.9	229.4	0.5	16	0.6	694	1385	15

Table 2: Results of different geothermometers for water samples from thermal springs in the South Khorasan geothermal prospects (°C)

Sample	$T_{Chalcedony}$ (Conductive)	T_{Quartz} (Conductive)	T_{Quartz} (Adiabatic)	$T_{Na\text{-}K\text{-}Ca}$	$T_{Na\text{-}K\text{-}Ca}$ (Mg corr.)	$T_{Na/K}$ (Fournier)	$T_{Na/K}$ (Truesdell)	$T_{Na/K}$ (Giggenbach)	$T_{K/Mg}$ (Giggenbach)
FS	55	86	89	121	-80	115	68	136	69
LT	57	89	91	93	-146	94	46	115	55
DM	72	102	103	166	-60	187	151	204	86
KN	85	114	113	164	-340	150	107	169	78
MI	23	55	62	50	-258	152	109	171	31
GK	23	55	62	66	-180	142	98	161	44

FS: Ferdows; LT: Lut; DM: Dig-e Rostam; KN: Kandegan; MI: Morteza Ali; GK: Gazik

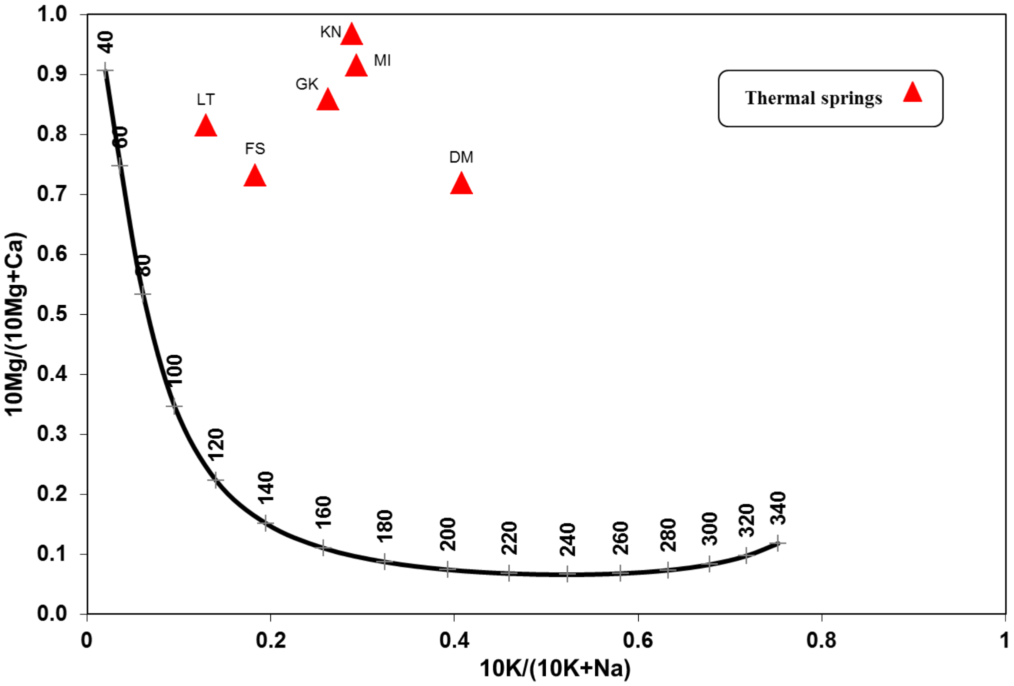

Figure 11: Na-K-Mg-Ca diagram for the South Khorasan thermal springs

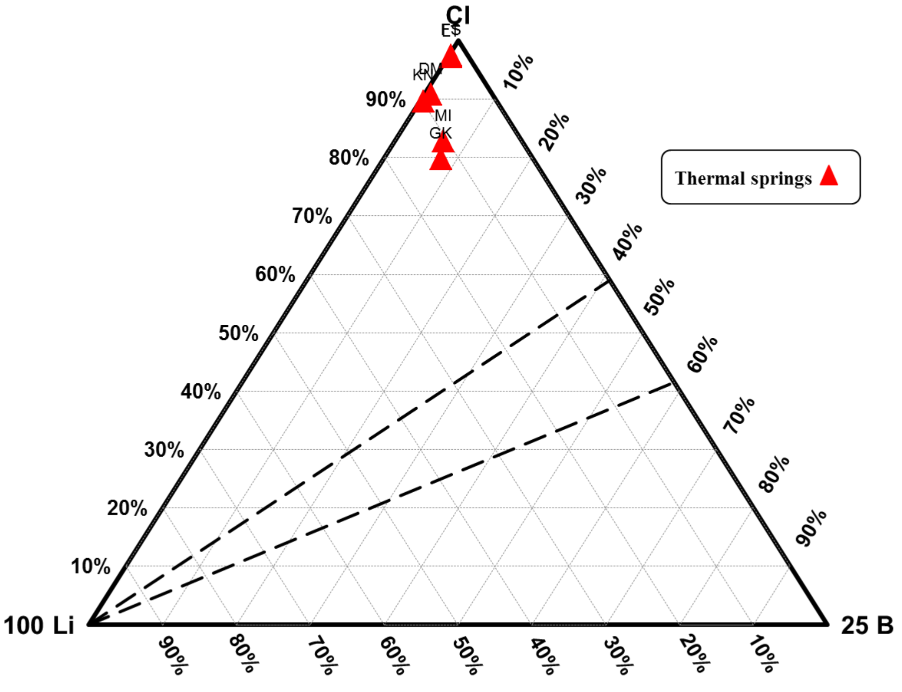

Figure 12: Cl-Li-B diagram diagram for the South Khorasan thermal springs

4. GEOTHERMOMETRY

During geothermal exploration, the most commonly used method to estimate reservoir fluid temperature is geothermometry calculations. D'Amore and Arnórsson (2000) classified geothermometers into three groups as: water or solute geothermometers, steam or gas geothermometers and isotope geothermometers. Excel spreadsheets by Powell and Cumming (2010) are used to estimate the subsurface fluid temperatures and the results are shown in Table 2. Characteristics of thermal waters indicate that the common geothermometers involving Na, K, Ca, and Mg are unlikely to be applicable to these waters. As the springs are not boiling, the most appropriate geothermometer is quartz conductive. Also, the geothermal reservoirs in South khorasan are long-lived systems and in the study area, the most of bedrocks are old sedimentary rocks and equilibration with quartz may be experienced at temperatures of even less than 100°C. In fact, in the old rock where chalcedony tends to becomes quartz after a long time, so it is possible to use both chalcedony and quartz geothermometers , therefore reservoirs temperatures have been calculated based on thermal spring samples using the chalcedony conductive and quartz conductive geothermometers as 57-89 °C, 55-86 °C, 72-102 °C, 85-114 °C, 23-55 °C and 23-55 °C for Lut, Ferdows, Dig-e Rostam, Kandegan, Gazik and Morteza Ali respectively.The temperature obtained from chalcedony geothermometer (23 °C) for both waters from Gazik and Morteza Ali is not valid as it is lower than spring's temperature.

5. CONCLUSION

The thermal waters from South Khorasan were found to be immature and far from the full equilibration curve according to Na-K-Mg and Na-K-Mg-Ca diagrams. Based on Cl-Li-B diagram, the thermal waters originate from relatively old hydrothermal systems. In accordance with Cl-SO_4-HCO_3 ternary diagram, the waters from Ferdows, Dig-e Rostam and Lut lie in the field marked "volcanic waters" while Kandegan and Gazik thermal waters plot in the HCO3 field and only Morteza Ali water plots between peripheral and volcanic waters. South Khorasan geothermal prospects are estimated to have the reservoir temperature range between 57-89 °C, 55-86 °C, 72-102 °C, 85-114 °C, 23-55 °C and 23-55 °C for Lut, Ferdows, Dig-e Rostam, Kandegan, Gazik and Morteza Ali respectively, according to chalcedony conductive and quartz conductive geothermometers .Of course, the temperature obtained from chalcedony geothermometer (23 °C) for both waters from Gazik and Morteza Ali is not valid as it is lower than spring's temperature. The high cations and anions concentration (such as SO4, Cl, Mg and Ca) in the thermal waters, especially in waters from Ferdows, Lut and Dig-e Rostam may derived from dissolution of sedimentary rocks (such as evaporites), since they are mostly in a sedimentary geological environment with desert and semi-desert climate. To prove this, further investigation is required. Finally, geochemical studies and field observations suggest that the South Khorasan geothermal prospects are low-temperature geothermal systems and waters from these fields can be used for space heating, fishing industry, greenhouse industry, tourist attraction like natural bathing and swimming pool.

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