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

Proceedings World Geothermal Congress 2020
Reykjavik, Iceland, April 26 – May 1, 2020

An Overview on Geothermal Energy Resource in Āq-Bolāgh Region (NW- Iran)

Amir Tamjidi[1], Javād Nouraliee[1], Dāvar Ebrāhimi[1]

1. Renewable Energy Department, Niroo Research Institute (NRI), P.O. Box 14665-517, Tehran-Iran,

atamjidi@yahoo.com, jnouraliee@nri.ac.ir, debrahimi@nri.ac.ir,

Keywords: Geothermal, Exploration, Warm spring, Āq-Bolāgh, Iran

ABSTRACT

After conducting of a preliminary geothermal exploration project in west Azarbāijān province in Iran, 12 geothermal prospects were identified in that province. One of the determined prospects is Āq-Bolāgh region which has 165 Km^2 area and is located SW of Māku city in the northwest of Iran. The most outstanding geothermal surface manifestations in this region are warm springs, hydrothermally altered areas, quaternary volcanic rocks and travertine deposits. The temperature of warm springs varies from 29 to 39 °C. Based on geochemical studies it is found that warm springs belong to bicarbonate water family and also, they have slightly mixed with underground water. According to Na/K geothermometers, approximate temperature of the geothermal reservoir is 102-150 °C. Due to the presence of quaternary volcanic rocks in the region they can be regarded as proper heat source for the geothermal reservoir. It is believed that Āq-Bolāgh geothermal resource is suitable for power generation using binary cycle power plant.

1. INTRODUCTION

Normally, exploration program is the first step to use a geothermal resource. Usually, the objectives of an exploration program, prior to deep drilling (1000 to 3000 m or more), are to locate areas underlain by hot rock, estimate the size and boundaries of a potential reservoir, including the type and permeability of rocks comprising the reservoir and determining of the temperature and chemical nature of geothermal fluids in the reservoir (Boden, 2017). In order to identifying and classifying of geothermal prospects, a preliminary exploration project carried out in the West Azarbāijān (WA) province of Iran. The results of that project revealed that WA province is very rich in the case of geothermal resources. This province contains 12 geothermal regions which based on geothermometry studies, some of them are suitable for power generation. One of the identified geothermal regions is Āq-Bolāgh region which is believed that is suitable for power generation and heating purposes as well (Nouraliee et al., 2015).

Āq-Bolāgh geothermal region (AGR) is located 40 Km to the southwest of Māku city in the west Azarbāijān province, positioned in the northwestern part of Iran (Figure 1). AGR area is 165 km^2 and its shape is almost ellipsoid. Geothermal surface manifestations in AGR are young volcanic rocks, travertine deposits, hydrothermal altered areas and warm springs. In this paper some information about geology and surface geothermal manifestations and also some results of geochemical studies about Āq-Bolāgh geothermal region will be introduced.

2. GEOLOGY

Āq-Bolāgh geothermal region is located in Khoy-Mahābād Tectono-Sedimentary zone, figure 2. The border of this zone and Azarbāijān zone are the major Tabriz and Urmia faults. This zone has a north-south trend. In this zone, there are some north-south trending and very old mountains which are the remnant of Katanga orogeny. Due to these mountains, sedimentary environment of their eastern side (Azarbāijān) and western side (Turkey) are obviously different. One of the significant characteristics of this zone are the extensive colored mélange rocks outcrops (Nabavi, 1979). AGR geological map is shown in Figure 3. Based on Dizaj and Khoy 1:100,000 geological maps which AGR is located in their border, there are numerous faults that aligned generally in approximately NW-SE directions especially in the northern part of the region. In fact, AGR is located in a specific section of the country which is tectonically active.

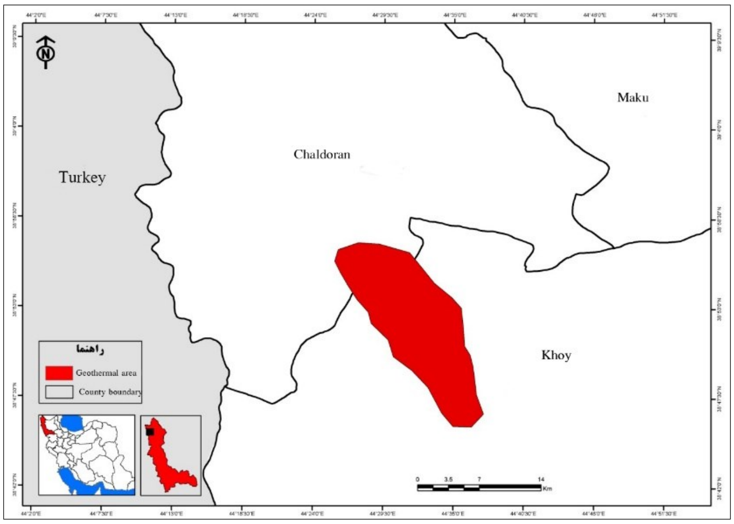

Figure 1. Location of Āq-Bolāgh Geothermal Region in the West Azarbāijān Province (NW-Iran)

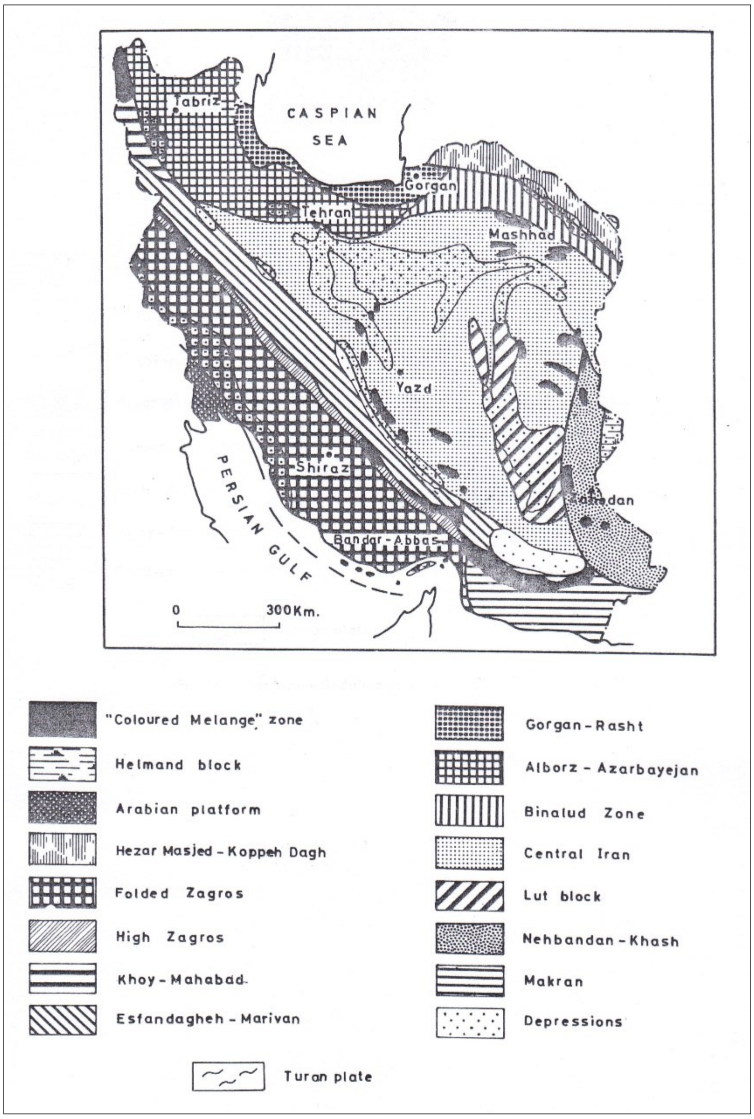

Figure 2. Tectono-Sedimentary zones of Iran (Nabavi, 1979)

There are several rock units which have been outcropped in Āq-Bolāgh region. They are as follows (from older to younger):

Cretaceous: shale and sandstone (Ks), limestone (Kpl), limestone and basaltic lava flows (Klv) and basalt, limestone and shale (Kbp) -**Paleocene**: shale and sandstone (Pasc) -**Paleocene-Eocene:** shale, sandstone and conglomerate (PEsc), nummulitic limestone (PEl1), nummulitic and reddish limestone (PEl2), basaltic lavas, limestone and shale (PEvls) -**Neogene**: andesitic and trachyandesitic lava flows (Ngan) -**Pliocene-Quaternary**: conglomerate and sandstone (Pl-Qc) and lahar (Pl-Qla) -**Quaternary**: young terraces (Qt2), andesitic lava flows (Qv), old terraces (Qt1), old fans (qf1), travertine (Qtr) and recent alluvium (Qal).

Ophiolite complex (Cretaceous) including serpentinite (Sr), ultramafic rocks (Ub), diabasic dykes (di) and diorite and gabbro (dg). **Metamorphic rocks of unknown age** consisting of metavolcanics (Mt and Mtmt), marble and schist (mb), schist (Mtsch) and crystalized limestone and schist (Mtmb). **Intrusive rocks** which include monzodiorite (mdg), granite (agr) and trachyte and trachyandesite (plpt) (Pliocene?) and pegmatitic dykes (gn).

According to the available 100k geological maps it is found that there are several faults in AGR. There is a major fault in the region that seems has a significant role in the formation of geothermal resource in AGR. It is elongated in NW-SE direction and has about 16 km length. As it can be seen in figure 3, AGR shape has been selected based on this fault. Besides, there are also several minor faults with different strikes in the region. There are two thrust faults in the northern part of AGR which their relation to Āq-Bolāgh geothermal resource is unclear now (Amini et al., 1997; Rādfar et al., 1998).

3. GEOTHERMAL SURFACE MANIFESTATIONS

3.1. Warm Springs

Warm springs are the most well- known and common surface manifestations of geothermal resources in the world. In the AGR there are only two warm springs which are very close together. Both of the Āq-Bolāgh warm springs named Qāranjeh 1, 2 are located 5 km from Qāranjeh village in the west of central part of AGR (Figure 3). These springs are appeared in a close relation to the major fault of the region which is shown very well in figure 3. The temperature of the springs varies from 29 to 39 °C. Their flowrate is less than 2 l/s. Geographic coordinates and some physical characteristics of the AGR warm springs are illustrated in Table 1.

Table 1. General Characteristics of Āq-Bolāgh Warm Springs

Spring Name	Longitude	Latitude	Elevation (masl)	Temperature (°C)	Flowrate (l/s)	EC (μS/cm)
Qāranjeh 1	44° 29´38″	38° 53´04″	1805	39	0.5	7160
Qāranjeh 2	44° 29´37″	38° 53´02″	1803	29	1	6060

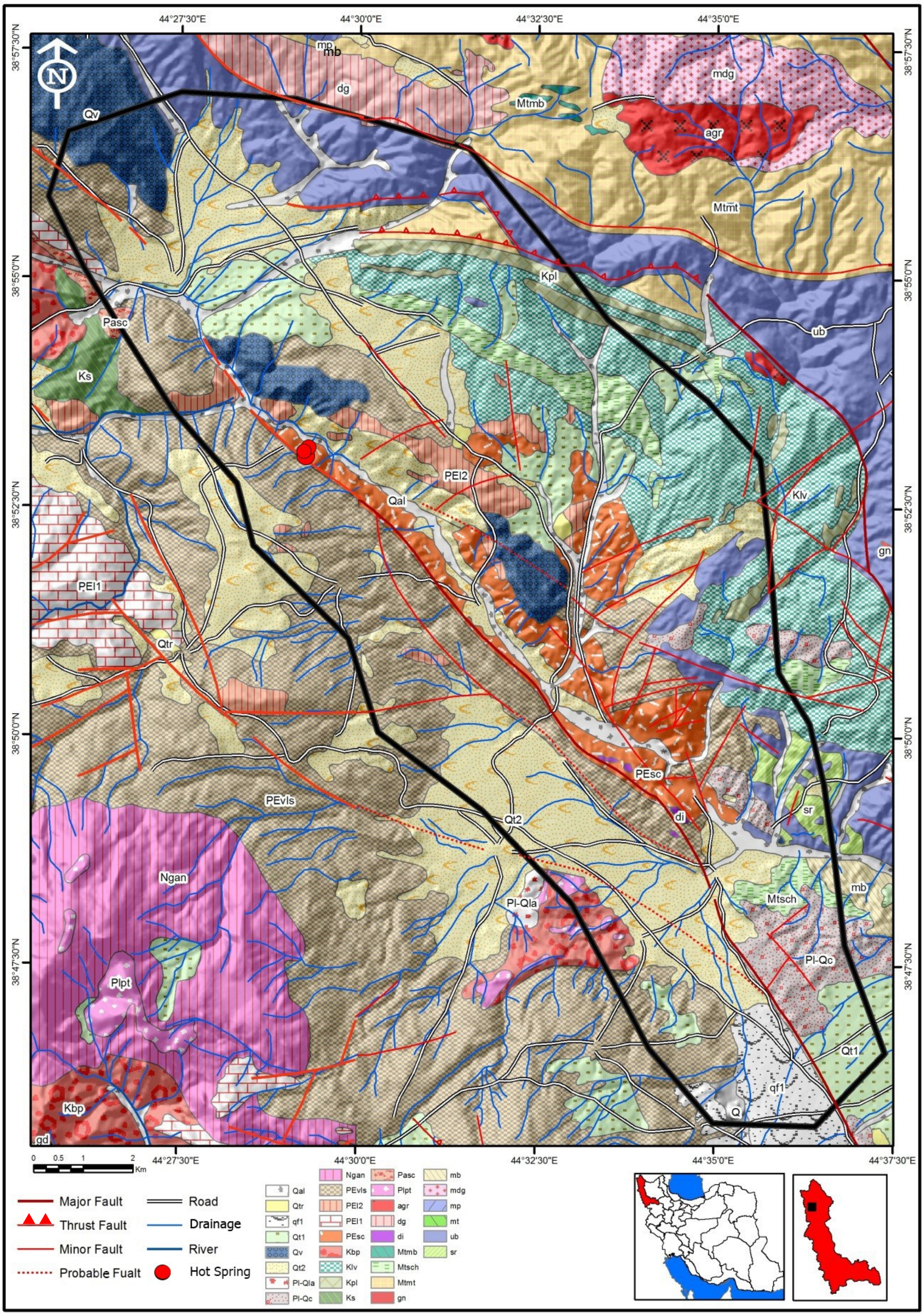

Figure 3. Geological map of Āq-Bolāgh Geothermal region (Amini et al., 1997; Rādfar et al., 1998)

3.2. Travertine deposits

This type of sediments is formed around some of warm springs. In an unknown region travertine deposits are the sign of a probable geothermal resource in that region (Littlefield and Calvin, 2014; Moeck, 2014). In AGR, there are two small outcrops of travertine deposits which are located in the east of warm springs, figure 4, (Amini et al, 1997; Radfar et al., 1998). One of them is accumulated at the intersection point of two faults, figure 4.

3.3. Young volcanic rocks

There appear to be five features that are essential to making a hydrothermal (i.e., hot water) geothermal resource commercially viable. They are: (a) a large heat source (b) a permeable reservoir (c) a supply of water (d) an overlying layer of impervious rock (e) a reliable recharge mechanism. Young volcanic rocks are the sign of recent magmatic activities in a geothermal region. It can be resulted that there is a suitable heat source for geothermal reservoir. One of the activities in the geological studies of especially a high-temperature geothermal region is identifying and age dating of young volcanic rocks in the region (Dippipo, 2007).
In Āq-Bolāgh region young volcanic rocks include pyroxene andesite lavas which have 20 to 60 m thickness and are marked in the geological map as a Qv, figure 3. These lavas cover plio-quaternary conglomerates. So, it is believed that they have been formed in quaternary time period. Young andesites have been erupted along the main fault of the region with NW-SE strike. Therefore, they are regarded as linear volcanoes (Amini et al., 1997). These lavas have had reasonable amount of volatiles and due to the low viscosity they have covered eroded surfaces of the older rocks (Rādfar et al., 1998).

3.4. Altered areas

Hydrothermal alteration is a general term which deals with mineralogical, textural and chemical changes in the rocks. These changes occur when the hot fluid or steam or different gases affect the rocks (Henley and Ellis, 1983; Simmons and Browne, 2000). In geothermal resources, due to the hydrothermal fluids, primary minerals convert to the new minerals. For example, volcanic glass changes to different types of zeolites, calcite and clay minerals (Hedenquist, 1995). Usually, hot fluids causes argillic, propylitic, chloritic, silicic and Fe-oxide alteration types around geothermal resources.

In this study we used ASTER satellite images in order to delineate hydrothermally altered areas in AGR. Based on the satellite images two types of altered areas including argillic and Fe-oxide alteration were found in the region. Argillic alteration is recognized by determination of illite and kaolinite minerals. These altered areas are very limited and scattered in the north and east of the AGR. Fe-oxide alteration identified by finding of hematite minerals in the region. This altered areas are determined in the center, east and northwest of the AGR, figure 4. As it can be seen in the figure, they are elongated parallel to the major fault of the region. This phenomena reveals the relation of Āq-Bolāgh geothermal resource and the main fault of the region.

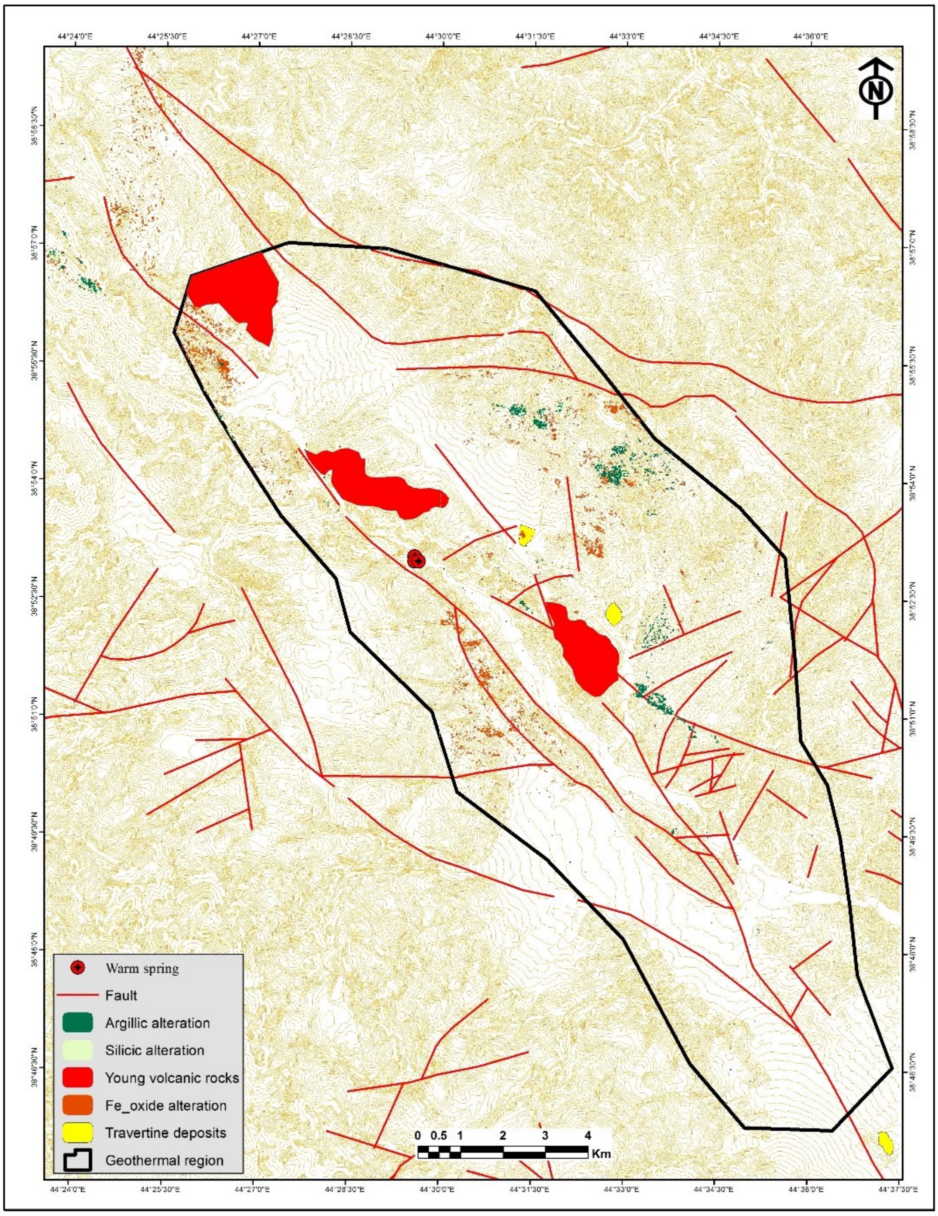

Figure 4. Surface manifestations of geothermal resources in Āq-Bolāgh region (Nouraliee et al., 2013)

4. CHEMISTRY OF GEOTHERMAL FLUIDS

The major goals of geochemical exploration are to obtain the subsurface composition of the fluids in a geothermal system and use this to obtain information on temperature, origin, and flow direction, which help locating the subsurface reservoir (Armannsson, and Fridriksson, 2009). In AGR, during the geochemical studies we sampled the warm springs and analyzed the water samples. Then all the data were interpreted.

Chemical analysis data of Āq-Bolāgh warm springs are shown in Table 2. According to Cl-SO_4-HCO_3 triangular diagram it is found that Āq-Bolāgh springs are bicarbonate type (Figure 5). This type of waters reveals mixing of geothermal fluid with cold underground waters. The location of the springs in this diagram shows the presence of relatively high chlorine in warm springs. Two factors possibly can cause this condition. First is that the fluid didn't mix well with underground water while moving from reservoir to the ground. Secondly, the amount of the geothermal fluid chlorine in the vicinity of chloride containing rocks has increased significantly.

The location of two mentioned springs in Na-K-Mg triangular diagram implies low mixing of geothermal reservoir fluid with underground water. The main reason is low amount of magnesium (Figure 6). As it can be seen in the figure, spring samples with high mixing, are close to Mg corner of the diagram. Actually chemical equilibrium of AGR warm springs in figure 6 with host rocks is relatively high, as they are slightly spaced from the chemical equilibrium. It should be noted that due to the high chemical equilibrium between the reservoir fluid and their host rocks, the results obtained from the chemical analysis of these springs compared to those springs with less chemical equilibrium are more reliable.

Table 2. Chemical analysis results of Āq-Bolāgh geothermal region warm springs
(Concentration of elements in mg/l)

Chemical Agent	Qaranjeh 1	Qaranjeh 2
Na	1410	1525
K	98	100
Mg	62.4	62.4
Ca	88	32
Al	0.1<	0.1<
Fe	0.03	0.007
As	0.15	0.15
Li	4.5	4.7
F	0.5	0.5
Cl	939	964
SO_4	269	303
B	5.5	5.7
CO_2	235.8	222.6
H_2S	0.2	0.1
SiO_2	0.1<	0.1<
TSS	2.3	49.3
TDS	4405	2540

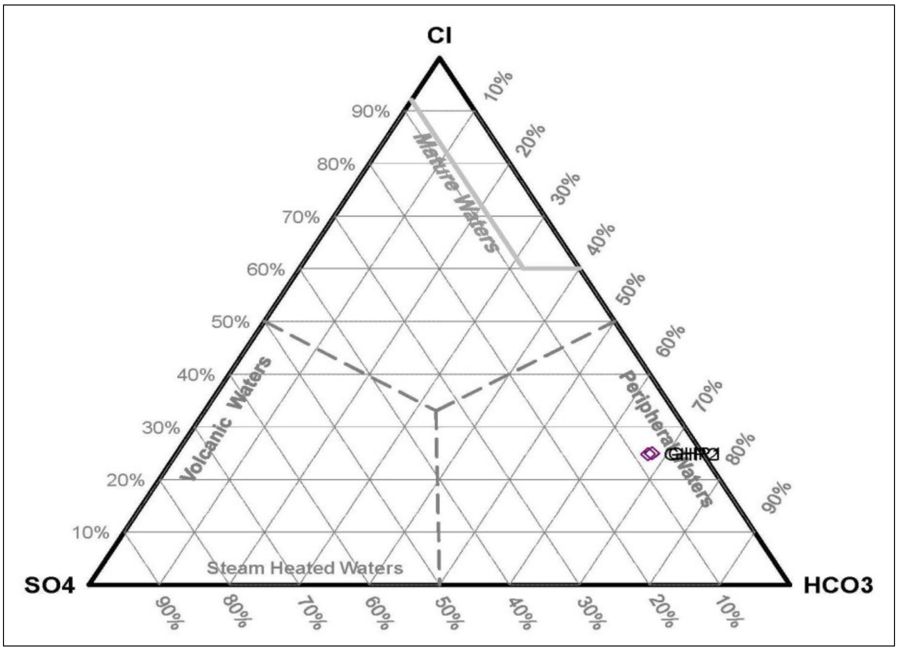

Figure 5. Cl-SO_4-HCO_3 Ternary diagram of Āq-Bolāgh geothermal region warm springs (Giggenbach, 1988)

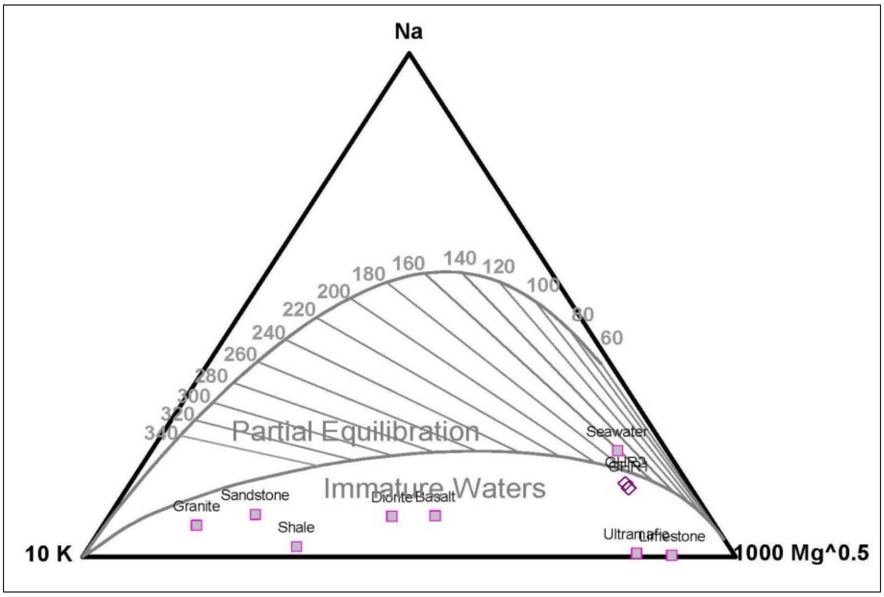

Figure 6. Na-K-Mg Ternary diagram of Āq-Bolāgh geothermal region warm springs (Giggenbach, 1991)

5. GEOTHERMOMETRY

During the exploration phase, geothermometry is used to estimate subsurface temperature, i.e. temperatures expected to be encountered by drillings, using the chemical and isotopic composition of hot springs and fumarole discharges. Chemical and isotope geothermometers probably constitute the most important geochemical tool for the exploration and development of geothermal resources. They are also very important during exploitation in monitoring the response of geothermal reservoirs to the production load (Arnorsson, 2000).

Different geothermometers are valid for different temperature ranges. The most important water geothermometers are silica, Na/K & K/Mg ratio and Na-K-Ca geothermometers. Due to the lack of silica in the chemical composition of Āq-Bolāgh warm springs, it is not possible to use silica geothermometry equations. So, in order to estimate Āq-Bolāgh geothermal reservoir temperature, cation thermometers are used. The results of geothermometry calculations of Āq-Bolāgh warm springs are illustrated in Table 3. As it mentioned earlier, Āq-Bolāgh region geothermal fluid is highly equilibrated with host rock, so its geothermometry results are relatively reliable.

Based on K/Mg geothermometer, minimum estimated temperature of Āq-Bolāgh geothermal reservoir is 102 °C. Also based on Na/K geothermometer, maximum estimated temperature of the reservoir is 151°C (Table 3). Other geothermometers estimate unrealistic numbers, because for the AGR warm springs which have not been severely mixed up, the estimated temperature difference of geothermal reservoir with the warm spring's temperature cannot be very high.

Table 3. Geothermometry results of Āq-Bolāgh geothermal region (°C)

Spring Name	**Na-K-Ca**	**Na/K** (Fournier)	**Na/K** (Truesdell)	**Na/K** (Giggenbach)	**K/Mg** (Giggenbach)
Qāranjeh 1	186	188	151	205	102
Qāranjeh 2	193	183	146	201	102

6. CONCLUSIONS AND RECOMMENDATIONS

Āq-Bolāgh geothermal region is one of 12 geothermal prospects in the West Azarbāijān province in the northwest of Iran. The main surface manifestations of geothermal energy in this region are two warm springs, a few travertine outcrops, young volcanic rocks and some altered areas. The temperature of warm springs varies from 29 to 39 °C. According to the geological studies it is found that a large fault with NW-SE strike controls the shape of Āq-Bolāgh geothermal resource. Also, probably cooling of the young volcanic rocks acts as a heat source for geothermal reservoir. Regarding lithological units of the region it is assumed that probably cretaceous sandstone and shale layers can play the role of reservoir and cap rock respectively.

Geochemical studies show that Āq-Bolāgh warm springs are bicarbonate type. Also, it is found that there is low mixing of geothermal fluid with underground water. Based on the geothermometry studies, Āq-Bolāgh reservoir approximate temperature is 102- 150 °C. Due to the AGR specifications, it is resulted that this geothermal resource is a low temperature one and is useful for power generation using binary cycle or direct use applications. The only matter of question is the presence of quaternary lavas in the region which normally accompanying high temperature geothermal resources. No doubt, more research activities are needed to find answer(s) for this question.

In order to better understanding of Āq-Bolāgh geothermal reservoir, the following detailed studies are suggested: detailed geological studies, isotopic studies about warm and cold springs, geophysical investigations such as gravity studies, magnetotelluric sounding and thermal surveying.

REFERENCES

1. Amini, B., Radfar, J., Khalatbari, M., Bahroudi, A. and Emami, M.H.: 1: 100,000 Geological Map of Dizaj, Geological Survey of Iran (GSI), 1997.
2. Armannsson, H., Fridriksson, T.: Application of Geochemical Methods in Geothermal Exploration. Short Course on Surface Exploration for Geothermal Resources, organized by UNU-GTP and LaGeo, in Ahuachapan and Santa Tecla, El Salvador, 17-30 October, 2009.
3. Arnórsson, S.: Isotopic and Chemical Techniques in Geothermal Exploration, Development and Use. Sampling Methods, Data Handling and Interpretation. International Energy Agency, Vienna, 351 pp., 2000.
4. Boden, D.R.:Geologic Fundamentals of Geothermal Energy. Taylor & Francis, CRS Press, 2016.
5. DiPippo, R.: Geothermal power plants: principles, applications, case studies and environmental impact. Butterworth-Heinemann, 493 pp., 2007.
6. Fournier, R.O.: Chemical geothermometers and mixing models for geothermal systems, Volume 5, Issues 1–4, 1977, Pages 41-50.
7. Giggenbach, W.F.: Chemical techniques in geothermal exploration. In Application of Geochemistry in Geothermal Reservoir Development. (F. D'Amore, co-ordinator), UNITAR, 119-144., 1991.
8. Giggenbach, W.F.: Geothermal solute equilibria. Derivation of Na-K-Mg-Ca geoindicators, *Geochimica et Cosmochimica Acta*, **52**(12): 2749-2765., 1988.
9. Hedenquist, J.: Epithermal Gold Deposits: Styles, Characteristics and Exploration. SEG Newsletter 23, 1995.
10. Henley, R.W. and Ellis, A.J.: Geothermal systems ancient and modern: a geochemical review. Earth-science reviews, 19(1), pp.1-50., 1983.
11. Littlefield, E.F., and Calvin, W.M.: Geothermal Exploration using Imaging Spectrometer Data over Fish Lake Valley, Nevada, *Remote Sensing of Environment*, **140**, January 2014, PP.509-518.
12. Moeck, I.S.: Catalog of Geothermal Play Types based on Geologic Controls, *Renewable and Sustainable Energy Reviews*, **37**, 2014, pp.867-882.
13. Nabavi, M.H.: An Introduction to Geology of Iran (In Persian), Geological Survey of Iran (GSI), 1979, 109 pp.
14. Nouraliee, J., Ebrahimi, D., Rezaei, A.: Characteristics of Geothermal Prospects in the west Azarbāijān Province (In persian), internal report, Renewable Energy Department, Energy and Environment Research Center, Niroo Research Instutute (NRI), 2013.
15. Nouraliee, J., Porkhial, S., Rahmani. M.R., Ebrahimi, D.: Reconnaissance Survey of Geothermal Resources in West Azarbaijan Province, NW-Iran, Proceedings World Geothermal Congress, Melbourne, Australia, 19-25 April 2015.
16. Radfar, J., Amini, B., Bahroudi, A., Khalatbari, M., Emami, M.H. and Bahremand, M.: 1: 100,000 Geological Map of Khoy, Geological Survey of Iran (GSI), 1998.
17. Simmons, S.F., and Browne, P.R.: Hydrothermal Minerals and Precious Metals in the Broadlands-Ohaaki Geothermal System: Implications for Understanding Low-sulfidation Epithermal Environments, *Economic Geology*, **95**-5, 2000, 971-999.
18. Truesdell, A.H.: Summary of section III, geochemical techniques in exploration. In Proc. 2nd UN Symposium on the Development and use of Geothermal Resources, San Francisco, 1975.