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Consideration of geological aspects and geochemical parameters of fluids in Bushdi geothermal field, south of mount Sabalan, NW Iran

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A B S T R A C T

The geothermal field at Bushdi to the south of Sabalan volcano encompasses both cold and hot springs along with surficial steam vents. This geothermal field is situated in a volcanic terrain which includes basaltic and trachy-andesitic lavas and pyroclastics which have undergone considerable faulting during Quaternary times. Regardless of conventional uses, no industrial utilization has been reported from this field yet. In the geothermal fluids Na is the most abundant cation following the trend $Na^+ >> Ca^{2+} > K^+ > Mg^{2+}$. Cl^- is the most abundant anion following two trends (1) $Cl^- >> HCO_3^- > SO_4^{2-}$ and (2) $HCO_3^- > Cl^- > SO_4^{2-}$. From a hydrogeochemical point of view the geothermal fluids in the study area can be divided into two categories: (1) Na-Cl and (2) Na-Ca-HCO_3. The conic and lenticular shaped travertine deposits around hot springs possessing a Ca^{2+}-Na^+-HCO_3^- composition are the most conspicuous features in this area. According to oxygen and hydrogen stable isotopes (δD and $\delta^{18}O$) data, a large proportion of the fluids in this geothermal system are of meteoric origin. Downward percolation along the brecciated rocks in the fault zones between the mount Sabalan and the Bushdi area can be regarded as the main fluid source for the geothermal system. The geothermal fluids have ^3H above 1 TU and hence can be considered as young (modern to sub-modern) waters, with a residence time of less than 63 years.

1. Introduction

Surface manifestations such as thermal springs, steaming grounds, fumaroles, mud pools, and geysers together with their locality, geologic control, physical environment, temperature, chemistry, and the rate of fluid discharge are the most important features for geothermal exploration (Gupta and Roy, 2007). Spring waters varying in temperature from cold atmospheric (ambient) to boiling can be found in many localities throughout the world. Geological and geochemical studies of these spring waters are the preliminary measures for exploring geothermal systems (Pentecost, 2005). Following this trend, geological studies of the area, tectonic characteristics of the fault system, petrological characteristics of the reservoir and cap rocks, and the chemical composition of the circulating waters in the geothermal system should be comprehensively assessed. Since all stages including exploration, estimation, and exploitation of a geothermal field are directly related to the fluid phase, a profound perception of the chemistry of the fluid phase is necessary. The chemical characteristics of these fluids provide valuable information on the hydrology of both the reservoir and the whole system (Nicholson, 1993). Preliminary activities in the context of the geothermal systems of Iran go back to 1975 when an Italian company (ENEL) carried out comprehensive investigations of the nation's geothermal fields. Since then, numerous studies concerning geothermal explorations were done in Iran and many potential prospect areas were identified.

A geothermal prospect area that is considered to be of prime importance is located around the Sabalan volcano in Azarbaidjan Block, northwest of Iran. The Azarbaidjan Block is a tectonically active region and its geotectonic characteristics are influenced by late Mesozoic geologic events. The Azarbaidjan Block is located at the collision point of the Arabic-Eurasian plates along the Alp-Himalayan orogenic belt, and has Cenozoic plutonic and volcanic

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sequences (e.g., Berberian and Berberian, 1981; Alavi, 1994; Mohajjel et al., 2003; Jahangiri, 2007; Dilek et al., 2010). Masson et al. (2006) concluded that besides the collision of the Arabic-Eurasian plates, the southward movement of the oceanic crust of the southern Caspian Sea had a lateral influence on the geotectonic conditions of the Azarbaidjan Block (Fig. 1). Considering the distribution of several Quaternary volcanoes of similar geothermal characteristics in the region spreading from the Black Sea through the Caspian Sea to the Anatolian Block, many researchers regarded the Azarbaidjan Block as the northern part of the Urmia-Dokhtar structural zone of Iran. The most westerly and one of the most distinctive volcano in this zone is the Sabalan stratavolcano covering a vast area (with a radius of ~10 km) with lavas, pyroclastics, and alteration zones (Dostal and Zerbi, 1978). The Sabalan volcano was formed during extensional activities during the upper Eocene-early Oligocene period (Alberti et al., 1976). The volcanic rocks are of andesitic, dacitic, and rhyolitic composition with a calc-alkaline character containing high K, Sr, and Ba (Dostal and Zerbi, 1978). In fact, the high-K calc-alkaline to shoshonitic characteristics of these rocks testify to a tectonic setting of post-collision island arcs (Riou et al., 1981; Shahbazi Shiran and Shafaii Moghadam, 2014). Around the Sabalan stratavolcano, there are several surface manifestations of a potentially widespread geothermal systems at depth. In the northwest of the Sabalan caldera in the Moil valley, there are several localities where thermal springs, gases and steams are currently emanating from the ground. In the east of Sabalan (Sarein and Sardabeh district), there are numerous cold and hot springs with gas and steam vents pointing to the geothermal activities beneath the surface. In the present study, the authors assess the geological characteristics of the geothermal field in the south of Sabalan volcano with special emphasis on the chemical composition of geothermal fluids.

At present, measures have been taken for exploration and exploitation of geothermal energy only in northwestern part of the mount Sabelan. In most localities, these hot springs are used merely for bathing and curing (dermatosis) aspects. Detailed studies on the

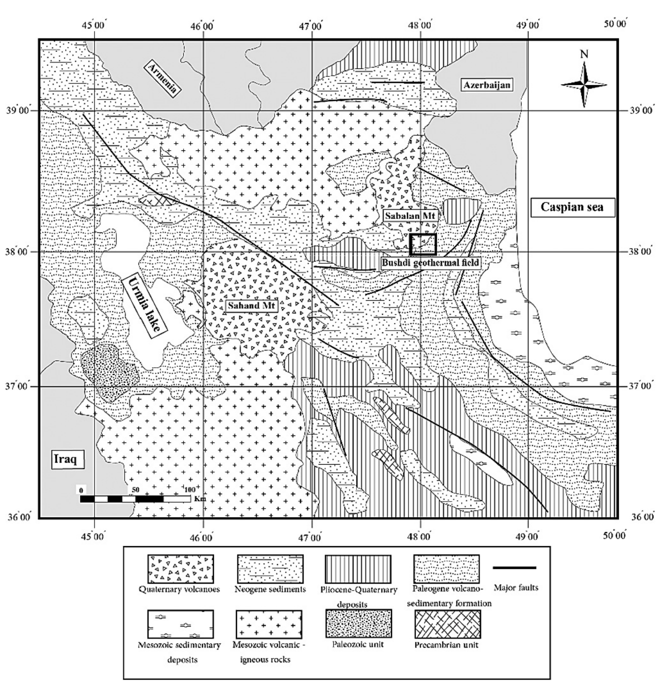

Fig. 1. Simplified geologic map (modified after Solaymani Azad et al., 2011) of the northwest of Iran on which the location of study area is shown.

geothermal fluids in the area have not been carried out so far. Therefore, the authorities in the Ministry of Energy have proposed a series of exploratory investigations which may lead to utilization of the geothermal energy in this region. To achieve this goal, the authors have endeavored to consider some geological and geochemical aspects particularly assessment of isotopic characteristics of the active hot springs in the region. The residence time in the reservoir rocks, origin, and mixing of these fluids with near-surface waters will be considered in detail in order to have a proper conception of the physico-chemical conditions prevailing in the geothermal environment in this region. These measures are the preliminary steps in direction of implementing drilling operation and detailed exploration for geothermal energy in near future.

2. Method of investigation

The study area was mapped at a scale of 1:60,000 (Fig. 2) and 27 samples from high fluid flow springs were collected. In sampling the hot springs priority was given to those with high discharge rates and temperatures. The water samples were collected from six springs in the following areas: Bushdi (#7), Sagizchi (#6), Gaynarja (#5), Garashiran (#4), Ilanjig (#3), and Doshanjig (#2). In this study, 27 water samples (19 from hot springs and 8 from cold springs) from these areas were chemically analyzed.

All water samples were kept in polypropylene bottles. The chemical analyses of these samples for determination of major and trace elements as well as for stable isotopes were carried out in the hydrogeochemistry lab at Bremen University (Germany). The samples were passed through a 0.45 μm filter and treated with concentrated HNO_3 in order to stabilize the sample for chemical analyses. Temperature and pH were measured directly in the field and HCO_3^- was determined by titration. The stable isotope analyses (δD and $\delta^{18}O$) were carried out using a LGR DLT-100 Laser Spectrometer (Los Gatos Research). The analytical precision of $\delta^{18}O$ and δD were ±0.2‰ and ±1‰, respectively. The ^3H values were measured in terms of tritium unit (TU) where $1\ TU = ([T]/[H]) \times 10^{18}$ (IAEA, 1979). Magnesium, Ca, K, Na, and Si were analyzed by ICP-OES (Perkin-Elmer) and Cl, F and SO_4 were determined by ion chromatography using IC-Plus Chromatograph (Metrohm).

3. Geology of the study area

Geologically, the geothermal field in south of the mount Sabelan is situated in a volcanic terrain. The volcanic rocks are the dominant lithologic units in the study area. However, some volcanic-sedimentary and sedimentary rock units are also cropping out in the area.

The Bushdi and Gaynarja hot springs pass through dacitic-andesitic rocks cropping out in the middle of the study area (Fig. 2). The dacitic lavas (varying in color from grey to violet) consist of phenocrysts of plagioclase, hornblende, biotite, augite, and rarely altered olivine set in a fine microlitic cryptocrystalline matrix showing typically porphyritic texture.

Basaltic and andesitic-basaltic rock units (with overall thickness of ~800 m) cover the northwestern part of the study area, and include lava flows and brecciated lavas accompanied occasionally by scoria. These rocks are often porous, and contain phenocrysts of plagioclase, hornblende, and augite showing typically porphyritic to aphanitic texture. These lavas, in most places, show alteration as a result of the infiltrating hydrothermal fluids almost obliterating their original mineralogy and texture (Amini, 1994). Apparently, the andesitic-basaltic rock units along with the associated pyroclastic units acted as reservoir rocks for the geothermal fluids in south of mount Sabelan. The pyroclastic unit contains lahar and