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Geothermal energy resources of Jizan, SW Saudi Arabia

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ABSTRACT

Jizan geothermal province has evolved over an oceanic ridge slice which is under plated a thin continental crust. The area is characterized by high heat flow and high geothermal gradient and hosts several thermal and warm springs whose chemistry indicates a high temperature reservoir within the granites. The geophysical data indicated that the thermal fluids are fault controlled. The residence time of the fluids, estimated based on ^{14}C, is about 33 kilo years. Oxygen isotope shift suggests that the reservoir temperature is around 220 °C. It is estimated that the province can generate electricity of the order of 134×10^6 kW h which can be effectively utilized to meet future fresh water demand and save CO_2 emissions by decreasing the domestic oil and gas consumption.

1. Introduction

Saudi Arabia's domestic consumption of oil has increased over the last few years. This increase is affecting the country's oil output. Till recently the domestic consumption has been 3 million barrels per day (mb/d) (Chandarasekharam et al., 2014) and according to a recent forecast, by the next decade, the domestic demand for the combined fuels i.e. gasoline, diesel, natural gas and fuel oil, may reach greater than 8 mb/d (Segar, 2014). Currently, 3 mb/d of oil is being consumed by the power sector for generating electricity and for the production of fresh water by desalination of sea water. Saudi Arabia has an estimated population of about 28 million (WB, 2009) spread over an area of about 2.2 million sq. km. Between 1980 and 2010 Saudi Arabia's population has increased by 180%, three times the global average. This increase apparently is exerting pressure on the electricity demand that grew only by 7.5% annually (Segar, 2014). In addition to electricity, 17 million kW h electricity is needed to provide water at the current rate of 235 L/day per person from desalination. In future, due to growing demand, this facility is being planned to expand by 50%. Therefore, there is considerable pressure on the domestic oil requirement (Chandarasekharam et al., 2014; Segar, 2014). Electricity generation is supported by 286 trillion cubic feet (tcf) of gas reserves, in addition to 600 tcf of combined unconventional and conventional reserves available in the north-western off shore of the Red Sea (Segar, 2014). High fossil fuel usage is responsible for high CO_2 emissions by the country. Currently the total CO_2 emissions by Saudi Arabia is 446,000 Giga-grams (Gg) and CO_2 emissions from electricity generation alone is 188,500 Gg (IEA, 2013). As a consequence of a large volume of CO_2 emissions from fossil fuel, the country is experiencing variable weather pattern (Almazroui et al., 2012). This is causing major concern to the political as well as to the major oil exploration and production company, ARAMCO. Thus, the need to exploit renewable energy is encouraging the country to develop solar photo voltaic (solar pv) and geothermal energy sources. By using renewable energy the country can save domestic consumption of oil and gas divert the same for export and continue to be the world leader in oil and gas supply. This will also help the country to save large volumes of CO_2 and mitigate climate change. The western Arabian shield has considerable hydrothermal and EGS (Enhanced Geothermal Systems) resources associated with the active volcanic fields (Harrats) and the radiogenic granites (Fig. 1a). Considerable geological, geophysical and geochemical investigations have been

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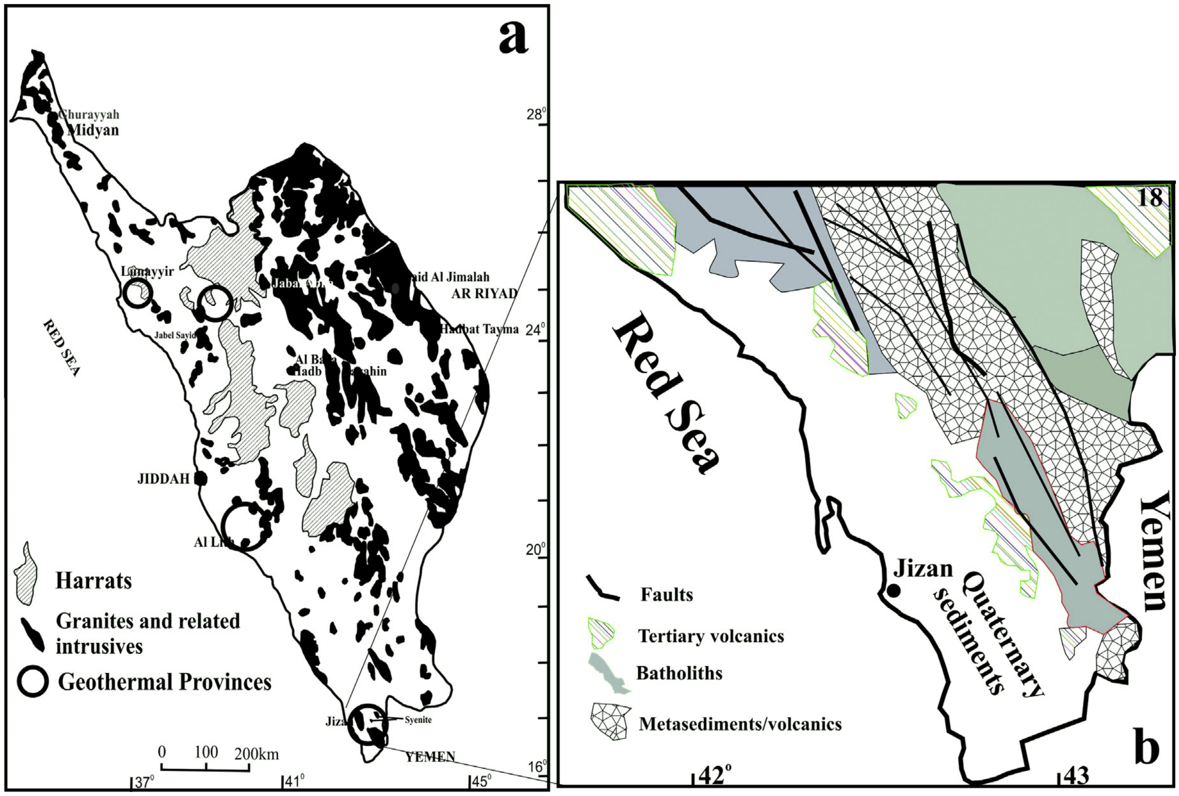

Fig. 1. Western Saudi Arabia shield (a) showing the Harrats, granites and related intrusives and geothermal provinces and (b) the regional geology and structure of Jizan (modified after Stoeser (1986) and Genna et al. (2002)).

carried out on these geothermal provinces. In the present investigation, the geothermal potential of Jizan province is presented, based on geological, geophysical, tectonic features and geochemical characteristics of the thermal springs.

2. Geology and structure of Jizan

2.1. Geology

The geological formations of Jizan include the Precambrian, the Quaternary igneous and sedimentary formations (Fig. 1b). The Precambrian forms the base of the above sequence and included Sabya Formation, Baish and Halaban Groups. The Sabya Formation is exposed over the escarpment that continues from the southern part of the shield through Yemen. This Formation, forming a linear belt parallel to the escarpment (Fig. 2), mainly consists of metasedimentary rocks that include quartzite, chlorite-schist, marble, metagraywacke and limestone. Basalt flows and sills cover part of the Formation and gabbroic intrusion represent subsurface equivalent of the basic members. The contact between these members is smudged and sometimes intermingled (Fig. 2). The Sabya Formation, in the study area, appears as a linear belt along the northern side of Jizan.

The Baish Group is well exposed along Wadi Baish. The most interesting feature of this group is the presence of greenstones that characteristically exhibit pillow structure and are spilitic. At places these rocks are interbeded with the members of the Sabya Formation. Basalt flows are the most predominant member of this group, which at places show intercalation of the upper metasedimentary Formation members. The pillow structure of the basalt flows indicate subaqueous eruption, indicating submergence of the region during that period. Shearing is common in basalt flows, giving rise to low temperature greenschist rocks.

Halaban group is represented mainly by metasedimentary and metaigneous rocks. Meta sedimentary rocks include greywacke and slates while metaigneous rocks include low grade metamorphosed basalt flows (metamorphosed to schist) and its acidic rocks like andesites, dacite and pyroclastics. The pyroclastics indicate central type of eruption during this period. These radiometric ages of the flows vary from 785 to 745 Ma (Hussein and Loni, 2011) that indicates volcanism during the first and second stages of shield building activity that occurred between 900 and 680 Ma (Stoeser, 1986). Pyritiferous and carbonaceous slates are commonly seen. Biotite is common in the schist. These metaigneous and metasedimentary members are intruded by gabbros, large number of basic dikes and acidic plutons that vary in age from Precambrian to Cambrian (Hussein and Loni, 2011). The acid plutonic rocks include granite, syenite and monzogranite. Gabbro and diorite occur as intrusive bodies and sheets. Large dikes transect the granites and metasedimentary Formations. Granophyres related to the volcanism occur as ring dikes towards the SE part of the study area (Fig. 2). All the above formations are also exposed over the northern part of Yemen Republic and Jizan, and host several thermal springs (Minissale et al., 2007).

2.2. Structure

The most important tectonic elements of the Arabian shield are the terranes, suture zones and orogenic belts (Stoeser and Camp, 1985) (Fig. 3). The most important terranes of the western shield are Asir, Hijaz and Midyan, that are located on the western side of the Nabitah shear zone. The geothermal province of Jizan falls within the Asir terrane. The Asir terrane encloses two generations of magmatic events related to arc magmatism formed during 950–800 Ma and 780–760 Ma. These rocks include diorites, tonalite plutons, volcanic flows of tholeiitic