

High Heat Generating Granites of Western Saudi Arabian Shield

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ABSTRACT

With growing demand for electricity and drinking water, Saudi Arabia needs to reassess its energy policy and source. The country has considerable volume of high heat generating granites along the western Arabian shield. These granites are under favorable stress condition and suitable to initiate EGS projects. The Midyan granite, located in the north, for example is capable of generating 160×10^{12} kWh of electricity. With the EGS technology making considerable advancement, Saudi Arabia is placed in a comfortable position to mitigate CO₂ emission and to meet the future energy and water demand.

1. INTRODUCTION

Amongst the Middle East countries, Saudi Arabia stands out prominently because of several reasons. This country is the world's largest oil and gas producers and consumer, with a growing population of 6% annually (WB, 2009). The country generates 240 terawatt hour of electricity as today from 500 000 barrels of oil (OPEC, 2013). By the year 2020 with growing demand for electricity the country is expected to consume three times the present day amount of oil for generating electricity (EIA, 2013). An additional 17 million kWh is needed to supply fresh water through desalination process. The average per capita consumption of water is 235 L/day. For every megawatthour of electricity generated, oil based power plants emit about 817 kg of CO₂ (Chandrasekharam and Bundschuh, 2008). By the next decade Saudi Arabia will be on the top of the list of countries emitting large amounts of CO₂ (OPEC, 2012, EIA, 2013). The total CO₂ emitted by the country is 446 000 Gg (Giga grams). The effect is already observed in the microclimate system of the country with temperatures over the past decade showing an increase on 0.7 °C (Almazroui et al., 2012).

The country is looking at energy source options to mitigate this problem. Major oil companies like ARAMCO are encouraging the renewable sources (Chandrasekharam et al., 2014). Although Saudi Arabia has substantial geothermal energy sources in the form of wet and EGS (Enhanced Geothermal Systems), the country never paid attention to this source since oil and gas is available at arm's length to the country. Here we highlight the vast EGS resource available to the country for development and mitigate the issues related to electricity demand and CO₂ emission.

2. POST TECTONIC GRANITES

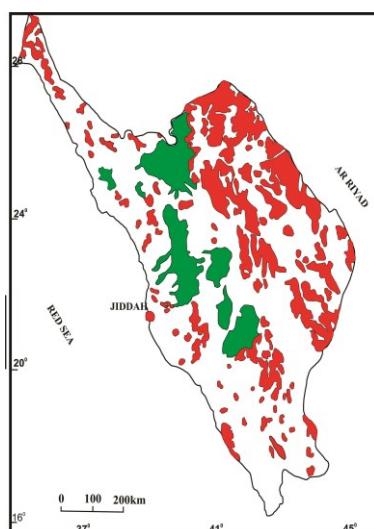


Figure 1: Distribution of granites and volcanic fields of the Arabian shield (modified after. Stoeser, 1986, Coleman et al., 1983).

The initial tectonic evolution of the Arabian shield followed the Phanerozoic plate tectonic regime. During the first stage, the extended between 900 and 631 Ma, plutonism was represented by large volumes of diorite, quartz diorite, tonalite and trondhjemite were intruded formed under an island arc setting. This island arc stage was terminated by continental collision between 680 and 630 Ma. This collision changes the tectonic style from arc to orogenic giving rise to plutonic rocks of granitic composition was predominant between 660-610. The final stage of plutonism was represented by peraluminous and peralkaline alkali felspar granites. The Arabian shield occupies an area of 770 000 sq.km. The felsic plutonic rocks occupies 55% of this area and the rest is occupied by the volcanic rocks (volcanic centre are also known as the Harrats) (Stoeser, 1986). Out of this 55%, granitic rocks constitute 63%. The distribution of the post tectonic plutonic and volcanic rocks is shown in figure 1.

The area occupied by the granites is 161 467 sq. km (Stoeser, 1986, Chandrasekharam et al., 2014) and the area occupied by the volcanic flows or the Harrats is 90 000 sq km (Coleman et al., 1983). The post tectonic plutonism resulted when the tectonic regime within the Arabian shield was transforming from an arc type to compressional type. The change-over of the tectonic style happened between 900 and 500 Ma, the time when major plutonic activity occurred within these terrenes. The remnants of the arc tectonic fabric is imprinted in the four major suture zones (figure 2) that divide the shield into five plates known as the terranes (Stoeser and Camp, 1985).



Figure 2: Paleo suture zones and terranes of the Arabian shield.

Table 1: U, Th and K content in certain granites and the heat production (source: Stuckless et al., 1987, Harris and Marriner, 1980, Chandrasekharam et al., 2014).

Site	U ppm	Th ppm	K%	μWm^{-3}	mW/m^2
Al Bara	4.07	14	3.93	2.4	64
Baid al Jimalah	13.3	35.2	3.87	6.2	102
Hadb ad Dayahin	13.7	28	2.4	5.7	97
Hadbat Tayma	14.6	25	3.9	5.8	98
Jabal Abha	9.12	29.8	3.4	4.7	87
Jabal Khinzir	30	8	3.5	8.6	126
Jabal Saqrab	26	49	4	10.4	144
Ghurayyah 4	104	625	3.12	70.2	742
Ghurayyah 5	88	160	3.17	34.0	380
Ghurayyah 6	363	590	1.4	134.2	1382

These paleo-suture zones host several hydrothermal mineral deposits of economic importance (Stoeser, 1986, Stern and Johnson, 2010, Du Bray, 1986, Elliot, 1983, Bokhari et al., 1986, Agar, 1992). Besides the heavy metals and transitional metals, the hydrothermal deposits associated these suture zones host uranium minerals like kasolite (uranyle mineral), uranium rich thorite, uraniferous fluoride-complexes and pyrochlore (Dawood et al., 2010). These minerals in the granites and associated pegmatites gave rise to high temperature geothermal systems along the western Arabian shield and maintain a high geothermal gradient and high heat flow value. These radioactive mineral deposits and the high concentration of radioactive elements make these granites very special. The uranium, thorium and potassium contents in these granites are shown in table 1. Together with the heat production values and calculated heat flow values for the region. The heat flow values are similar to the heat flow values reported from bore hole measurement from Precambrian basement along the western margin of the Red Sea in Egypt (175 MW/m^2 , Morgan and Swanberg, 1978) and over the geothermal sites along the eastern margin of the Gulf of Suez (Zaher et al., 2011). The geothermal gradient measured in the bore hole drilled within the Precambrian crystalline complex and Palaeocene varies from 40 to >80 $^{\circ}\text{C/km}$. Numerical simulation model of temperate distribution with depth at Hammam Faraun geothermal site gave value of 170-

180 °C at 2 km depth (Morgan and Swanberg, 1978). A schematic cross section of the high heat producing Midyan granite at about 2 km is given in figure 3. In fact some of the geothermal systems located in granites i.e. at Al Lith (Lashin et al., 2014) and at Jizan (Hussein and Loni, 2011) are driven by such granites. The tritium content in the thermal waters from the above sites indicate long circulation time (> 600 years, Lashin et al., 2014) within the granites indicating prolonged water rock interaction giving rise to high chloride content (Al Lith: 1594 ppm, Lashin et al., 2014, Jizan 1934 ppm, Hussein and Loni, 2011) in the thermal waters.

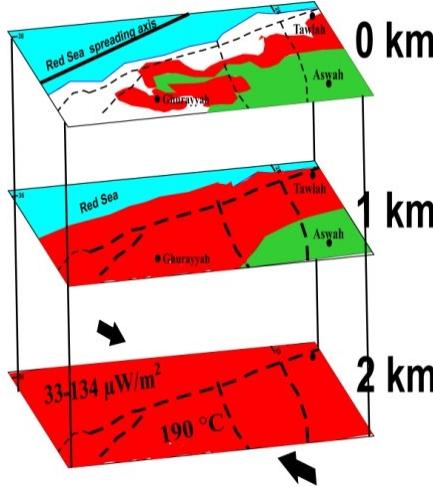


Figure 3: Schematic cross section of Midyan granite features projected to a depth of 2km. Regional stress distribution is shown as solid arrows at the bottom slice.

3. STRESS PATTERN

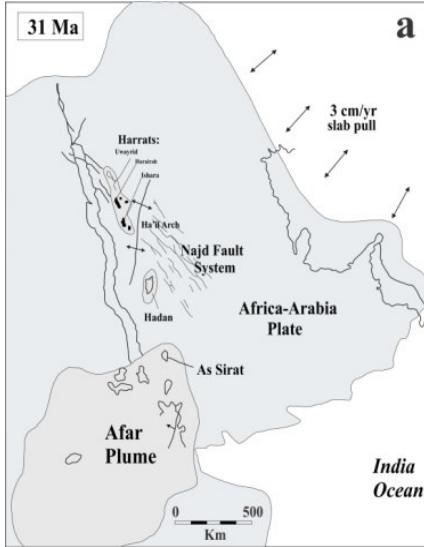


Figure 4: Plume and rift interaction below the Arabian Shield (modified after Bosworth et al., 2005).

The Red Sea rift initiation was triggered by plume activity below the then Precambrian basement at about 45 Ma shown in figure 4, when the continental masses (Africa and Arabia) were together. The break up of the land mass gave rise to the Nubian and Arabian shield that continued its magmatic and tectonic activity with the opening of the Red Sea rift at 31 Ma.

(Royer, 2002; Bosworth et al., 2005) towards the southern end of the sea and propagated northwards. The plume activity gave rise to older lava fields (Harrats) at As Sirat (lies just over the plume), Hadan, Ishara, Harairah and Uwayrid (figure 4). Similar volcanic flows spread over Yemen, Eritrea and Ethiopia also that later developed into major volcanic field. The initial rifting was at an angle to the Nubian-Arabian shield tectonic fabric represented by the Najd fault system (NW-SE) over the Arabian shield. The remnants of the mantle plume were recorded in several seismic refraction line surveys across the continental margin of the Arabian shield (Milkerieit and Fluh, 1985; Mooney et al., 1985; Prodeh, 1985). The investigations indicate presence of mantle at shallower depth (~18 km) below the Asir terrane (figure 2). The Moho rises from a depth of 38 km beneath the shield (west of Jabal Zalm and Nabita suture zone) to 18 km beneath Asir terrane (figure 2). This zone coincides with the Al Lith geothermal provinces (in granitic rocks) giving rise to heat flow value of 115 mWm^{-2} over this region (Gettings et al 1986). Numerical modelling based on the seismic reflection profile and finite element analyses under plane strain condition reveal the dynamics of the forces acting, distribution, orientation, magnitude and intensity of the stress distribution and fault system development along the coast (Kumer and Daigoro, 2007). While along the Red Sea rift and continental margin of west coast of Saudi Arabia the stress distribution is

conducive to develop normal faults, away from the coast along the escarpment of the shield and under the harrats, the stress distribution is extensional giving rise to linear fault systems (dike swarms; Bosworth et al., 2005) and intrusives (dikes) and aligned volcanic centres (the Makkah-Madinah-Nafud volcanic line, Camp and Roobol, 1992). The stress analyses of Kumer and daigoro, (2007) model show that the least horizontal stress direction for the Red Sea is NE-SW.

4. POWER GENERATION

Following the successful demonstration and implementation of EGS projects in France and Australia (Genter et al., 2010, Chen, 2010, Gareth et al., 2010), high heat generating granites are the future focus of energy source in the world (MIT, 2006). The peralkaline granite plutons that contain the highest content of uranium, thorium and potassium (Table 1) are seventy in number and it is the largest number of plutons ever recorded in the world (Drysdall et al., 1977, Jackson et al., 1984, Ramsay, 1982, Ramsay et al., 1986, Chandrasekharam et al., 2014). 1 km³ of such granite can generate 79×10^6 kWh of electricity for a period of 30 years (Somerville et al., 1994). By considering the area of high heat generating granites exposed in the western Saudi Arabian shield, and the prevailing NE-SW compressional stress acting on these granites, these rocks are excellent source for initiating EGS projects for power generation. In fact, according to the MIT report on EGS (MIT, 2006), the high heat generating granites are going to be the main source of energy in the 21st Century in USA, anticipated to generate 100,000 MWe of baseload electricity by 2050. Adopting the procedure followed by the Cooper Basin EGS project of Australia and assuming 2 % energy can be tapped from such high heat generating granites, the Midyan granites with heat generating capacity of 134 $\mu\text{W}/\text{m}^3$ (figure 3), can generate about 160×10^{12} kWh of electricity.

5. CONCLUSIONS

Although Saudi Arabia has large oil and gas resources, the amount of CO₂ the country is generating is growing at an exponential rate and soon the country will have the dubious distinction of being at the top of the list of countries emitting large amount of CO₂. As on date the country is emitting 446 000Gg of CO₂ by generating 240 terawatt hours of electricity and this is already affecting the country's weather pattern (Almazroui et al., 2012). Nearly 80 % of this electricity is used for space cooling resulting in the emission of 900 Gg of CO₂. Besides this, the demand for supply of fresh water is growing with a 6% annual population growth. In future the country will be burning several million barrels of oil to meet growing drinking water demand, unless mitigation strategies are adopted and renewable energy policies are enacted, the country's future energy security will not be same as it is now. Saudi Arabia has the advantage of being located along a tectonically active zone with a constant heat sources along its west coast. By using geothermal energy as a source mix, the country can extend the life of its oil reservoirs and continue to hold the supremacy with respect to oil production in the world. There are no technical barriers for developing geothermal as an energy source mix. The country can attract investors if a sound energy policy and tariff structure is adopted. The Government needs to adopt renewable as a part of its national energy agenda anticipating future demand, depleting oil reserves and climate change.

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