High heat generating granites of Tanzania

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ABSTRACT

Fossil fuels alone may not be able to meet the aspiration of 'Power Africa" initiative. Geothermal resources will have a greater say in fulfilling this aspiration in the near future. The high heat generating granites spread over the entire Tanzania Craton have tremendous capacity to light the rural Tanzania with grid connected electricity in the near future. Each cubic kilometre of such granite has the capacity to generate about 42 x 1015 kWh of electricity. Kenya with its expertise in geothermal development will have major role in supplying major infrastructure facility to make Tanzania energy independent and save millions of hectors of forest that is being used traditionally as energy source. Geothermal energy will further save about 6 million metric tonnes of CO_2 emission and protect the ice-cap over the Mt Kilimanjaro.

1. INTRODUCTION

The "Power Africa" initiative taken by the USA will double access to power in Sub-Sahara Africa including Tanzania. This initiative will provide grid connected power to rural population in Africa and Tanzania as well. This Power Africa's goal is to generate 10,000 MW in Sub Sahara Africa and in 2014 it has achieved financial closer to generate about 2800 MW. Since it a clean energy initiative, the sources are geothermal, solar PV and wind. The Sub Sahara Africa in deed has a large geothermal potential as the region falls within east African Rift valley. In fact Kenya alone has the capacity to generate 5000 MW from its geothermal sites. Nearly 80% of Tanzanian population live in rural areas and depend on charcoal, fire wood, dung, agricultural waste to meet their energy demand. The major demand for energy comes from tobacco, brick making and tea industries. Tanzania's electricity generation has grown from 156 x 10^6 MWh in 2000 to 6.9 TWh in 2013 (IEA, 2013). The major consumption of this energy is by the rural population and the power is generated mainly from oil and partly by gas. Both these sources are imported. Tanzania has rich geothermal resources spared across the country in the form of high heat generating granites. Majority of the thermal springs that are emerging with high temperatures are in fact occur within these granites. Here we present the EGS prospects of Tanzania which in future will be a good source of power for the country's development and mitigate CO_2 emission from different fuel sources and reduce emission of black carbon (BC) from biomass fuels.

2. POWER SCENARIO

The per capita electricity consumption is only 91 kWh and only about 14 to 18 % population has access to grid connected electricity (Power Asia). The total primary energy supply has grown from 13.4 mtoe in 2000 to 20.1 mtoe in 2013 (IEA, 2013) with increase in population from 34 to 45 million during the same years. The electricity output has grown from 3.5 terawatt hours in 2000 to 6.9 terawatt hours in 2013. The major sources of energy are biomass (90%, mainly wood), oil and gas (~7%), and coal, solar and wind (3 %). The installed capacity of electricity is 6.9 terawatt hours and 561 MWe (3.9 terawatt hours) is generated from hydropower and 490 MWe (3 terawatt hours) from thermal (oil, gas and coal). Biomass generates 36 MWe. As biomass is extensively used by the rural population, nearly 400 000 hectares of forests are destroyed annually causing tremendous impact on the environment and water resources. Due to such severe poor supply of electricity the country's industrial growth and economic development is being hampered. Many business establishments own generators paying a high tariff cost (29 US cents/unit) compared to the supply cost of 9 US cents/unit. Consumption of high volume of biomass generates large volumes of black carbon (BC) and CO_2. The CO_2 emission from fossil fuels based power plants alone is about 6 million tonnes (IEA, 2013).

3. CARBON DIOXIDE EMISSION

The emission of CO_2 by Tanzania is much higher compared to other countries in the east Africa, except Kenya). While the CO_2 emission from South Africa (347 million tonnes) and Kenya (11 million tonnes) is the highest amongst the east African countries, emission from Zambia (1.9 million tonnes), Mozambique (2.5 million tonnes) and Democratic Republic of Congo (1.7 million tonnes) is much smaller compared to Tanzania (Table 1).

Table 1. CO_2 emission from power and transport sectors, Tanzania.

CO_2 emission	2000	2013
Total (million tonnes)	2.6	6
Coal (million tonnes)	0.2	0.3
Oil (million tonnes)	2.4	4.2
Gas (million tonnes)	0.8	1.5
Transport (million tonnes)		3
Per capita (tonnes)	0.08	0.13
Emission/kWh (gm)	192	329

Although black carbon concentration in the atmosphere over Tanzania is not available, the BC emission by Kenya is in the range of 0.7 to 2.3 μgm^{-3} (Gatari and Boman, 2003). Since the consumption of bio fuels by Tanzania is much greater than Kenya, the BC emission by Tanzania is expected to be more than the above value. Although BC layers in the soils along the hill slope of Kilimanjaro were reported (Zech, 2006), the relation between the melting of the ice cap over Kilimanjaro and BC is yet to be established.

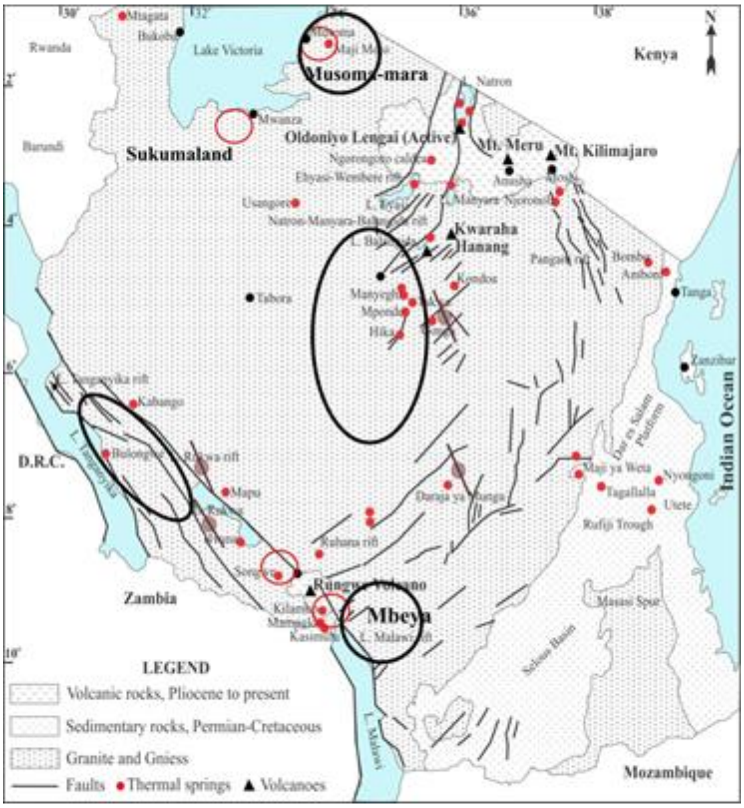

Figure 1. Geological map of Tanzania and the location of thermal springs and volcanoes (modified after Hochstein et al., 2000, Mnzava and Mayo, 2013)

4. GEOTHERMAL PROVINCES

Tanzania contains nearly 15 thermal springs with issuing temperature varying from 34 to 73 °C distributed mainly in three regions. The southern extension of the East African Rift, that enters almost to the centre of the Tanzanian Craton, is the loci of a large number of thermal springs (Fig. 1). A second group occur along the rift bordering lakes Tanganyika and Malawi (TMR) towards the SW part of the Carton. A third group is located along the major faults connecting the EAR extension and TMR. The thermal springs occurring within TMR and EAR rift extension are associated with active volcanoes. There are several thermal springs occurring along the border of Lake Victoria between Musoma and Mwanza. One common feature with all the thermal springs is that they are fault controlled and issue through the rocks of granitic composition. Detailed investigation on these thermal springs have been conducted by several authors (Makundi and Kifua, 1985). These thermal waters record high fluoride content indicating their interaction with rocks of granitic composition (Table 1) and it is possible that these granites could be the reservoir rocks for many thermal systems in the Craton. Further, high chloride content in the thermal waters and high helium content (13%) in the thermal gases from Musoma geothermal site (Hochstein et al., 2000) clearly indicate long circulation of thermal water within granites. The granites and associated gneisses of Tanzania Craton have very high uranium, thorium and potassium content and these all these rock generate high heat above the average crustal rock values. Thus these granites represent natural EGS system suggesting their potential as future energy source.

Table 2. Range of major ion and trace element content in the thermal waters from Tanzanian Craton (mg/L) **(Source:** Makundi and Kifua, 1985, Hochstein et al., 2000, Mnzava and Mayo, 2013)

Area	pH	T °C	Na	K	Ca	Mg	Cl	HCO_3	SO_4	SiO_2	F
Mbeya	8 to 9.9	53 to 73	20 to 5450	3 to 102	1 to 78	1 to 34	14 to 4800	44 to 3400	18 to 680	85 to 150	1 to 60
Songwe	7 to 8.78	54 to 80	5 to 41	10 to 89	17 to 47	8 to 20	30 to 270	204 to 1820	16 to 184	63 to 112	7
Musoma	9.4	60	1980	33	1	1	4800	3400	680	44	20

5. HIGH HEAT GENERATIONG GRANITES

Greater than 90% of the central Tanzania Craton contains rocks of granitic composition. The Craton is traversed by the East Africa Rift valley structural features towards the northern part that extends to southwards represented by numerous faults and shears. The southern part of the rift valley within the Tanzanian domain is represented by three prominent volcanoes: Mt. Oldoniyo Lengai, Mt. Kilimanjaro and Mt Meru that are active. The East African struictural fabric towards the southern part of Tanzania is truncated by NW-SE trending rift that host Lake Malawi and Lake Tanganyaka and an active Rungwe volcano. The Tanzania Craton is divided into three main units: 1) The oldest Dodoman Super group, 2) the middle Nyanzian Super group and 3) the younger Kavirondian Super group (Barth, 1990, Borg and Shackleton, 1997, Salinslav et al., 2014). The Craton is further subdivided into several shear zones bordered by accretionary terranes (Kabete et al., 2012). A generalized regional geological map of Tanzania is shown in figure 1. The Dodoman Super group consist of granites and migmatites. The Nyanzianand the Kavirodian Super groups is represented by greenstone belt rocks that included metavolanics, sediments and granites. The granites associated with this greenstone belt are widely studied rocks and the characteristic feature of these granites is that they contain high potassium and occupy 60% of the volume of the rocks included under these two Supergroups. The greenstone rocks of the last two super groups are exposed Shinyanga-Malita, Kilimafedha, Nzega, Iramba-Sekenke, Sukumaland and Musoma-Mara. Uranium mineralization is wide distributed within the Tanzania Craton and some of the mineralization sites host deposits of economic importance (Kilimajaro). The uranium mineralization zones are shown in figure 1. Thus the granites and associated rocks of granitic composition register high concentration of uranium, thorium and potassium and generate considerable quantity of heat (Table 3) and support geothermal systems in this region. It is seen from table 3 that the heat generated by these granites is much higher compared to the average crustal values (5.0 μWm^3, Raybach, 1976). The calculated heat flow values are also much higher indicating a prevalence of high temperature regime in this Craton. U-Th dating on the travertine deposits associated with Songwe geothermal site indicate that the geothermal system are about 360 ka old (Delvauxe et al., 2010). Thus long circulation time of the thermal waters within the granites is indicate by high chloride, high fluoride, (Table 2) strontium (Delalande et al., 2011) and helium (13%, Hochstein et al., 2000) contents in the thermal waters.

Table 3. Heat generation by granites, Tanzania concentrations of U, Th and K are from 1: Mshiu and Moboko, 2012, 3:Manya et al., 2007, 4: Sanislav et al., 2014)

No	U (ppm)	Th (ppm)	K (wt%)	RHP (μWm^{-3})	Heat Flow (mW/m^2)	Ref
MS10	9	41.7	4.3	5.60	96.00	1
MS18	18.7	30.4	3.9	7.27	112.74	1
MS19	18.7	52.1	4.9	8.86	128.64	1
MS20	11.6	40.1	4.6	6.19	101.86	1
MS44	14.1	23.7	3.7	5.61	96.14	1
MS45	11.3	36.5	3.5	5.76	97.57	1
MS46	11.7	40.9	3.8	6.19	101.88	1
MS47	15.8	26.1	3.8	6.22	102.23	1
MS49	28.9	38.7	4.8	10.55	145.50	1
MS50	22.8	56.9	4.5	10.21	142.12	1
TA 92	14.8	39.7	4.1	6.9	109.3	3
TA 83	15.3	21.1	3.8	5.7	97.3	3
TA 87	15.9	20.9	3.8	5.9	98.9	3
TA 88	16.6	20.7	3.8	6.0	100.5	3
TA 29	17.2	20.5	3.8	6.2	102.0	3
TA 30	17.9	20.3	3.8	6.4	103.6	3
TA 31	18.6	20.1	3.8	6.5	105.2	3
TA 48	19.2	19.9	3.8	6.7	106.7	3
TA 50	19.9	19.7	3.8	6.8	108.3	3
TA 84	20.6	19.5	3.8	7.0	109.9	3
TA 85	21.2	19.3	3.8	7.1	111.4	3
TA 86	21.9	19.1	3.8	7.3	113.0	3
XU-02	13.2	46.3	4.46	7.01	110.12	4

In addition to the heat generated by the radiogenic granites, presence of shallow plume below the Tanzanian Craton (Weeraratne et al., 2003) is driving the geothermal systems located within the Craton (Fig 1).

6. STRESS FIELD IN TANZANIA

Based on satellite images, topographic and geological maps, detailed tectonic architecture of southern parts of Tanzanian Craton was documented by (Delvauxe et al., 2010, Delvaux, and Barth, 2010). Two horizontal compressional stress directions exist over the Craton. One is along WNW (H_{max}) and the other along ENE (H_{max}). The most prominent one is along WNW (H_{max}) which is perpendicular to the MIOR spreading axis (Fig. 1). The stress pattern is consistent since Quaternary period and is supported by earthquake focal mechanism, fault plane analyses and fault plane solution of minor earthquakes (Iranga, 1992).

7. POWER GENERATION CAPACITY

Although several investigations have been carried out assessing the power generation potential of the wet geothermal systems in then NE and SW Tanzania craton (650 MWe, McNitt, 1982, Hochstein et al., 2000,), there is no published work on the potential electricity that can be generated from the high heating granites. Presence of a mantle plume, anomalous high content of radioactive elements, presence of active volcanoes along the periphery of the Tanzanian Craton, occurrence of uranium deposits and well established stress pattern makes the high heat generating granites of Tanzania a potential EGS source. Assuming a conservative geothermal gradient of 40 °C/km and an average heat flow of 75mW/m^2 (Omenda et al., 2010) the temperature of the granite source rock at 5 km depth appears to be about 180 °C. With such resource temperature, following the method of estimating power generation potential of hot granites (Somerville et al., 1994) 1 m^3 of such granite is expected to generate about 42 x 10^{15} kWh of electricity. Even about 1 percent of this energy is extracted from such granites, it will provide relief to thousands of rural people in obtaining grid connected electricity and save minimum of 6 million tonnes of CO_2

7. CONCLUSION

The Tanzanian Craton has abundant natural resources that is being destroyed to support the countries socio-economic development. The rural population is using a minimum of 16 million m^3 of wood to support tobacco drying, brewing, ceramic, brick, baking and tea drying industries (Sheya and Mushi, 2000). This entire wood volume and the emissions from the biomass can be saved by using geothermal energy in rural sectors. The only natural energy resource that will have a positive impact on the environment and support socio-economic development is geothermal energy that is available in the form of thermal springs and high heat generating granites. Rayleigh wave tomography investigation indicate the presence of an active plume below the Tanzanian Craton (Weeraratne et al., 2003) that is providing additional geothermal heat to the high radiogenic granites. It seems apparent that the East African Rift is propagating towards south cutting across the Tanzanian Craton and enhancing the geothermal potential of the country (Fig. 1). Besides the estimated 650 MWe available from the wet geothermal systems located around NE, SW corners of the country, the high radiogenic granites spread across the country have substantial potential to light the entire Tanzania and support energy to the neighbouring courtiers like Uganda, Rwanda, Burundi that need large energy infrastructure for development. The gold, diamond and other transitional metal mining companies can take the initiative in developing geothermal energy resources of the country and make the country energy independent with clean energy supply.

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