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INTERPRETAION OF GEOCHEMICAL DATA FROM THE LOW-TEMPERATURE GEOTHERMAL AREA, FLJOTIN NORTH ICELAND, COMPARED TO SELECTED GEOTHERMAL SAMPLES FROM RUNGWE TANZANIA

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ABSTRACT

The chemical analysis of geothermal water require proper sample collection, analysis and presentation of the data. The interpretation and evaluation of all available information regarding the geochemistry are accomplished by the methods of Na-K-Mg ternary diagram, Cl-SO_4-HCO_3 ternary diagram, geothermometer, WATCH programme and Suffer 12.6.963 software. Data sample from Fljótin-Iceland are analysed pertaining to their geochemistry surface exploration and compared to selected data from Rungwe geothermal area from Tanzania. The geothermal fields differ according to volcanic activities, rocky types and mineral composition. Fljótin are low temperature geothermal field while Rungwe is classified as high temperature geothermal field at Ngozi-Songwe (northern system) and a low temperature field at Kiejo- Mbaka (southern system). The reservoir temperatures at Fljótin are estimated by Na-K-Mg ternary diagram in the range of 120°C -160°C and confirmed with geothermometers with temperature range from geothermometers; 74-136°C (chalcedony) and 64-158°C (Na/K). The mineral saturation stated were by calculated chalcedony temperature where calcite and anhydrite, are saturated but not precipitating while amorphous silica is under saturated. The estimated reservoir temperature at the Rungwe volcanic zone are 130-200°C by Na-K-Mg ternary diagram, which is in agreement with quartz and K/Mg geothermometers at a temperature range of 119-154°C and 106-252°C respectively. Detailed study in the Rungwe thermal fluid chemistry is required in order to be satisfied for direct or indirect use, due to its high concentration of CO_2 which can affect the utilization of the fluid, both field has a penitential for geothermal utilization. Fljótin on the other hand can be used direct due to its low total dissolved elements and low temperature.

1. INTRODUCTION

The global pollution has increase awareness of the detrimental environmental effects that results on burning of fossil fuel for power generation and an increasing global interest is sparked towards using green renewable energy source such as geothermal energy. Currently, Tanzania has put more efforts towards affordable and sustainable energy by increasing number of experts for developing of geothermal resource.

1.1 Problem Statement

Globally, Critical issues associated with supply of fossil fuels, increase of primary energy demand which predicted to be 40% between 2007 and 2030 (Kovacevic & Wesseler, 2010) and their adverse impacts on the environment has generated significant interests in renewable energy (Tran et al., 2010). Geothermal energy is one of the most promising among renewable energy source due to its proven

reliability and environmentally nature. However the geothermal resource not yet exploited as other source of renewable such as hydro, solar, wind and biomass due to its complexity nature and intensive capital. At the moment the world focusing on promoting power generation from renewable energy source due to its sustainability and conservation of the world for future Generation. Global fund mechanisms have been provided for development of clean energy such as SE4ALL, SREP, NAM, and GMRF etc. for development of renewable energy for developing countries. (Mutia, 2010) reported that the fossil fuel power generation has contributed to 25.9% of world carbon emission which it affect every sector due to climate change; however, emphasis has been placed on electricity sector to lower the level of carbon emission from power generation which emits between 400 and 989 tonnes of carbon per gigawatt-hour of electricity produced. Therefore, for the world to reduce level carbon emission, there is a need of having a base load from carbon free source such as renewable energy for both developed and developing countries.
With increase awareness of the detrimental environmental effects that results on burning of fossil fuel for power generation, an increasing global interest has sparked towards using green renewable energy source such as geothermal energy. The intensive capital of geothermal technology has led to difficulties for decision makers to develop the source, especially in developing country such as Tanzania as well as lack of geoscientist and engineers in geothermal industry. Currently the country has put more efforts in increasing number of experts and capturing funds opportunity for development of geothermal resource. The complexity geothermal resource require detail studies on surface exploration for reducing risk in drilling, operation and monitoring of geothermal system. Therefore more experts are required in analysis geothermal fluid system such as Geology, Geophysics, Geochemistry and environment concern of the system. My study will focus on data analysis and interpretation of low-temperature geothermal field in Iceland called the Fljótin and compare with samples from the geothermal area in the Rungwe volcanic zone, Tanzania.

1.2 Main objectives

- To carry out the interpretation geochemistry data from surface exploration
- To formulate a conceptual model of geothermal field
- Comparison (cross-correlation) to Iceland field data

1.3 Methodology

The Fljotin data have been sampling in 1985 while the Rungwe data were sampled in 2010. The sample were analysed by geochemistry method usefully for thermal fluid such as classfication of water by Na-K-Mg ternary diagram and CL-SO_4-HCO_3 ternary diagram Cation geothermometry and silica geothermometry were used for estimation of reservoir temperature whereas Na/K, quartz and chalcedony geothermometers were analysed. Mineral saturation was analysed by Chemical speciation programme WATCH Version 2.1A. Component distribution for major elements of geothermal field were interpreted with Surfer 12.6.963 software by Golden Software.

2. ICELAND – GEOLOGICAL BACKGROUND

2.1. Fljótin, N-Iceland geology

Fljótin is a district located in north Iceland Figure 1 on the northern part of Tröllaskagi, a mountainous peninsula between two ocean fords called Skagafjördur in the west and Eyjafjördur at the east. The whole part of Fljótin is covered by basaltic lavas and minor intermediate extrusive rocks and sedimentary horizons (Saemundsson et al., 1973). The bedrock in the Fljótin district is tertiary in age, tholeiitic basalts in composition, the lava pile has a westerly dip and the mountainous strata is near totally of lavas with only minor sedimentary horizons. Dykes generally trend near N10°E and are rear in Fljótin district but more numerous to the northeast. Large N-S faults are observed north of Miklavatn, and such faults are like to be present in the western part of Fljótin. The pores in the lavas are mostly filled by deposition reducing the permeability and it is likely that permeability of geothermal systems are largely related to fractures, faults and dykes. The area is low temperature liquid dominated with widespread distribution of warm spring (25-50°C) and hot spring (50-75°C) which few are shown in Figure 2 and in Table 1. Fljótin are flat low land and covered by green vegetation (Jóhannesson, 1991).

The young rock is main heat source for the Fljótin low temperature field. Rainwater from the high mountainous area surrounding reaching above 1000 m above sea level seep through the north-south trending faults down to hot rocks at a temperature around 150°C. Normally rain water has lower density than cold water, after heated with hot rock it flow up to reach the surface at temperature around 60-70°C (Saemundsson, pers. comm. 2015). Thermal springs are widespread in the area which as shown in Figure 1 and fluid composition in Table 1

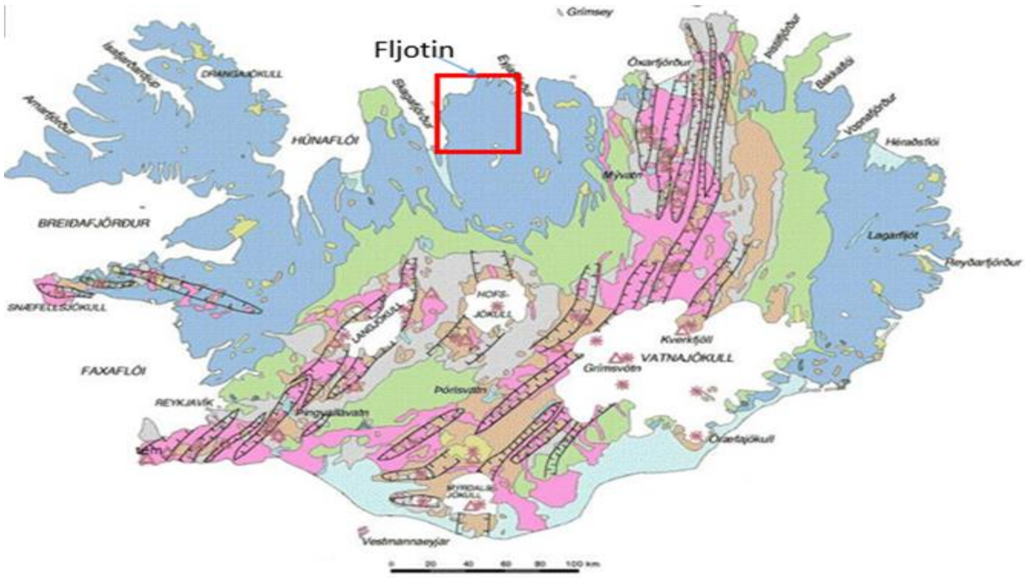

FIGURE 1: A simplified geological map of Iceland showing the volcanic zones, fissures swarms and central volcanoes (Jóhannesson and Saemundsson, 1999). The box represent the study area of Fljótin.

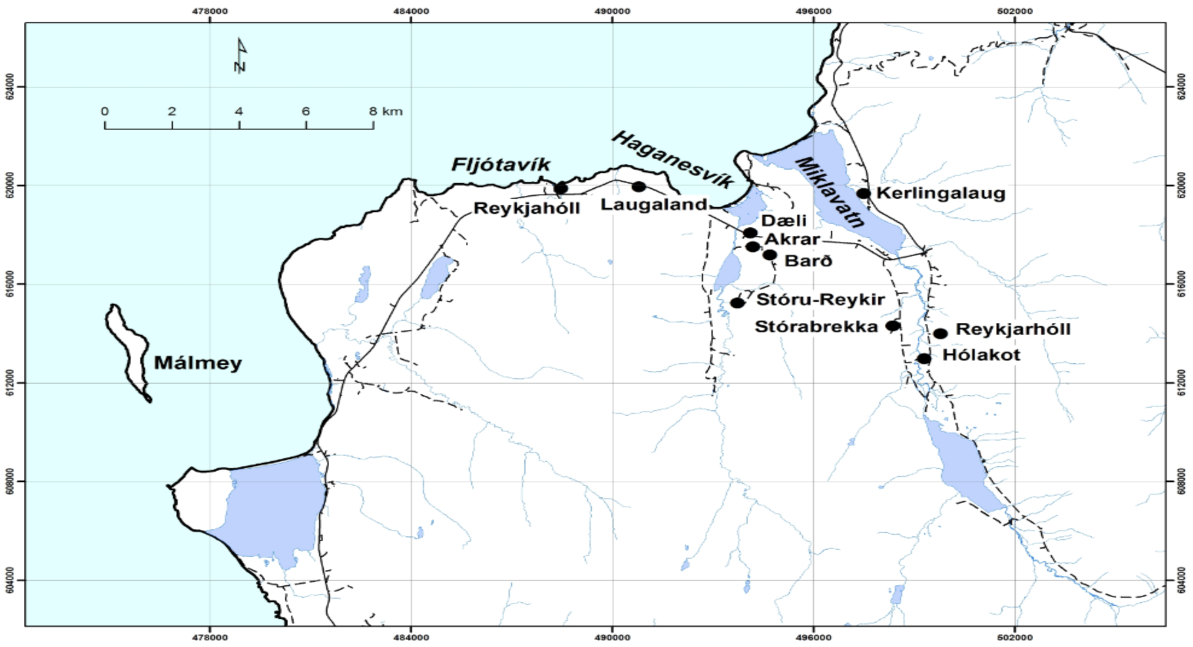

TABLE 1: Fluid composition from Fljótin *(samples collected in October 1985).*

Name	Sample No	Temp. surface (°C)	pH/°C	CO_2	H_2S	SiO_2	Na	K	Mg	Ca	Cl	SO_4	F	dO_{18}	Conduct-ivity/ 25°C	Charge balance
Bardslaug (1)	19850276	66.5	9.76/22.0	18.9	0.49	135.7	77.3	1.96	<0.001	1.77	29.23	53.63	0.62	-12.22	385	-0.24
Bardslaug (1*)	19730114	-	9.78/20.0	24.2	<0.10	146.0	75.3	1.9	0.060	1.63	24.80	52.7	0.70	-	-	-4.31
Daelir_(2)	19850277	46.4	9.72/22.0	20.6	0.16	142.2	80.5	2.69	0.005	2.3	29.65	56.5	0.61	-12.43	402	2.49
Akrar _(3)	19850278	61.0	9.7/22.2	20	0.23	147.1	78.7	2.71	0.004	1.77	29.68	56.32	0.63	-12.31	395	-0.08
Reykir (4)	19850279	48.8	10.2/22.5	13.4	0.10	90.4	65.2	0.87	0.001	2.09	22.50	40.15	0.53	-12.31	338	-5.31
Laugaland _(5)	19850280	64.7	9.85/22.3	18.9	<0.10	95.9	61.0	1.08	0.015	0.28	21.48	34.83	0.62	-12.33	304	-0.97
Reykjarhóll á Bökkum - well (6)	19850281	57.5	9.64/22.4	23.6	0.95	147.8	76.2	2.42	<0.001	2.41	29.89	50.79	0.73	-12.11	381	-0.43
Kerlingalaug_(7)	19850282	55.5	9.98/23.0	18.8	0.53	94.2	62.6	0.98	<0.001	1.86	22.45	35.3	0.59	-11.97	321	-3.98
Kerlingalaug (7*)	19690130	49.0	9.45/22.0	18.5	0.58	97.0	76.5	2.37	0.040	1.78	24.20	34.7	0.60	-	-	51.48
Hólakot_(8)	19850283	23.8	10.16/22.5	14.6	0.15	101.5	50.1	0.86	0.063	2.05	8.55	19.69	0.50	-12.21	252	-3.96
Reykjarhóll east (9)	19850284	52.8	10.19/22.7	14.1	0.17	102.8	51.3	0.8	<0.001	1.78	8.78	19.76	0.51	-12.19	255	-5.61
Reykjarhóll east (9*)	19690128	58.0	9.74/22.0	13.5	0.16	107.0	50.0	0.87	0.030	1.66	9.10	20.1	0.60	-	-	50.86
Stóra-Brekka (10)	19850285	88.5	10.21/22.5	8.2	0.13	52.0	74.7	0.32	<0.001	4.53	36.28	72.01	0.42	-12.67	406	-2.62
Stóra-Brekka (10*)	19690131	55.0	9.71/22.0	13	<0.10	87.0	65.5	1.1	0.08	1.94	23.4	38.5	0.40	-	-	36.92

Sample (1, 7, 9, and 10) have Mg value below detection limits therefore author use 0.001 mg/L in these samples in diagrams. Number in brackets represent the numbers in ternary diagrams. All sample are hot springs except for sample number 6 which is from a well - Not analysed

3. TANZANIA GEOLOGICAL BACKGROUND

3.1. RUNGWE VOLCANIC ZONE

The area of investigation belongs to the Rungwe Volcanic Province in Mbeya as shown in Figure 3 and Figure 4. The Mbeya area is located at the intersection between the western and eastern branches of the East African Rift system (EARS) forming a triple junction. The area is characterised by hydrothermal surface manifestations, potential volcanic heat sources, and fault- controlled permeability favouring fluid pathways along faults associated to the East African Rift system. Additionally, there is sufficient recharge in the high elevated area for filling up the naturally lost fluid (Ochmann and Garofalo, 2013). The previous study reveal that almost 10 MW of thermal fluid is lost from Songwe hot springs (geothermal outflow zone), which is indicating a substantial reservoir in the subsurface. Table 2 represent fluid composition of geothermal water from Rungwe.

The triple junction of the NW-SE trending south Rukwa and North Malawi rift basin intersected by younger NE-SW trending Usangu basin is covered by Rungwe volcanic rocks. There is also a number of Cretaceous carbonatite intrusive in the Mbeya region, including the Panda Hill Carbonatite which is located between Ngozi Volcano and Songwe hot springs. The condition for high enthalpy resources are principally favourable in the Mbeya region due to the presence of active faults which allowing fluid flow, young volcanic heat sources (which are sparse in other areas of western branch of the east African system) and the occurrence of surface manifestation such as hot spring indicating geothermal subsurface activity. Figure 4 indicate the hot spring sample selected for Rungwe area.

Rungwe volcanic zone has been divided into two geothermal field; Northern geothermal system (Ngozi-Songwe) which is high temperature field (>200°C) and Southern geothermal system which is low temperature field (<200°C) (Ochmann and Garofalo, 2013).

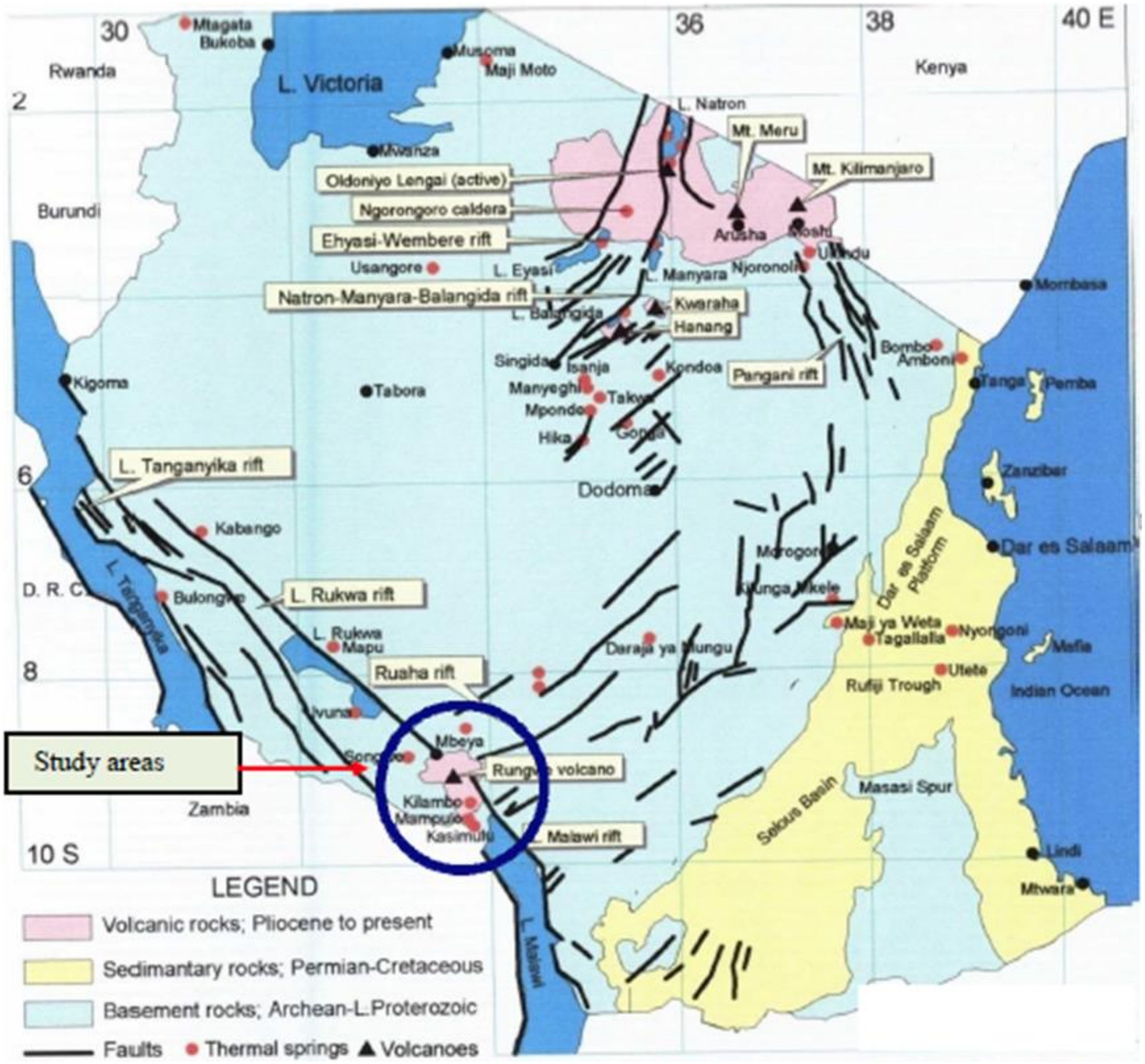

FIGURE 3: Geothermal site, study area and the rifting system in Tanzania. The blue ring represents Rungwe volcanic zone with selected thermal springs used in this report (Mwihava 2004)

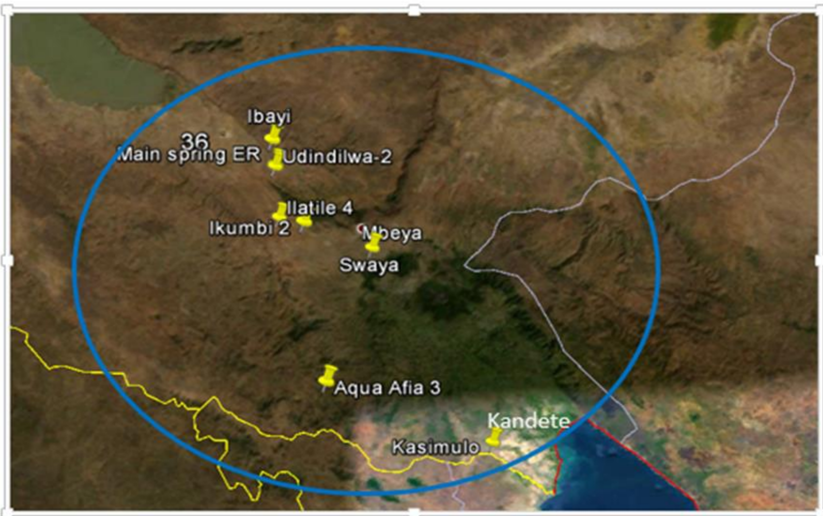

FIGURE 4: Locations of selected samples form Rungwe area used in this work. The map is from the geothermal site, study area and the rifting system in Tanzania (source google earth).

4. RESULTS AND DISCUSSION

4.1. The Fljótin geothermal area

4.1.1. The geothermometers

The geothermometer were selected according to volcanic activities, rock type, and mineral composition and sampling surface temperature. The geothermometer used to calculate the reservoir temperature for Fljótin were quartz geothermometer by Fournier & Potter (1982), the chalcedony geothermometer by Arnórsson et al., (1983), the amorphous silica geothermometer by Fournier (1977) and the Na/K geothermometer by Giggenbach (1988). The results of the calculations were shown in Table 3.

The chalcedony geothermometer gives temperature range between 74 and 136°C, the quartz geothermometer temperature range between 104-160°C, the amorphous silica range in 10-38°C and Na/K geothermometer temperature range was 64-158°C. Amorphous silica geothermometer gives unexpected lower temperature compare to surface temperature for such situation amorphous silica will not full fill the estimation of the reservoir temperature.

The Na/K geothermometer and Na-K-Mg ternary diagram gives similar temperature value for reservoir the temperature estimation. Arnórsson (1975) concluded that the Icelandic water are equilibrated with chalcedony at a temperature < 180°C. Therefore chalcedony geothermometer was considered here to give the most likely reservoir temperature range of 74-136°C.

TABLE 2: Fluid composition of Rungwe *(Collected 2006-2008;* Ochmann. and Garofalo, 2013)

Name	Sample number	pH	Temp °C	CO_2	SiO_2	Na	K	Mg	Ca	Cl	SO_4	Al	Fe	Li	Charge balance
Udindilwa (a)	23	7.00	82.40	854.75	72.7	893.0	28.50	3.90	13.40	82.40	247.	0.017	0.100	0.30	0.019
Ibayi (b)	29	6.80	80.20	1269.50	82.3	646.0	40.30	2.30	12.00	116.00	297.00	0.008	0.100	0.30	0.001
Main spring ER (d)	19	6.70	65.70	1441.20	71.8	775.0	95.40	15.60	30.30	197.00	154.00	0.023	0.100	0.70	0.005
Aqua Afia 3 (e)	15	6.90	60.30	1384.20	133.0	106.0	48.70	4.50	12.10	9.00	1.70	0.007	<0.100	20.60	-0.015
Aqua Afia 1 (f)	16	6.70	56.60	1990.80	124.0	100.0	46.90	5.80	15.50	8.20	1.00	0.003	<0.100	17.50	0.009
Ikumbi 2 (g)	26	6.80	54.70	2019.70	125.0	102.0	48.70	4.90	13.50	8.70	1.40	0.004	<0.100	20.60	-0.007
Kandete (h)	9	7.40	56.60	295.02	126.0	1246.0	66.00	13.90	15.50	224.00	252.00	<0.005	0.300	0.40	0.164
Kasimulo (i)	10	7.70	42.40	293.57	105.0	1218.0	68.10	15.80	26.10	204.00	317.00	<0.005	0.200	0.40	0.144
Ilatile 4 (k)	5	8.50	80.20	139.21	70.3	818.0	82.00	8.00	17.10	184.00	143.00	<0.005	0.200	0.80	0.013
Swaya (m)	12	7.20	44.10	295.02	89.5	52.1	80.40	4.80	13.10	12.50	14.00	0.019	0.027	0.00	0.162

Letters in brackets represent the numbers in ternary diagram

TABLE 3: Solute geothermometer for Fljótin samples (°C)

Sample name	Surface temperature (°C)	Chalcedony (°C) (1)	Quartz (°C) (2)	Amorphous silica (°C) (3)	Na/K (°C) (4)
Bardslaug (1)	66.5	130	155	33	142
Bardslaug (1*)	-	135	160	37	122
Daelir (2)	64.7	134	158	36	158
Akrar (3)	57.5	136	160	38	159
Reykir (4)	55.5	104	132	12	110
Laugaland (5)	52.8	108	135	15	124
Reykjarhóll á Bökkum, well (6)	88.5	136	161	38	155
Kerlingalaug (7)	48.8	107	134	14	118
Kerlingalaug (7*)	49.0	109	136	15	134
Hólakot (8)	46.4	111	138	18	122
Reykjarhóll east (9)	61.0	112	139	18	118
Reykjarhóll east (9*)	58.0	115	141	20	102
Stóra-Brekka (10)	23.8	74	104	33	64
Stóra-Brekka (10*)	55.0	102	130	10	100

Number in brackets represent the numbers in ternary diagrams
1. Arnórsson et al., 1983; 2. Fournier & Potter, 1982; 3. Fournier, 1977; 4. Giggenbach, 1988

4.1.2. The mineral saturation

According to the theory of mineral saturation equilibrium was reached when saturation index (SI) was equal to zero, under saturated when SI was less than zero and supersaturated when the SI was greater than zero. In Fljótin the system was under saturation with higher temperature of chalcedony by considering sample from Bardslaug (1, 1*), Kerlingalaug (7, 7*), Reykjarhóll east (9, 9*), and Stóra-Brekka (10, 10*) as in Table 4. The mineral saturation state of the Fljótin geothermal field were calculated by the chalcedony reservoir temperature by Fournier (1977) which was indicate saturation for calcite and amorphous silica while under saturation for anhydrite as shown in Table 4. This indicate low minerals precipitation when utilizing the fluid.

TABLE 4: Mineral saturation state for Fljótin. SI index calculated at chalcedony temperature

Hot spring	Surface temperature (°C)	Chalcedony temperature (°C)	Calcite ($CaCO_3$) SI index	Anhydrite ($CaSO_4$) SI index	Amorphous silica (Am.SiO_2) SI index
Bardslaug (1)	66.5	97.9	-0.1	-3.38	0.065
Bardslaug (1*)	.	104.8	-0.049	-3.425	0.116
Daelir (2)	64.7	102.8	0.02	-3.25	0.101
Akrar (3)	57.5	105.7	-0.11	-3.36	0.122
Reykir (4)	55.5	46.5	0.09	-3.42	-0.383
Laugaland (5)	52.8	74.2	-0.82	-4.34	-0.125
Reykjarhóll á Bökkum well (6)	88.5	109.1	0.05	-3.27	0.146
Kerlingalaug (7)	48.8	64.5	0.08	-3.52	-0.21
Kerlingalaug (7*)	49	102.6	-0.718	-3.51	0.1
Hólakot (8)	46.4	55.6	0.12	-3.71	-0.293
Reykjarhóll east (9)	61	53.5	0.07	-3.77	-0.313
Reykjarhóll east (9*)	58	103.6	-0.599	-3.74	0.107
Stóra-Brekka (10)	23.8	20.9	0.21	-2.85	-0.664
Stóra-Brekka (10*)	55	92.1	-0.597	-3.423	0.02

Numbers in brackets represent the numbers in ternary diagrams and in Table 1.

4.1.3. Components distribution in Fljótin

The distribution of the major elements of geothermal field in contour map was interpreted with the Surfer 12.6.963 software by Golden Software. The contour map was provide useful information for fluid composition distribution and up flow zone in geothermal field. However resource management and environment effect would be viable in component distribution map up on utilization of the geothermal field. The selected elements were, SiO_2, CO_2 and Cl, element were selected according to their application in geothermal field where SiO_2 was the indication of heat source, CO_2 describe the size of the reservoir and the major fracture of the geothermal system and Cl indicate the water maturity in geothermal field. Components distribution for Fljótin were presented in Figures 5. The SiO_2 concentrations range between 52-148 mg/l in the Fljótin geothermal area. As shown in Figure 5 the concertation of SiO_2 increase from 52 mg/l in the SE to NW with SiO_2 concentration range between 136-147 mg/l. The CO_2 concentrations range between 8-24 mg/L increase with the same trend as the silica concentration from SE to NW with the low concentration 8 mg/L to higher concentration (148 mg/L). The Cl concentration which was very low, range between 9-36 mg/L, increase from 9 mg/L in the SE towards NW—SE with high concentration of 36 mg/L.

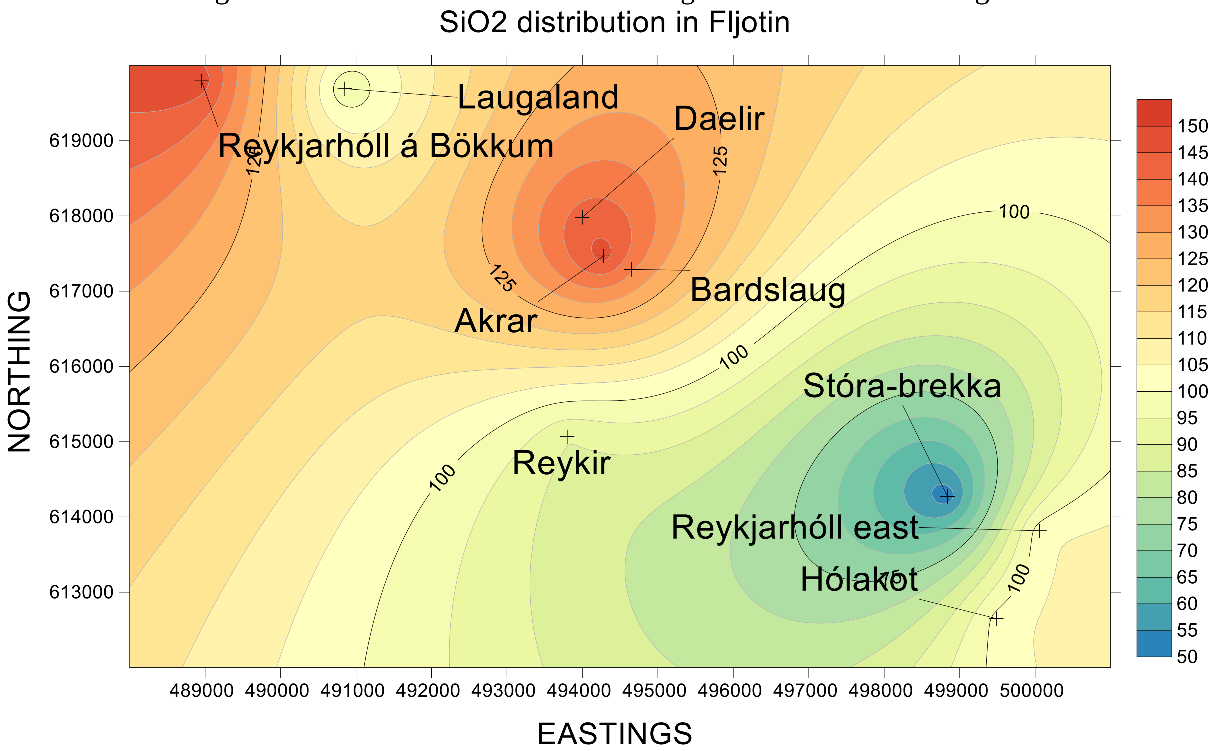

FIGURE 5: Distribution of CO_2, SiO_2, and Cl in Fljótin Iceland

This SiO_2 concentration was highest between 136-147 mg/l in Daelir, Akrar, Bardslaug and Reykjarhóll (the well in the north) which was consistent with the calculated temperature shown in Figure 12.
According to geology and chemical analysis of Fljótin reservoir temperature could be estimated as 120°C to 160°C, the area has a potential for direct utilization such as swimming pool, fishing industry and green house regarding the temperature of hot spring with liquid dominated fluid which is characterized by low temperature geothermal fluid with low enthalpy

4.2. The Rungwe geothermal area

The mineral saturation state (index) were expressed by calculated quartz temperature (Fournier & Potter, 1982) where calcite and anhydrite will be saturated while amorphous silica will be supersaturated as in shown Table 5.

TABLE 5: Mineral saturation state – Rungwe SI index calculated at quartz temperature

Hot spring	Surface temp (°C)	Quartz temp (°C)	Calcite ($CaCO_3$) SI index	Anhydrite ($CaSO_4$) SI index	Amorphous silica (Amr. SiO_2) SI index
Udindilwa (a)	65.7	120.20	-0.980	-2.187	0.017
Ibayi (b)	82.4	126.80	-1.081	-2.152	0.071
Main spring ER (d)	60.3	119.70	-0.758	-2.058	0.012
Aqua Afia 3 (e)	44.1	154.00	-1.100	-4.070	0.28
Aqua Afia 1 (f)	42.4	149.80	-1.250	-4.210	0.249
Ikumbi 2 (g)	44.1	150.20	-1.180	-4.130	0.253
Kandete (h)	56.6	150.50	-0.899	-2.512	0.256
Kasimulo (i)	54.7	139.60	-0.363	-1.840	0.176
Ilatile 4 (k)	80.2	118.60	0.013	-2.256	-0.004
Swaya (m)	44.0	131.20	-0.800	-3.080	0.107

Letters in brackets represent the numbers in ternary diagram and in Table 2.

4. 2. 1 Components distribution in Rungwe

According to Figure 6 the highest SiO_2 concentration 105-133mg/l was in the SE and in the centre where there was most of the hot springs. Northern of the area the SiO_2 was lower of ~70-80 mg/l. The trend of CO_2 concentration increasing towards SE with high concentration of 294mg/l and 295mg/l. The Cl concentration increase NW-SE direction. From BGR report Ibayi and Udindilwa were reported to equilibrate at temperature <200°C (Ochmann and Garofalo 2013). The interpretation and discussion based on Ochmann and Garofalo 2013 report from selected data sample.

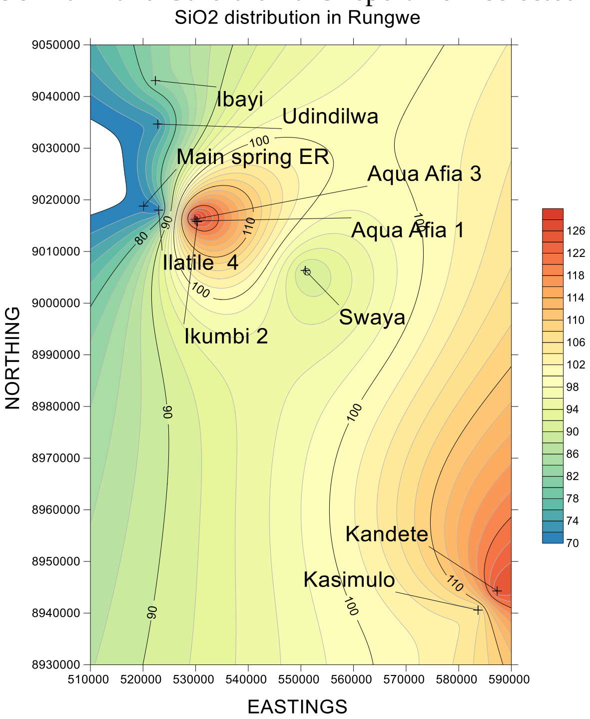

FIGURE 6: Distribution of CO_2, SiO_2, and Cl Rungwe Tanzania

5.0 Comparison of the Fljótin and the Rungwe geothermal fluids

As written earlier these two geothermal areas were very different both in age and rock composition and therefore the fluids compositions were also very different. The Fljótin geothermal area have estimated reservoir temperature in the range 120-160°C where the Rungwe geothermal area reservoir temperature range were in 130-200°C according to figure 7. Rungwe were divided into two geothermal field Northern geothermal system (Ngozi-Songwe) which was high temperature field (>200°C) and Southern geothermal system (Kiejo-Mbaka) which was low temperature field (<200°C) (Ochmann and Garofalo 2013).

The Fljótin and Rungwe might be saturated and under saturation by considering the mineral saturation state of calcite, anhydrite and amorphous silica at the reservoir temperature estimated by chalcedony mineral. Fljótin water classified as low temperature geothermal volcanic water and Rungwe classified as peripheral water with high concentration of HCO_3 as seen in Figure 8. The reservoir temperature for Fljótin could be estimated by chalcedony geothermometer and cation geothermometer in relation with Na-K-Mg ternary diagram. Due to different volcanic activities, rock type and mineral composition (Arnórsson 2000) the chalcedony and Na/K geothermometer has promising result for Fljótin (Table 3), while Rungwe quartz and K/Mg was providing necessary information compare to other geothermometry (Table 6).

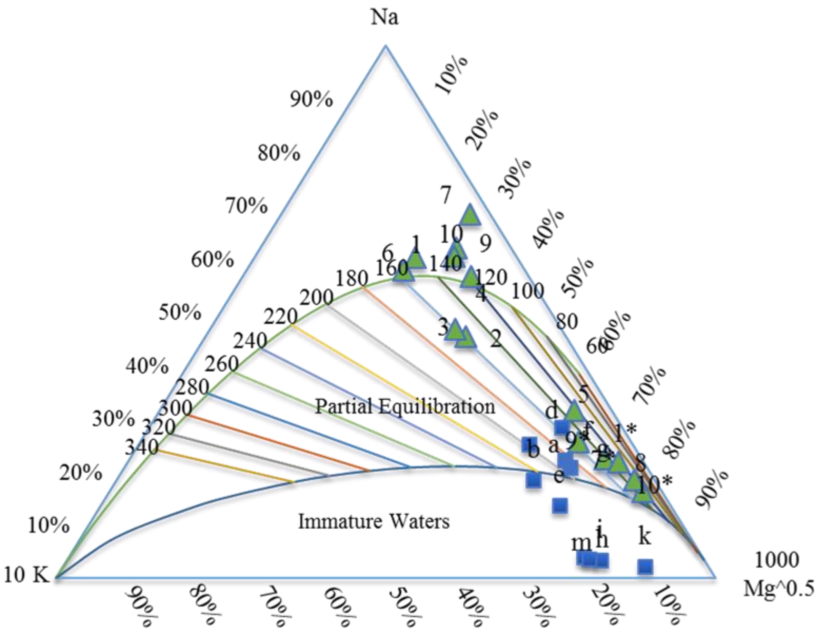

FIGURE 7: Comparisons of the Fljótin samples (green triangle) and the Rungwe samples (blue square) on the Na-K-Mg ternary diagram

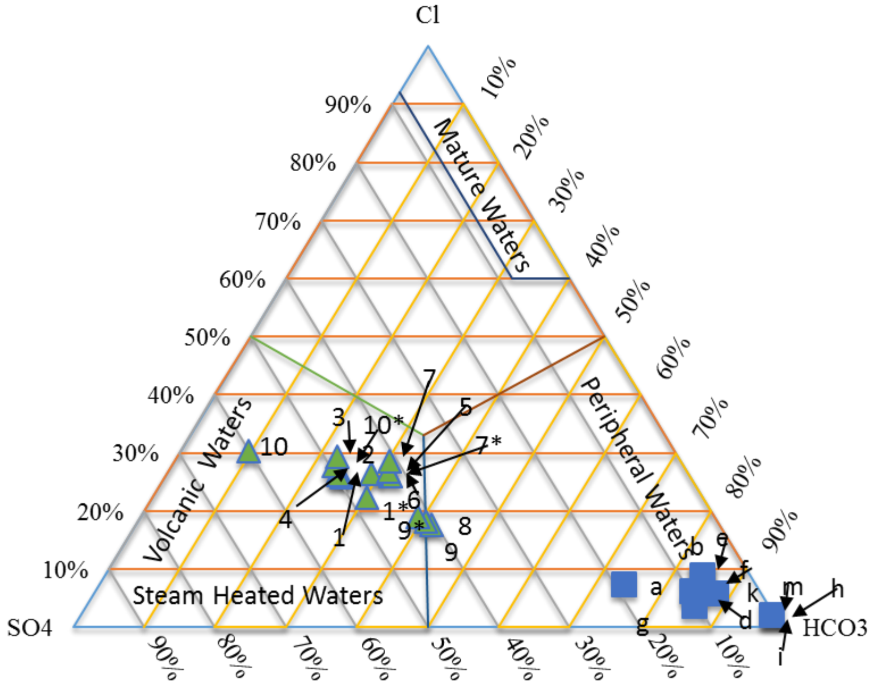

FIGURE 8: Relationship of Fljótin (green triangle) and Rungwe geothrmal field samples (blue square) by Cl_SO_4-HCO_3 ternary diagram

6.0 CONCLUSIONS

The Fljótin were classified as low temperature geothermal fluid with low total dissolved elements, low Ca, SiO_2 and CO_2 concentrations, all indicating that the fluid could be used directly without precipitation of calcite and amorphous silica. Fljótin were estimated to have the reservoir temperature range of 120°C-160°C according to chalcedony geothermometer and with temperature range of 64°C-159°C temperature range according to Na/K geothermometer. Which was in agreement with the full equilibrated fluid on the Na-K-Mg ternary diagram. The Fljótin area could be used directly for direct heating, greenhouse industry, aquaculture, fishing industry, tourist attraction like swimming pool, and natural bathing.

Rungwe volcanic zone were divided into two geothermal field; Northern geothermal system (Ngozi-Songwe) which was high temperature field (>200°C) and Southern geothermal system (Kiejo-Mbaka) which was low temperature field (<200°C) (Ochmann and Garofalo 2013). The selected point of thermal water from Rungwe volcanic zone were characterized by Mg-HCO_3 peripheral waters that are partially equilibrated, with estimated reservoir temperature range around 106°C-200°C Although, Rungwe volcanic zone has a promise results for geothermal industry, although, Ochmann and Garofalo (2013) report indicate high concertation of CO_2 which require detail studyfor temperature determination and effect of chemicals in order to reduce the high operation risk. However at the moment the field could be used for direct use such as green house, fishing and tourist attraction.

REFERENCES

Ármannsson, H., and Fridriksson Th.,: *Geochemical sampling and analysis*. UNU-GTP, Iceland, unpublished lectures, (2015).

Arnórsson, S.,: Application of the silica geothermometer in low-temperature hydrothermal areas in Iceland. *Am. J. Sci., 275,* (1975), 763-783.

Arnórsson, S.,: Geothermal systems in Iceland; structures and conceptual models; I, high-temperature areas. *Geothermics, 24, (*1995), 561-602.

Arnórsson, S.,: Mixing processes in upflow zones and mixing models. In: Arnórsson, S. (ed.), *Isotopic and chemical techniques in geothermal exploration, development and use. Sampling methods, data handling, and interpretation*. International Atomic Energy Agency, Vienna, *(*2000), 200-211.

Arnórsson, S., Gunnlaugsson, E., and Svavarsson, H.,: The chemistry of geothermal waters in Iceland III. Chemical geothermometry in geothermal investigations. *Geochim. Cosmochim. Acta, 47*,(1983), 567-577.

Arnórsson, S., Sigurdsson, S. and Svavarsson, H.,: The chemistry of geothermal waters in Iceland I. Calculation of aqueous speciation from 0°C to 370°C. *Geochim. Cosmochim. Acta, 46,(* 1982), 1513-1532.

Arnórsson, S., Stefánsson, A., and Bjarnason, J.Ö.,: Fluid-fluid interaction in geothermal systems. *Reviews in Mineralogy & Geochemistry, 65,(* 2007), 229-312.

Ebinger, C.J., Deino, A.L., Drake, R.E., and Tesha, A.L.,: Chronology of volcanism and rift basin propagation: Rungwe volcanic province, East Africa. *J. Geophys. Res., 94 B11:15*, (1989), 785-803.

Ellis, A.J., and Mahon, W.A.J.,: *Chemistry and geothermal systems*. Academic Press, New York, (1977), 392 pp.

Fournier, R.O.,: Chemical geothermometers and mixing model for geothermal systems. *Geothermics, 5,* (1977), 41-50.

Fournier, R.O., and Potter, R.W.,: An equation correlating the solubility of quartz in water from 25° to 900°C at pressures up to 10,000 bars. *Geochim. Cosmochim Acta, 46*, (1982), 1969-1973.

Giggenbach, W.F.,: Graphical techniques for the evaluated water/rock equilibration conditions by use of Na, K, Mg and Ca contents of discharge water. *Proceedings of the 8th New Zealand Geothermal Workshop,(* 1986), 37-43.

Giggenbach, W.F.,: Geothermal solute equilibria. Derivation of Na-K-Mg-Ca geoindicators. *Geochim. Cosmochim. Acta, 52*, (1988), 2749-2765.

Giggenbach, W.F.,: Chemical techniques in geothermal exploration. In: D'Amore, F. (coordinator), *Application of geochemistry in geothermal reservoir development*. UNITAR/UNDP publication, Rome, (1991), 119-144.

Gunnarsson, I. and Arnórsson S.,: Amorphous silica solubility and the thermodynamic properties of $H_4SiO_4°$ in the range of 0° to 350°C at P_{sat}. *Geochim. Cosmochim. Acta, 64*, (2000), 2295-2307.

Hjartarson, Á., and Saemundsson, K.,: Geological map of Iceland. Bedrock, 1:600 000. ÍSOR – Iceland GeoSurvey, Reykjavík, (2014).

Jóhannesson, H.,: The mountains west of Eyjafjordur, In: *The Icelandic Tourist Association yearbook 1991* (in Icelandic). The Icelandic Tourist Association, Reykjavík, (1991), 246 pp.

Jóhannesson, H., and Saemundsson, K.,: *Geological map of Iceland, 1:1.000.000*. Icelandic Institute of Natural History, (1999).

Kharaka, Y.K., and Mariner, R.H.,: Chemical geothermometers and their application to formation waters from sedimentary basins. In: Naesar, N.D. and McCollon, T.H. (editors), *Thermal history of sedimentary basins.* Springer-Verlag, New York, (1989), 99-117.

Mwihava, N.: United Republic of Tanzania – Brief on status of geothermal energy. *International Conference Geothermal Energy Territory, Pomarance, Italy, (*2004*),* 217-220.

Nicholson, K.,: *Geothermal fluids: chemistry and exploration techniques*. Springer-Verlag, Berlin, (1993), 268 pp.

Ochmann, N., and Garofalo, K.,: *Geothermal energy as alternative source of energy for Tanzania.* BGR, Germany, final report, (2013).

Pope, L.A., Hajash, A., and Popp, R.K.,: An experimental investigation of the quartz, Na-K, Na-K-Ca geothermometers and the effect of fluid composition. *J. Volcanol. Geotherm. Res., 31*, (1987), 151-161.

Roychowdhury, T.,: Influence of several factors during collection and preservation prior to analysis of arsenic in groundwater: A case study from West Bengal, India. *J. Int. Environmental Application & Science, 3-1, (*2008*)*, 1-20.

Saemundsson, K.,: Outline of the geology of Iceland. *Jökull, 29,(* 1979*)*, 7-28.

Saemundsson K, Arnórsson S and Stefánsson V,: Geological researches at Bardslaug in the Fljótin area (in Icelandic). Orkustofnun, Reykjavík, report OSJHD 7326, (1973), 6 pp.

Schlitzer, R., Roether, W., Weidmann, U., Kalt, P., & Loosli, H. H.: A meridional 14C and 39Ar section in northeast Atlantic deep water. *J. Geophysical Research: Oceans (1978–2012)*, *90*(C4), (1985), 6945–6952.

Sekento, L. R..,: Geochemical and isotopic study of the Menengai geothermal field, Kenya. Report 31 in: geothermal Training in Iceland 2012. UNU-GTP, Iceland, (2012), 769-792

Verma, M.P.,: Chemical thermodynamics of silica: a critique on its geothermometer, *Geothermics 29,* (2000), 323-346.

Verma, S.P., and Santayo, E.,: New improved equations for Na/K, Na/Li and SiO_2 geothermometers by outlier detection and rejection*.* *J. Volcanol. Geotherm. Res., 79*, (1997), 9-23.