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Geochemical and Isotopic Study of Dofan-Fantale Geothermal Prospect

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ABSTRACT

Dofan-Fantale geothermal prospect is one of the geothermal fields in Ethiopia that was recommended for further study by UNDP (1973). Currently detailed geological, geochemical and geophysical studies are going on. Dofan-Fantale area is located in the Southern Afar Region, at Ethiopian Rift Valley, which is about 200km NE of the capital, Addis Ababa. Twenty-eight water samples from thermal springs, boreholes, lakes, rivers, and dug wells were collected in the area under study. Water chemistry suggests the existence of $NaHCO_3$, $CaHCO_3$ and $Na/ClHCO_3$ water types. The reservoir temperature as indicated from the geothermometry results of Habilo spring (Sp-4) is close to ~250ºC. Water - mineral equilibria study has shown that most of the common geothermal minerals are over saturated at ~100Cº at atmospheric pressure. However, they are found to be in equilibrium with the rock reservoir at a temperature of ~250ºC at depth. The δ^2H versus $\delta^{18}O$ plot has revealed ¨^{18}O - shift¨ of 1.4 ‰ for Habilo thermal feature (Sp-4), which might indicate higher circulation period and longer residence time.

1. INTRODUCTION

The Dofan-Fantale geothermal prospect is located in the Ethiopian Rift Valley where the Rift starts funneling into the Afar triangle, which is in the north western part of the Southern Afar geothermal area, about 200 km to the north east of Addis Ababa (figure 1).

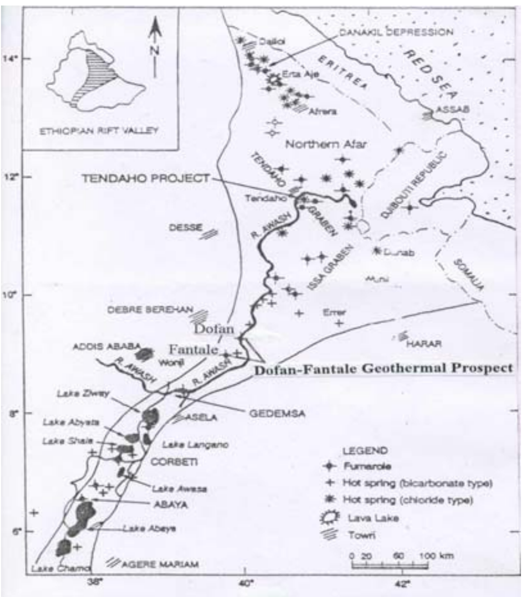

Figure.1: Location of Dofan-Fantale geothermal area

The Dofan-Fantale geothermal area consits of:

1) Dofan volcano, (9° 19"N, 40° 05" E), that has long been known for its fumarolic activity and associated sulfur deposits, (Mohr, 1962).

2) Fantale volcano (8° 58"N, 39° 54" E), a Quaternary strato volcano characterized by fumarolic activity, warm ground and low-pressure fumaroles.

Filoa hot springs occur to the north east of Fantale volcano and the combined flow forms a pool surrounded by palm trees. The prominent features in the study area are: the dramatically expanding Lake Beseka and the Awash River. Governmental and non-governmental activities have made the area of study easily accessible. The ambient temperature of the area is variable and it ranges from 22 to 28°C. The elevation of the study area varies from 700 to 1000 m.a.s.l. and the annual rain fall is 400 to 800 mm.

2. THE OBJECTIVE OF THE STUDY

The geochemical study includes: 1) identification of water type 2) determination of deep temperature and 3) prediction of possible scaling. Therefore, the objective of the study is to investigate the geothermal potential of the area in order to supply geochemical information that helps in selecting sites for future temperature gradient well drilling and to play part in pinpointing sites for deep drilling of exploration wells together with the geological and geophysical information

3. SAMPLING TECHNIQUES AND ANALYTICAL METHODS

3.1 Sampling Techniques

The 28 water samples that were collected in the area of study include 12 thermal springs, 8 boreholes, 2 dug wells, 4 rivers, and 2 lakes,

Spring samples were collected from relatively strong flow rates that remain constant throughout the year. Borehole samples were collected from the hand, electric or Diesel pumping systems at the depth ranging from 45-180 m. Dug wells, (5-19 m deep) were sampled from the water level using plastic bucket tied to a nylon rope. River samples were collected from the central part of the channel. Lake samples were collected by deepening the sample vessel to approximately 50 cm and at a distance of 10 meters from the lake shore.

The sample size depends upon the type of constituents to be determined (Giggenbach and Goguel 1989). From each feature, 50ml of sample for stable isotopes and 500ml for major and minor chemical analyses were collected and stored in polyethylene double-capped bottles. Electrical conductivity and pH were measured in situ.

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3.2 Analytical Method

The isotopic ratios $^{18}O/^{16}O$ and $^{2}H/^{1}H$ were analyzed at the Isotope Hydrology Laboratory, IAEA, Vienna. The isotopic results are reported in per mill deviation with respect to the Vienna Standard Mean Ocean Water (SMOW), with uncertainty levels of ±0.1‰ and ±1.0‰ for ^{18}O and ^{2}H respectively, IAEA (1981).

Chemical analyses of major and minor ion compositions were carried out at the Geological Laboratory of the Geological Survey of Ethiopia and reported in parts per million (ppm).

4. CHEMISTRY OF THE SAMPLED FEATURES

The assessment of the chemistry of the hot and cold features helps in understanding the water type as well as the deep temperature of the system. The water features sampled in the area of study are close to neutral to slightly alkaline with respect to pH. Habilo, this is the most impressive and vigorous thermal feature in the area. It emerges from a hole like opening and shows geyseric effect with no periodicity. The water jets up to 1½ meters high. There are sinter and travertine deposits and small fumaroles around the spring. Its temperature is 81.5ºC, which is the highest in the entire study area (others range from 42-56ºC). It has also relatively high ionic composition, SiO_2 (364ppm), Na (530 ppm), Cl (432 ppm), and SO_4 (278ppm).

The Filoa springs emerge near the base and on the downthrown eastern side of a 16-meter high fault in basalt. They have the highest flow rate than any other spring in the area. This rate is 340 liters per second, (UNDP 1973). These springs have SiO_2 (60-65ppm) and SO_4 (90-100ppm). The Dofan spring has lower flow rate than the Filoa springs, (20 litres per second). However, it has higher SO4 (156ppm), and SiO_2 (123ppm), content compared to Filoa springs.

Debhile has lower discharge than the Filoa spring, (0.5 liters per second) but it has higher SiO_2 (144ppm) and SO_4 188ppm) content than both Dofan and Filoa springs. The boreholes sampled in the area have low temperature (27-44ºC) and they have also low TDS values (400-700mg/l).

Two dug wells sampled are located in the northern and in the southern part of the study area. The one in the northern part has very low TDS value of 176mg/l. The one in the southern part has relatively high TDS value of 1830mg/l.

Three rivers were sampled in the area of study, namely Awash, Kebena, and Bulga. All are perennial rivers that flow to the study area from the highlands. The Awash river which is the largest of the three was sampled at three points of its course and it was observed that it increase chemically north wards. The pH values of the river samples are ranging from near neutral to slightly alkaline. They have low TDS values (145-390mg/l). Beseka lake has temperature of 27ºC and high Cl (638ppm) but, low SiO_2 (150ppm). Its pH is 9.5, which is strongly alkaline. The second lake sampled is Debhile, which is located in the northern part of the study area. It has lower TDS value than Beska lake, (826mg/l).

5. WATER TYPE IDENTIFICATION

According to the Langeler Ludwig diagram in figure 2, the chemical composition of the waters suggests the existence of $NaHCO_3$, $CaHCO_3$ and $Na/ClHCO_3$ water types in the area.

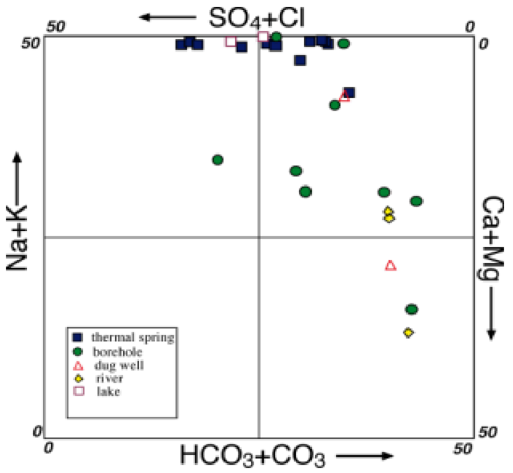


Figure 2: Langeler Ludwig diagram of water samples from Dofan-Fantale geothermal area

$Cl-SO_4-HCO_3$ ternary diagram, is shown in figure 3. This is mostly applied to geothermal waters, with relation to the application of geothermometers:

1) The near neutral to slightly alkaline pH features (7.5-8.2) with relatively low SO_4 and high Cl, of 278-188ppm and 432ppm respectively plot along the $Cl-HCO_3$ axis close to the Cl quadrant. This is important in the application of most of the geothermometers, e.g: Habilo thermal feature.

2) The water features those are more alkaline in pH and with high HCO_3, and/or high SO_4 content. The good examples are 1.) Beseka lake with pH of 9.5 and HCO_3 of 1869ppm. 2.) Arowadi dug well with pH of 8.9 and SO_4 388ppm. These and similar springs, boreholes, dug wells, lakes and rivers, are not required in the application of geothermometers

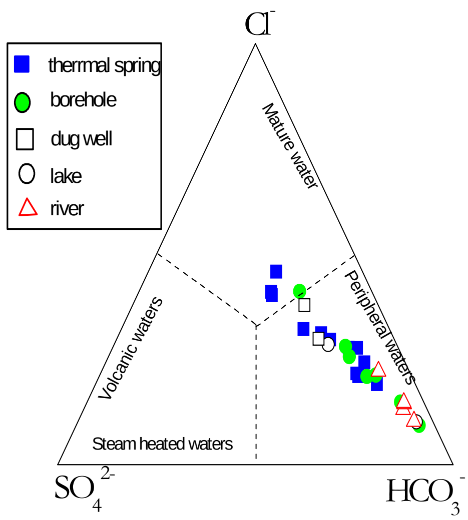


Figure 3: $Cl-SO_4-HCO_3$ plot for waters from Dofan-Fantale geothermal area.

6. DEEP TEMPERATURE DETERMINATION

6.1 Molecular Ratio

Molecular ratio serves the dual purpose: 1.) to determine qualitatively whether the system is of high or low temperature 2.) to determine whether the different water features originate from the same source or not.

The thermal feature Habilo (Sp-4) and Debhile (SP-5), show relatively high Na/Mg of 1767 and 3450 respectively and low Na/K of 6 and 17 respectively. This might indicate high deep temperature.

Filoa spring (Sp-2) and Debhiti borehole (Bh-3A) might have originated from the same source with similar rock environment, because they have similar molecular ratio of Cl/SO_4 (1.7 and 1.8) and Cl/B (160 and 170).

6.2 Chemical Geothermometers

One of the parameters to know in the assessment of thermal systems for practical use is the actual temperature of the reservoir, (Giggenbach and Goguel 1989). Application of solute geothermometers is inevitably very essential. Most of the geothermometers that are used have shown the highest subsurface temperature to the Habilo thermal feature (Sp-4), followed by Debhile spring (Sp-5) and Na/400-K/10-√Mg of Giggenbach geothermometer,

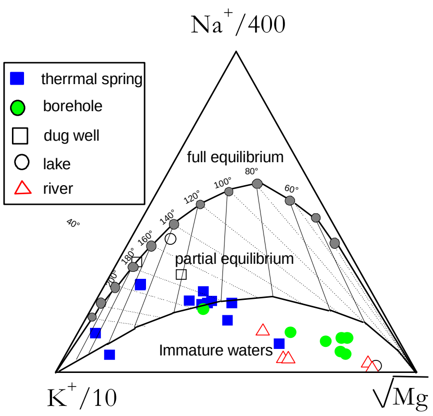


Figure 4: Na/400-K/10-√Mg plot for waters from Dofan-Fantale geothermal area.

Figure 4 expressed in the ternary diagram is plotted using the percentage concentration of the elements that has indicated a general equilibrium temperature of 180°C. It has also indicated about 250°C for Habilo thermal feature (Sp-4). The silica geothermometer has given 224°C for Habilo whch might suggest that there is no sea water interference. Therefore, from the geothermometry analysis it might be possible to suggest that Habilo is the most promising area in the Dofan-Fantale geothermal prospect. From the figure above it can be seen that Habilo thermal feature has not reached the equilibrium line but it is above the immature line, which might suggest that it is partially equilibrated with the reservoir rock at a temperature of 250°C.

7. MINERAL WATER EQUILIBIA

Natural hot waters are saturated with silica in equilibrium with quartz and frequently close to equilibrium with calcite ($CaCO_3$), anhydrite ($CaSO_4$), etc (Ellis and Mahon 1977)

Flashing geothermal fluids is a problem for two reasons:

1) when steam is extracted from the fluid the solution left behind becomes more concentrated.

2) as CO_2 is extracted from the system, more $CaCO_3$ (calcite) will precipitate because calcite is one of the few minerals that becomes more soluble when temperature is dropped.

All geothermal fluids contain dissolved solids, and these solids are in equilibrium with the rock reservoir at elevated temperatures and pressures. As the fluid is brought to the surface the geothermal fluid is conductively cooled and therefore the possibility of depositing some of the dissolved species takes place and the likelihood of scaling is higher.

Therefore, in order to evaluate mineral deposition (scaling) tendencies of the Habilo thermal feature (Sp-4), the saturation index of selected minerals such as anhydrite ($CaSO_4$), Ca-montmorilonite, Na-montmorilonite, Laumonite, K-montmorilonite, Amorphouse silica, Albite, Calcite, Analcite, Chalcedony, Quartz and Mg-montmorilonite was plotted versus temperature figure 5. Most of the common geothermal minerals are over saturated at ~100ºC at atmospheric pressure and they are near equilibrium at ~250ºC at depth.

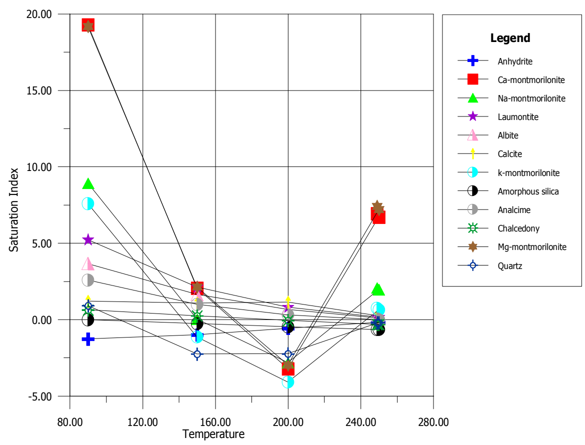
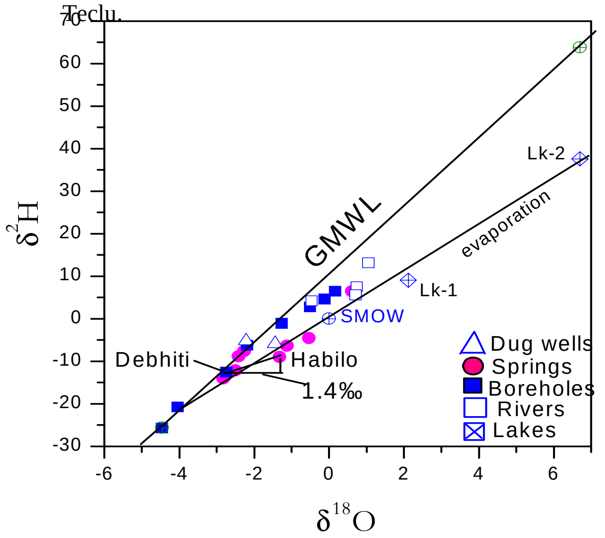


Figure 5: Saturation index versus temperature plot for Habilo spring

8 ISOTOPIC COMPOSITION OF THE SAMPLED FEATURES

The $\delta^{18}O$ versus δ^2H plot for the water samples collected from the Dofan-Fantale geothermal prospect is given in figure 6. The isotopic composition of Beseka lake shows higher surface evaporation effect than Debhile lake, resulting in disequilibrium enrichment of $\delta^{18}O$ and δ^2H content.



. **Figure 6: $\delta^{18}O$ versus $\delta^{2}H$ plot for waters from Dofan-Fantale geothermal area**

The isotopic composition of Habilo thermal feature shows '^{18}O- shift' which might indicate an exchange of ^{18}O with rocks having higher $^{18}O/^{16}O$ ratio in relation to the original source water. The '^{18}O- shift' is in the order of 1.4‰ that might show relatively higher circulation period and longer residence time as well.

It is again possible to see that the Debhiti borehole is the recharge source for Habilo since both lie in a line segment parallel to the $\delta^{18}O$ axis with little difference of $\delta^{2}H$ content which might be due to evaporation effect, as indicated in figure 6 above. Since Habilo doesn't have flow rate but shows geyseric effect, the water simply jets up to 1½ meters high and back to the source. Therefore, it is exposed to evaporation and as a result little deflection from a parallel line takes place.

The isotopic composition of the borehole samples of Debhiti and Kurkura are more depleted in heavy isotopes as compared to those collected from Metehara and Merti area due to evaporation effect.

The isotopic composition of Debhiti and Kurkura ranges from –4.46 to –2.18‰ and from –2.75 to –6.32‰ for oxygen and hydrogen isotopes respectively. In the contrary those of Metehara and Merti range from –0.12 to 0.16‰ and from –1.09 to 4.58‰ for ^{18}O and ^{2}H respectively.

Boloyta dug well, Merti borehole, Kebena River, Hubicha and Filoa springs and Welenchiti borehole are all clustered in the WMWL showing that they are meteoric in origin, which implys that they were recently involved in atmospheric circulation, figure 6.

9. SUMMARY OF RESULTS AND RECOMMENDATION

The main results of the geochemical and isotopic studies of the features of Dofan-Fantale geothermal prospect can be summarized as follows:

1) using the Lngeler Ludwig diagram, the water chemistry suggests the existence of $NaHCO_3$, $CaHCO_3$, and Na/Cl HCO_3 water types in the area of study.

2) According to the Cl-SO_4-HCO_3 ternary diagram it was possible to group the features as those that can be used in the application of geothermometers and those that cannot.

3) the deep temperature determination using the chemical geothermometers and the Na/400-K/10-√Mg ternary diagram have shown an equilibrium temperature of 180°C. The SiO_2 (quartz with no steam loss) and the Na-K geothermometers have shown 224 and 252ºC respectively for Habilo thermal feature.

4) the saturation index versus temperature plot for Habilo thermal feature has revealed that most of the common geothermal minerals are over saturated at ~100°C at atmospheric pressure and they are found to be in equilibrium with the rock at ~250°C at depth.

5) Habilo spring has shown an '^{18}O-shift' of 1.4‰, which might indicate higher circulation period and longer residence time.

6) Therefore, it can be recommended that further geophysical and drilling of TG-wells focus on the Habilo geothermal prospective area.

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