GEOCHEMISTRY OF DOFAN-FENTALE GEOTHERMAL PROSPECT

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ABSTRACT

Dofan-Fantale geothermal prospect is one of the geothermal fields in Ethiopia that w recommended for further study by UNDP (1973). Currently detailed geological, geochemical a geophysical studies are going on. Dofan-Fantale area is located in the Southern Afar Region, Ethiopian Rift Valley, which is about 200km NE of the capital, Addis Ababa. Twenty-eight wat samples from thermal springs, boreholes, lakes, rivers, and dug wells were collected in the ar under study. Water chemistry suggests the existence of $NaHCO_3$, $CaHCO_3$ and $Na/ClHCO_3$ wat types. The reservoir temperature as indicated from the geothermometry results of Habilo h spring (Sp-4) is close to ~250°C. Water - mineral equilibria study has shown that most of th common geothermal minerals are over saturated at ~100C° at atmospheric pressure. Howeve they are found to be in equilibrium with the reservoir rock at a temperature of ~250°C at dept 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 water-rock interaction than the other hot springs.

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). 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 an associated sulfur deposits, (Mohr, 1962).

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

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

bjective of the study is to carry out detail geochemical investigation that helps for selecting or the drilling of temperature gradient wells.

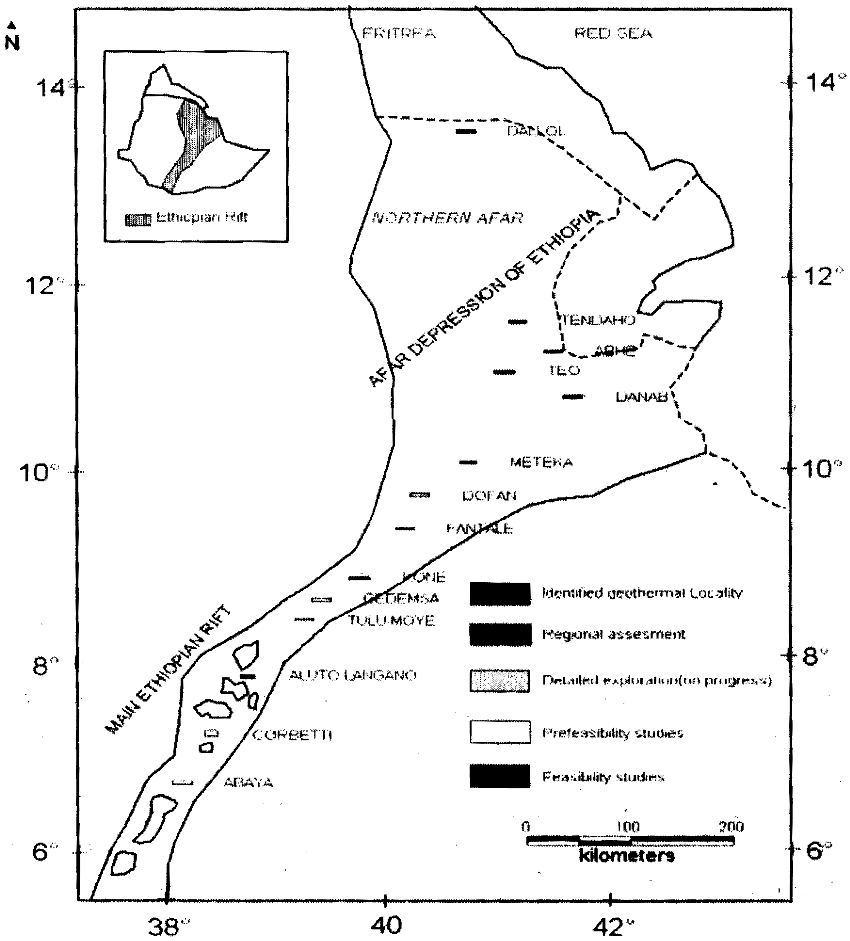

Figure 1: Location map of the geothermal prospect areas within the Ethiopian Rift Valley.

2 SAMPLING TECHNIQUES AND ANALYTICAL METHODS

2.1 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.

Thermal 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 th 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 t approximately 50 cm and at a distance of 10 meters from the lakeshore.

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, 125ml which is filtered and treate with 1 ml 1+1 HCl for cations, 125 ml of sample which is filtered and treated with 1 ml of zin acetate for SO4 and Cl and 500ml of sample for anions were collected and stored in polyethylen double-capped bottles. Electrical conductivity and pH were measured in situ.

2.2 Analytical Method

The isotopic ratios $^{18}O/^{16}O$ and $^{2}H/^{1}H$ were analyzed at the Isotope Hydrology Laboratory, IAEA Vienna - Austria. The isotopic results are reported in per mill deviation with respect to th Vienna Standard Mean Ocean Water (SMOW), with uncertainty levels of ±0.1‰ and ±1.0‰ fo ^{18}O and ^{2}H respectively, IAEA (1981). Chemical analyses of major and minor ion composition were carried out at the Geological Laboratory of the Geological Survey of Ethiopia and reported i ppm see table 1.

3. CHEMISTRY OF THE SAMPLED FEATURES

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

Table 1: Analytical data of water samples from Dofan-Fentale geothermal prospect in ppm.

Feature Name	Feature Code	PH 25°C	Cond $\mu S/25°C$	Na	K	Ca	Mg	CO_3	HCO_3	Cl	SO4	NO_3	F	SiO_2	B
Filoa	Sp-1	8.5	1886	383	20	4.3	2.0	8.5	735	150	89	2.7	5.2	63	1.0
Filoa	Sp-2	8.6	2115	428	21	8.8	1.3	14	762	194	98	2.9	7.1	70	1.0
Melka. T	Sp-3	8.2	1751	360	24	15	6.0	-	662	173	100	5.2	5.2	143	1.2
Habilo	Sp-4	7.5	2649	560	67	12	0.5	-	521	429	285	3.6	11	343	4.0
Hubicha	Sp-5	8.6	1716	284	19	49	17	19	627	119	108	6.3	6.3	74	0.7
Hubicha	Sp-6	8.5	1670	338	19	2.0	1.5	15	612	113	98	6.0	6.5	82	0.4
Dofan	Sp-1	8.5	1769	319	15	6	2	10	422	167	159	0.4	8	123	0.8
Dofan	Sp-2	7.7	1850	320	20	5	5	-	381	213	190	0.5	9	105	1
Debhile	Sp-3	8.6	1929	350	17	5	0.2	11	311	217	182	19	20	144	1
Debhile	Sp-4	8.4	1780	345	14	4	0.2	10	303	210	177	19	20	61	1
Kelo-ale	Sp-5	7.6	2347	465	27	20	0.5	-	617	324	157	0.1	21	261	2.2
Bilen	Sp-6	8.0	937	180	17	12	7.4	-	414	76	49	2.0	3.3	96	0.2
Merti	Bh-4	7.9	2766	345	36	39	17	-	630	223	149	14	3.5	93	0.4
Merti	Bh-7	7.9	1659	256	10	42	10	-	622	87	78	5.0	3.1	86	0.4
Metehara	Bh-1	7.7	2376	325	12	85	30	-	758	234	166	7.4	5.3	123	0.4
Metehara	Bh-2	8.0	2280	280	14	90	30	-	781	194	114	11	4.9	93	0.2
Debhiti	Bh-3	8.4	1956	380	26	9.0	3.8	11	802	168	85	2.7	5.4	81	0.8
Kurkura	Bh-5	7.8	681	93	8.3	41	12	-	35	35	22	3.6	1.4	111	0.2
Bulga	Rv-1	8.1	474	76	7.0	20	12	16	234	31	18	4.3	0.9	31	0.2
Awash.P	Rv-2	8.0	513	52	11	46	6.0	6.0	208	22	13	1.4	1.9	23	0.2
Kebena	Rv-3	7.7	240	15	3.0	24	7.0	-	132	9.0	5.5	2.1	0.4	34	0.2
Arowadi	Dw-1	9.1	3806	1052	30	1.5	0.5	174	1337	411	338	164	14	53	1.5
Boloyta	Dw-1	7.8	448	33	5	44	12	-	238	14	9	20	0.7	80	0.1
Beseka	Lk-1	9.5	6140	1735	70	2.8	0.5	671	1817	592	542	1.2	35	135	3.8
Debhile	Lk-1	8.6	2082	395	18	50	0.6	16	491	222	164	8.2	22	159	1.5

The Filoa springs emerge near the base and on the downthrown eastern side of a 16-meter h fault in basalt. They have the highest flow rate than any other spring in the area. This rate is 3 liters per second, (UNDP 1973). These springs have SiO_2 (60-65ppm) and SO_4 (90-100ppm). T Dofan spring has lower flow rate than the Filoa springs, (20 litres per second). However, it h higher SO_4 (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 Si (144ppm) and SO_4 188ppm) content than both Dofan and Filoa springs. The boreholes sampled the area have low temperature (27-44°C) 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. T one in the northern part has very low TDS value of 176mg/l. The one in the southern part h relatively high TDS value of 1830mg/l.

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

4. WATER TYPE IDENTIFICATION

According to the Langeler Ludwig diagram in figure 2, the chemical composition of the waters suggests the existence of Na/SO4-Cl, $NaHCO_3$ and $CaHCO_3$ water types in the area.

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

1) The Features with near neutral to slightly alkaline in pH (7.5-8.2) with relatively SO_4 and Cl, 278-188ppm and 432ppm respectively plot along the Cl-HCO_3 axis close to the high Cl regio These are important for the application of most geothermometers, e.g: Habilo thermal spring.

2) The features which are more alkaline and with high HCO_3, and/or high SO_4 content are n required in the application of chemical geothermometers The good examples are a) Beseka lal with pH of 9.5 and HCO_3 of 1869ppm. b) Arowadi dug well with pH of 8.9 and SO_4 388ppm.

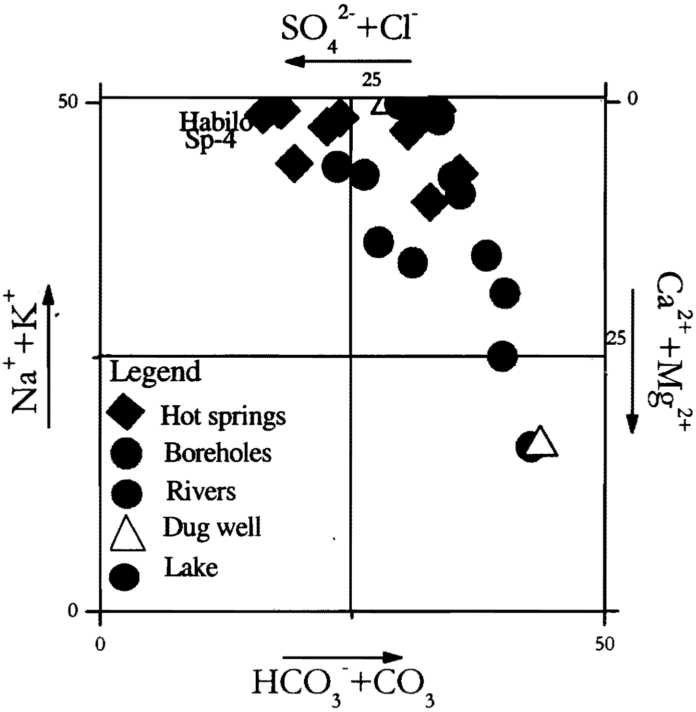

Figure 2: Langelier-Ludwig plot for water samples from Dofan-Fentale geothermal prospect

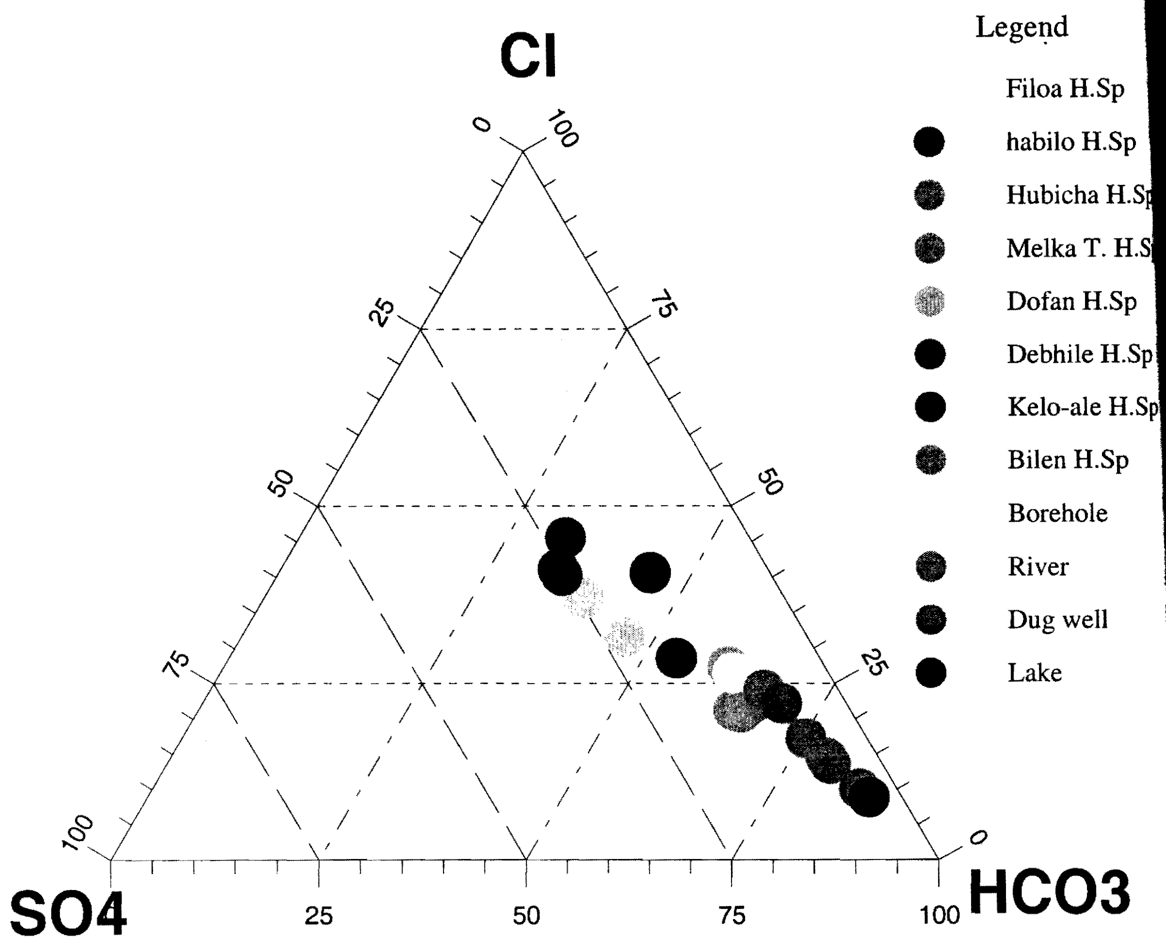

Figure 3: Cl-SO4-HCO3 plot for waters from Dofan-Fentale geothermal prosp

ECULAR RATIO AND CHEMICAL GEOTHERMOMETERS

cular Ratio

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

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

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

emical Geothermometers

the parameters to be known in the assessment of thermal systems for practical use is the temperature of the reservoir, (Giggenbach and Goguel 1989). Application of chemical ometers is inevitably very essential. Most of the geothermometers that are used have the highest subsurface temperature to the Habilo thermal spring (Sp-4), followed by e thermal spring (Sp-5). In figure 4 a ternary diagram is plotted using the percentage tration of the Na, K and Mg and has indicated a general equilibrium temperature of 180°C

also indicated about 250°C for Habilo thermal spring (Sp-4). The silica geothermometer has 224°C for Habilo. Therefore, from the geothermometry analysis it might be possible to t that Habilo is the most promising area for more detailed geothermal investigation in the -Fantale geothermal prospect. From figure 4 above it can be seen that Habilo thermal spring reached the full equilibrium line, but it is above the immature water line, which might t that it is partially equilibrated with the reservoir rock at a temperature of 250°C.

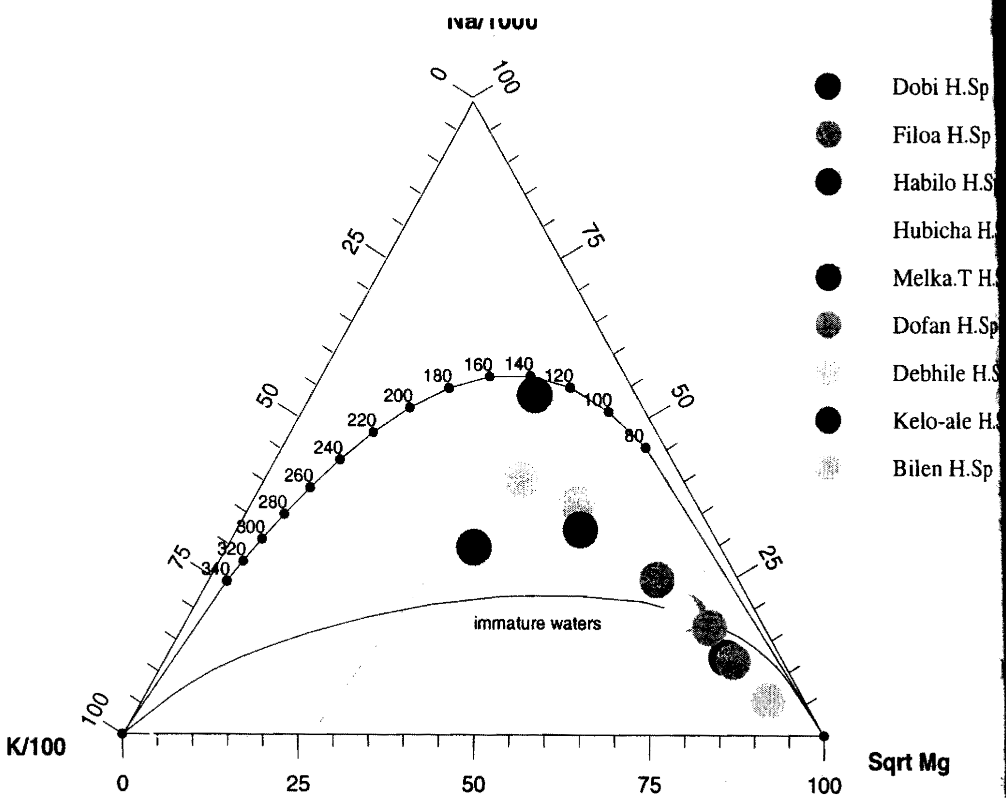

Figure 4: Na-K-Mg plot for waters from Dofan-Fentale geothermal prospect

6. 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 fluid is a problem for two reasons:

1) When steam is extracted from the fluid the solution left behind becomes more and more saturated with minerals.

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

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

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

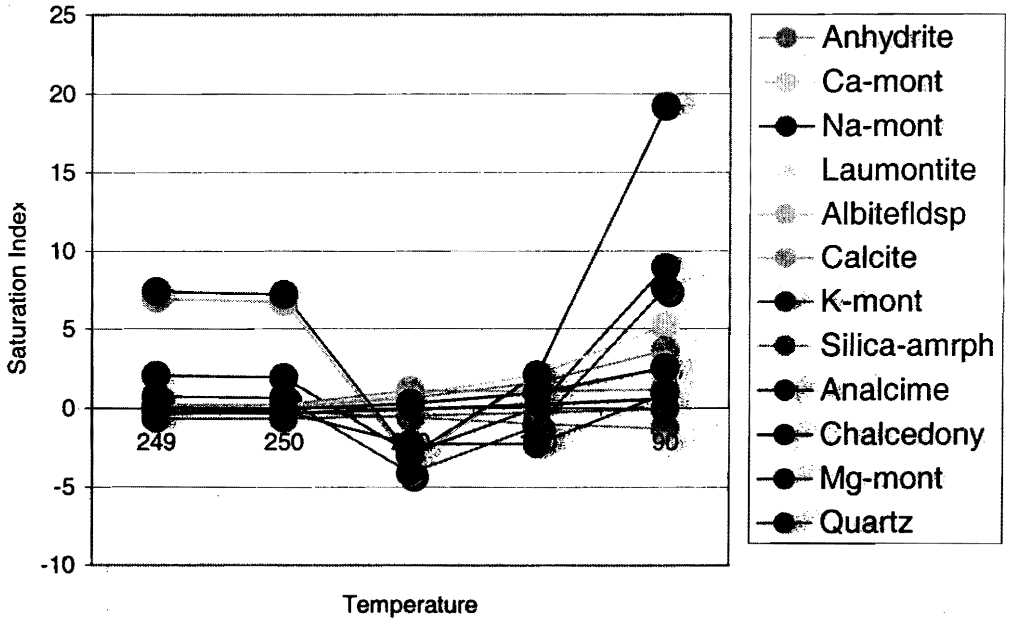

Figure 5: Saturation index versus temperature plot for Habilo hot spring

7. ISOTOPIC COMPOSITIONS OF THE SAMPLED FEATURES

The $\delta^{18}O$ versus $\delta^{2}H$ 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 $\delta^{2}H$ content.

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. Habilo doesn't have flow rate but shows geyseric effect, and the water simply jets up to 1½ meter 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 heavy isotopes as compared to those collected from Metehara and Merti area.

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 Me 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 Welench borehole are all clustered in the WMWL showing that they are meteoric in origin, which impli that they were recently involved in atmospheric circulation, figure 6.

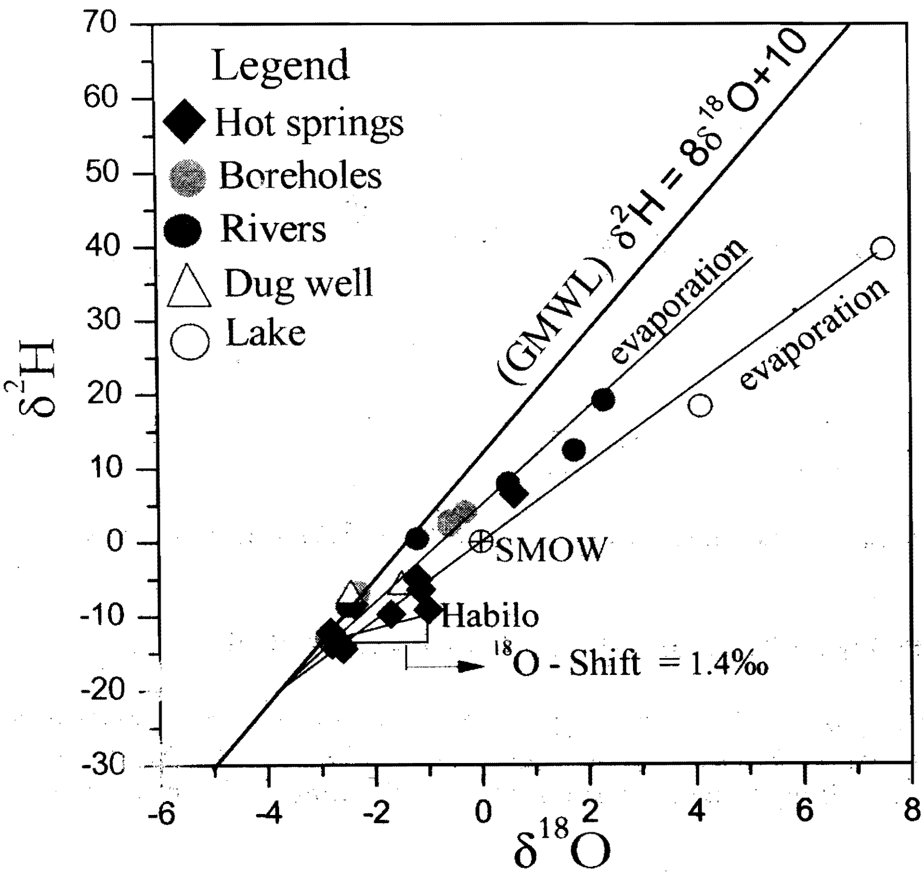

Figure 6: $\delta^{18}O$ versus $\delta^{2}H$ plot for waters from Dofan–Fentale geothermal prospect.

MARY OF RESULTS AND RECOMMENDATION

in results of the geochemical and isotopic studies of the features of Dofan-Fantale mal prospect can be summarized as follows:

ng the Lngeler Ludwig diagram, the water chemistry suggests the existence of Na/SO4-Cl, HCO_3 and $CaHCO_3$ water types in the study area.

e deep reservoir temperature determination using the Na/400-K/10-√Mg ternary diagram ve shown an equilibrium reservoir temperature of 180°C. The SiO_2 (quartz with no steam ss) and the Na-K geothermometers have estimated 224 and 252°C for equilibrium reservoir mperature respectively for Habilo thermal spring.

he saturation index versus temperature plot for Habilo thermal spring has revealed that most f the common hydrothermal minerals are over saturated at ~100°C at atmospheric pressure nd they are found to be in equilibrium with the reservoir rock at ~250°C at depth.

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

Therefore, it is recommended further geophysical study and drilling of TG-wells around Habilo thermal spring.

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