Geochemical and Isotopic Study of North Lake Abaya geothermal Prospect

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ABSTRACT

Abaya geothermal prospect is one of the geothermal fields in Ethiopia that was recommended for further study by the UNDP (1973). It is located about 500 km south of Addis Ababa in the southern part of the Lakes District, Main Ethiopian Rift. It is named after the Abaya Lake which is 6º 15`N 37º 55`E that occupies a tectonic depression in the Rift floor, because most of the thermal springs are located around the lake shore.

Twenty water samples that include thermal springs, cold springs, a lake and rivers were collected in the area of study of which most are near neutral to slightly alkaline in pH. According to the Langelier Ludwig diagram the water chemistry suggests the existence of NaCl-HCO_3 and $NaHCO_3$ water types. The reservoir temperature as shown in the Giggenbach ternary diagram indicated an equilibrium temperature of 250ºC and 180ºC for Wache and Bolocho hot springs respectively. Furthermore the ternary diagram has indicated that Wache and Bolocho are in the quasi equilibrium zone.

Soluble constituents in association with Cl may be used to determine whether the system contains one or several aquifers, therefore from the Cl versus B, Cl versus Na and Cl versus SO_4 plot it was possible to observe the existence of two types of aquifers. The δ^2H versus $\delta^{18}O$ plot has revealed "^{18}O-shift' of 1.5‰ for Wache spring which might indicate higher circulation period and longer residence time. Others are shown to cluster in the GMWL (Global Meteoric Water Line) showing that they are meteoric in origin which implies that they are recently involved in the hydrologic circulation.

1. INTRODUCTION

This paper mainly focuses on deep temperature determination and water type identification of the Abaya geothermal prospect, figure 1.

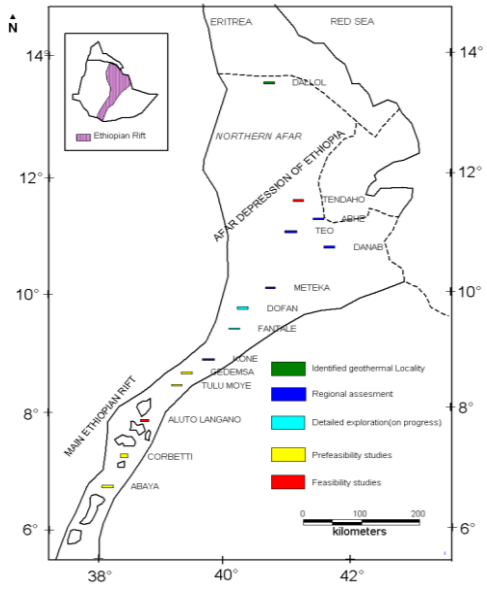


Figure 1: Location map of Abaya geothermal prospect

The thermal springs emerge close to the permanent water bodies i.e., Lake Abaya and Bilate River. The most spectacular hot springs are located on the North West shore of Lake Abaya, where north-north east trending regional faults border the lake (UNDP 1973). For the purpose of geochemical and isotopic investigation of the area twenty water samples were collected in duplicate for chemical and isotopic analysis. These samples include thermal springs that have temperatures (37 - 95ºC) and medium to high flow rate. The cold spring has a temperature of 19ºC and having variable flow rate that is high during the rainy season and low during the dry season. The rivers sampled are all

perennial and having good flow rate. The lake sample was collected from Abaya Lake, the largest of all the lakes in the Lakes District, Main Ethiopian Rift.

2. OBJECTIVE OF THE STUDY

The objective of the geochemical study is to investigate the geothermal potential of the area in order to supply geochemical information that helps in selecting sites for future drilling of exploration wells together with geological and geophysical information.

3. SAMPLING TECHNIQUES AND ANALYTICAL METHODS

3.1 Sampling Techniques

The nineteen water samples that were collected in the study area include 15 thermal springs, one cold spring, 3 rivers and one lake water sample as well.

Spring samples were collected from relatively appreciable flows that remain constant throughout the year. River samples were collected from the central portion of the channel. The lake sample was collected by deepening the sample vessel to approximately 50 cm, and at a distance of 10 meters from the lake shore.

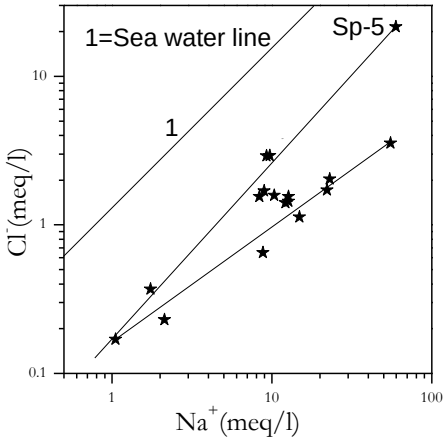
3.2 Analytical Methods

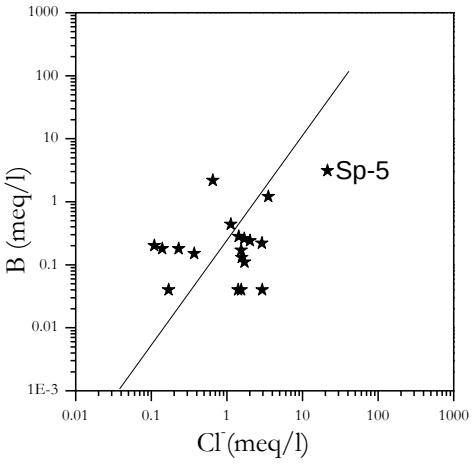
The isotopic ratios $^{18}O/^{16}O$ and $^{2}H/^{1}H$ were analyzed at the Isotope Hydrology Laboratory, IAEA, in Vienna. The isotopic results are reported in per mill (‰) deviation with respect to the Vienna Standard Mean Oceanic Water (VSMOW), with uncertainty levels of ±0.1 and ±1.0‰ for ^{18}O and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

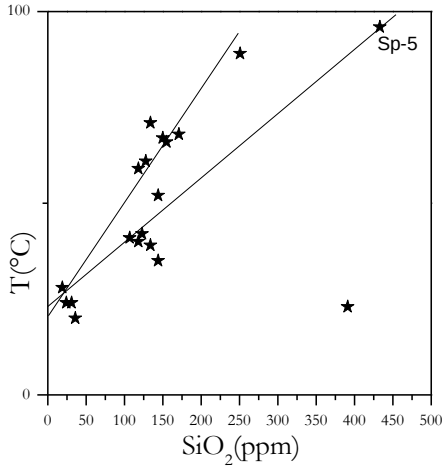
Chemical analysis of the major and minor ion compositions were carried out in the Geological Laboratory of the Geological Survey of Ethiopia and reported in parts per million (ppm).

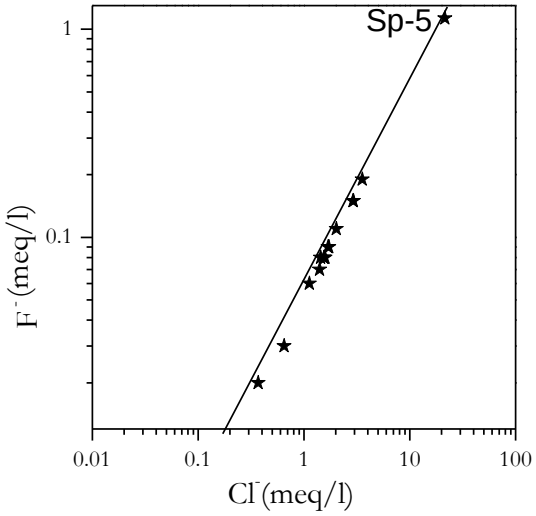
4. CHEMISTRY OF THE SAMPLED FEATURES

The assessment of the chemistry of the thermal and cold water 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 near neutral to slightly alkaline in pH. Wache is the most vigorous hot spring in the area, located on the north-west shore of Lake Abaya. Its pH is alkaline, 9.6. It has comparatively high Cl (762ppm), and high TDS (total dissolved solids) value (2860mg/l), Its SiO_2 content (433ppm) is the highest in the Lakes District (UNDP-1973). The Bilate hot springs have relatively low Cl (50-55ppm) and low SiO_2 (130-150ppm). Where as Bolocho spring has relatively higher Cl (126ppm) and SiO_2 (251ppm). The cold spring, the river samples and the lake sample have low ion composition, but Abaya Lake has rather higher HCO_3 content (477ppm). Soluble constituents in association with Cl may be used to determine whether the system contains one or several aquifers, Ellis and Mahon (1977). Therefore from the Cl versus Na, Cl versus B and SiO_2 versus T°C plots it might be possible to observe the existence of two types of aquifers, see figures below (figure 2). Besides the F versus Cl plot indicates that there is a good correlation of the respective constituents, see figure below.









5. WATER TYPE IDENTIFICATION

5.1. Langelier Ludwig Diagram

According to the Langelier Ludwig diagram fig. 3

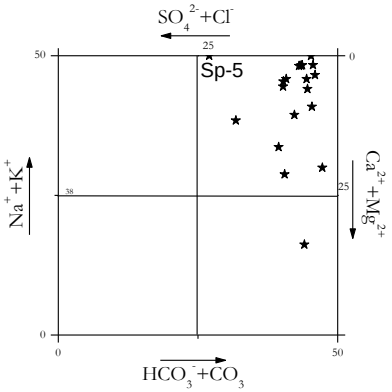


Fig 3: Langelier Ludwig plot for Abaya water samples

the water chemistry suggests the existence of two major water types, in the Abaya geothermal prospective area, namely: NaCl-HCO_3 and $NaHCO_3$ waters.

5.2. Cl-SO4-HCO3 Diagram

This is mostly applied to geothermal waters in relation to the application of geothermometers, as shown in figure 4 below.

1) The near neutral to slightly alkaline in pH waters with relatively high Cl content that plot along the Cl-HCO_3 axis close to the Cl quadrant are favored in the application of geothermometers.
2) The waters that are more alkaline in pH and with high HCO_3 content are not important in the application of geothermometers. As a result only the thermal springs are used in the application of geothermometers.

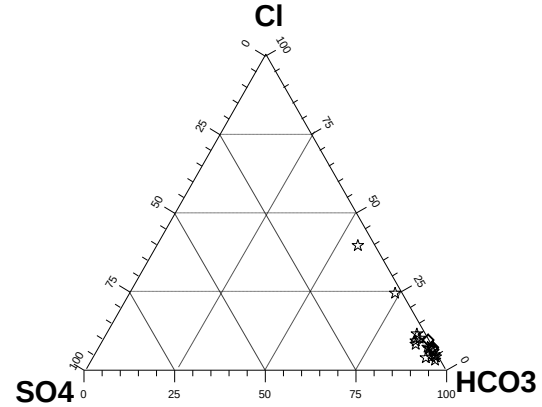


Fig 4: Cl-SO_4-HCO_3 plot for Abaya water samples.

6. DEEP TEMPERATURE DETERMINATION

One of the important parameters to know in the assessment of thermal systems for practical use is the actual temperature of the reservoir, (Giggenbach and Goguel 1989). For doing so the application of chemical geothermometers is inevitably very essential.

The high Na/Ca (6850), (1154) and low Na/k (7.8), (19.2) ratio for Wache (Sp-5) and Bolocho respectively, qualitatively indicate high reservoir temperature. The graphical presentation of the Giggenbach geothermometer Na/1000-K/100-√Mg, figure 5, has indicated equilibrium temperature of 250ºC for Wache (Sp-5) hot spring and 180ºC for Bolocho hot spring. The SiO_2 geothermometer (quartz) with no steam loss, D'Amore (1999) has also given 220ºC for Wache which might suggest that there is no sea water interference. Furthermore the ternary diagram has shown that Wache and Bolocho are in the quasi equilibrium zone.

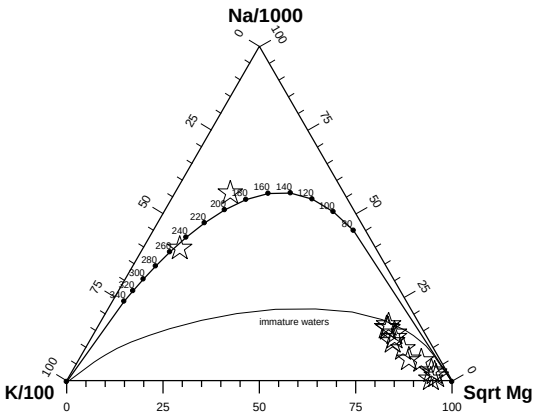


Fig 5: Na/1000-K/100√Mg plot for Abaya water samples

7. ISOTOPIC COMPOSITION OF THE SAMPLED FEATURES

The $\delta^{18}O$ versus $\delta^{2}H$ plot for the water samples collected from the Abaya geothermal prospect is given in figure 6. The isotopic composition shows that the water features have not been subjected to evaporation effect. As a result they are all shown to cluster along the GMWL, revealing that they are meteoric in origin which implies that the waters have been involved recently in the hydrologic cycle.

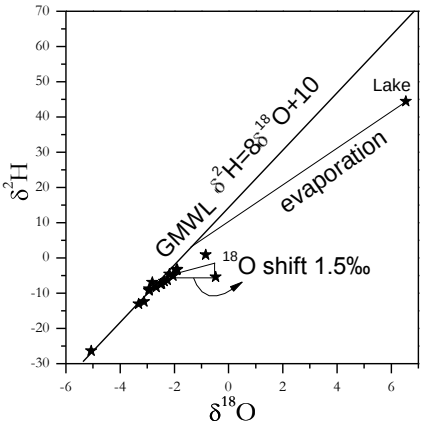


Figure 6: $\delta^{18}O$ versus $\delta^{2}H$ plot for Abaya water samples

The isotopic composition of Lake Abaya shows surface evaporation effect, resulting in disequilibrium enrichment of $\delta^{18}O$ and $\delta^{2}H$ content. Wache spring has shown ^{18}O-shift which probably indicates an exchange of ^{18}O with rocks having higher $^{18}O/^{16}O$ ratio with respect to the original source water. The ^{18}O-shift is in the order of 1.5‰ which might indicate higher circulation period and longer residence time as well.

8. SUMMARY OF RESULTS AND RECOMMENDATIONS

The main results of the geochemical and isotopic studies of the water features of Abaya geothermal prospect can be summarized as follows:

1) Using the Langelier Ludwig diagram the water chemistry suggests the existence of NaCl-HCO_3 and $NaHCO_3$ water types in the area of study.

2) The deep temperature determination using the chemical geothermometers and the Na/1000-K/100-√Mg ternary diagram have shown 250ºC for Wache (Sp-5) thermal spring, The SiO2 geothermometer (quartz with no steam loss) has given 220ºC for Wache (Sp-5) which implies that there is no sea water interference. Furthermore the Na/1000-K/100-√Mg ternary diagram has indicated that both Wache and Bolocho thermal springs are in the quasi equilibrium zone.

3) The different plots such as Na versus Cl, Cl versus SO4, and Cl versus B have shown a clue of the possible existence of two different aquifers.

4) Wache (Sp-5) thermal spring has shown ^{18}O-shift in the order of 1.5‰ which might indicate higher circulation period and longer residence time.

5) Therefore as far as the above results are considered it might be possible to recommend that further geophysical and drilling of TG-well (Temperature Gradient) to focus on Wache area followed by Bolocho.

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