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Evaluation of Past Hypothesis on Recharge of the Tendaho Geothermal Field, Ethiopia

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ABSTRACT

The Tendaho geothermal field is located in the Afar triangle (Northern Afar) about 700km northeast of Addis Ababa within the Dupti cotton plantation. The Afar triangle is an area of active extensional tectonics and basaltic magmatism from which the Gulf of Aden, the Red Sea and the Ethiopian rift systems radiate. Normal faults and open fissures are the principal elements of the Afar tectonics. These phenomena are exhibited by lineaments of hot springs, warm springs and mud pools.

In the Tendaho Geothermal Field, three deep (1811m-2100m) and three shallow (466m-516m) exploratory wells were drilled, four of which (one deep and three shallow wells) were found to be potentially productive. These productive wells supply sufficient steam to produce about 3 MWe.

The main purpose of this work is to evaluate the different hypotheses given previously regarding the recharge of the Tendaho geothermal field.

In order to evaluate the given hypotheses, previous work and data was reviewed and water samples collected for chemical and isotope analysis with the aim of getting full information about the Tendaho geothermal system. After using different chemical and isotopic techniques, the following conclusions are given: both the chemical and the isotopic constituents of the waters of the Lakes District are different from the waters of Northern Afar and have no imprint of genetic relation with the waters of Northern Afar.

1. INTRODUCTION

Exploration of geothermal resources in Ethiopia started in 1969 under a joint Ethiopian Government - United Nations development program. The survey (UNDP, 1973) proved the existence of high temperature geothermal resources along the Ethiopian Rift Valley that could be harnessed for electric power generation, and identified numerous geothermal prospects (Fig.1). Three major geothermal prospect areas were pinpointed in Ethiopia - Lake District, Tendaho and Dalol area in the Danakil depression.

Exploration work peaked during the early to mid-1980s when exploration drilling was carried out at Alutu Langano. Eight exploratory wells were drilled with 4 of these proving productive. During the period 1993-98, exploration drilling was also carried out at Tendaho. Three deep and three shallow wells were drilled and geothermal fluids encountered in the 200-600m-depth range.

The Aluto Langano Geothermal Pilot Plant is located on Aluto Volcano in the Ethiopian Lakes District of the East African Rift Valley between Lake Langano and Ziway, about 220km South of Addis Ababa.

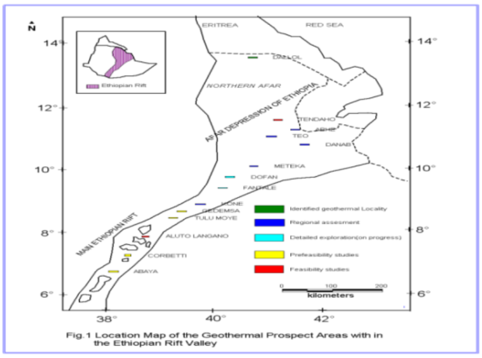

Figure 1: Location map of the geothermal prospect aras within the Ethiopian Rift Valley

The recharge for Tendaho Geothermal Field is the main interest of this work. The Tendaho Geothermal Field covers an area of about 4000km^2 in the NE part of Ethiopia, some 650km from the capital, Addis Ababa, within the Tendaho graben in the inner part of the Afar depression. Between 1993 and 1998 six exploration wells were drilled in this area in two phases. Three deep wells, to a depth of 2200m. and one shallow well, to a depth of 500m were drilled in the first phase from October 1993 to May 1995. Two more shallow wells were drilled in the second phase from December 1997 to February 1998. Of these, one deep (TD2) and three shallow wells (TD4, TD5, TD6) are productive wells. These productive wells can supply sufficient steam to produce about 3 MWe.

Rifting, to which the existence of the Ethiopian geothermal fields are related, began in the Afar region during the Lower Miocene. The Afar depression is believed to have reached its present geological setting during the Pleistocene. Intense tensional tectonics affects the entire depression, thus forming a complex mosaic of horsts and grabens that are still active and contain localized sedimentary basins. The rift is filled with lacustrine and alluvial deposits and with post-stratoid basalt flows. In the Tendaho geothermal prospect, both active and extinct, hydrothermal activity is present. The extinct hydrothermal activity is indicated by silica deposition within NW to NNW sub-vertical fractures cross-cutting the rift sediments. Active surface manifestations are represented by steaming grounds, mud cones and fumaroles at Dubti, as well as silica sinter and hot springs at Alalobeda (Aquater, 1995, 96). In 1969-70, water samples were collected from the northern Afar region for chemical and isotopic analyses (Gonfiantini et al., 1973). Later, Craig (1977) conducted a regional chemical and isotopic study covering almost the whole of the Ethiopian Rift Valley. Environmental isotopes of 18O, D, tritium, 4He, 14C and 13C were analyzed and interpreted. Craig confirmed the presence of a high temperature deep circulating geothermal fluid that could be used for electric power generation.

The Tendaho Geothermal Field was the second to be drilled after the Aluto Langano (Teklemariam, 1996; Gizaw, 1989). In 1979, Aquater, began detailed geological, geophysical and geochemical surveys including a regional isotopic study held in 1994 as well as monitoring the deep Tendaho wells. The isotopic information highlighted that the recharge of the geothermal reservoir in the Tendaho Graben originates in the Western Escarpment and Plateau (elevations from 2000 to 3000 m a.s.l.), without significant contribution from local recharge. Long residence times were confirmed by the absence of tritium.

Panichi (1994) reviewed all the available isotopic and chemical data during his mission as an IAEA project expert. He interpreted chemical, 18O, D and tritium data from the entire Ethiopian Rift and hypothesized that the Lakes District in the south region could recharge the Tendaho Graben. Teclu (1995) pursued this study using the stable isotope and chemical data samples collected from the western escarpment and the southern Afar region and reached the same conclusion as Panichi (1994). Ali (1998) continued the interpretation of the chemical and isotopic data from the northern Afar region during his training in the International Institute for Geothermal Research, Pisa, Italy. He however hypothesized that more than one recharge area could contribute to feed the Tendaho geothermal system and recommended further studies to confirm this possibility.
The main purpose of this work is to evaluate the consistency of the different hypotheses stated in the above paragraphs, regarding the recharge of the Tendaho Geothermal Field.

2. DATA SELECTION

A total of 304 water chemical analyses raw data was taken from the archive of Geological Survey of Ethiopia (GSE) from Aquater (1996) and Panichi (1994).

The chemical analyses were carried out at the Central Laboratory of the Geological Survey of Ethiopia (CLGSE). Isotope analyses for δ2H, δ18O and tritium were performed by the Isotope Hydrology Section, International Atomic Energy Agency (I.A.E.A), and Vienna, Austria.

After reliability checks using the ion balance to select the proper data to use for this particular work, 229 data sets within the normal range of ±5% were selected.

To organize the data it was initially compiled on EXCEL and then imported in AQUACHEM 4.0 using proper importing procedures.

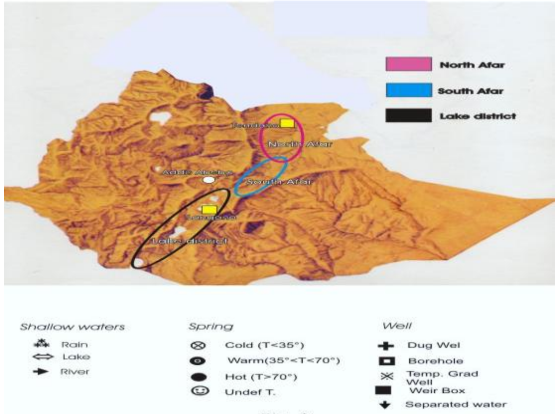

Fig.2

Figure 2: Three different colors given to localites to separate data

3. WATER CHEMISTRY

To interpret these huge set of data, I tried to observe general similarities and differences at a regional scale. The chemical compositions of cold, warm and hot springs as well as geothermal waters are examined using some relevant diagrams. Three different colours are used to differentiate symbols of water samples from the different localities - black for Lakes District, blue for Southern Afar and red for Northern afar (see figure 2).

Figure 3 shows the plotted data, of all types of features in all the three areas, presented in a Piper diagram. Most of the waters from the Lakes District appear to be the Na-HCO_3 type of water. There is the presence of high chloride in the hot springs and geothermal waters of these localities which are dominated by the carbonate ion and shifting towards the direction of Na-Cl vertex could not be observed. This high bicarbonate observed in Lakes District is mainly due to the contributions of CO_2 degassing from magma (UNDP 1973). Generally the large scattered points of the Northern Afar ground waters are diluted waters of the Ca/Mg-HCO3, Na-HCO3 and Na-Cl type water, with the exception of the geothermal and the Alalobeda hot springs water that clustered on the Na-Cl vertex. Samples from the Southern Afar appeared to be intermediate water of the two localities. These discontinue shows that the Lakes District water has no dominant effect on the northern afar region

Table 1: Numbers of total data collected per locality and selected data in the proper range of (±5 %.)

Prospect Areas	Total Chemical Data taken	No. of samples within 5% error	2H and 18O	Tritium	Sampling years
Lakes District	110	71	63	55	1982-1999
Southern Afar	50	43	25		2000
Northern Afar	144	115	114	66	1990-2003

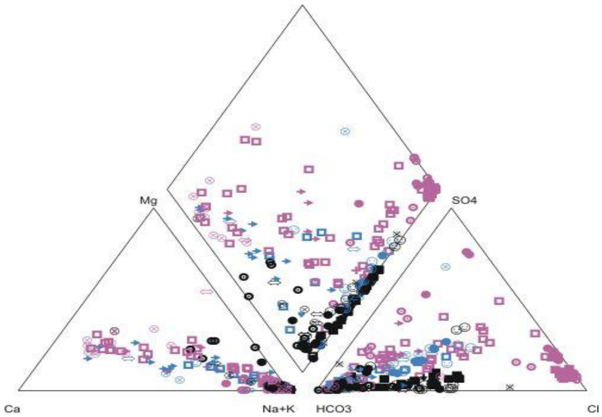

Fig. 3

Figure 3: Piper diagram for all data

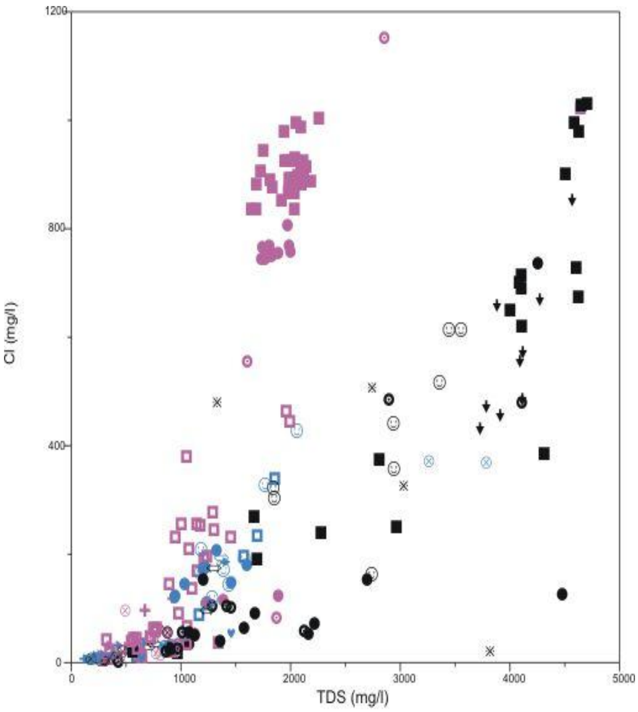

Fig.4

Figure 4: Chloride Vs TDS (Concentation in ppm)

It is also worth observing the similarities of chloride in the two localities as shown in Figure 4 - the geothermal waters of both the Aluto Langano and Tendaho areas exhibit similar Cl concentration, but quite different TDS. In addition the high difference in concentration of bicarbonate as depicted in Figure 5 could lead to fact that, the Lakes District area has different groundwater circulation compared to others. The sulphate content of the geothermal waters of both localities, the Langano and Tendaho, are almost similar (see Figure 6) to their chlorides in Figure 4. These similarities may indicate the possibility of independent evolution of both localities within their own time - the existence of different groundwater circulation and different evolution trends of these areas. It is also better to observe the big difference in conservative ions such as Na, K and Cl shown in Figure 7 and the high disparity of F vs. Ca contents as shown in Figure 8. The F concentration of Lakes District, mainly associated with geothermal waters, is 10 to 100 times greater than that of the Northern Afar region

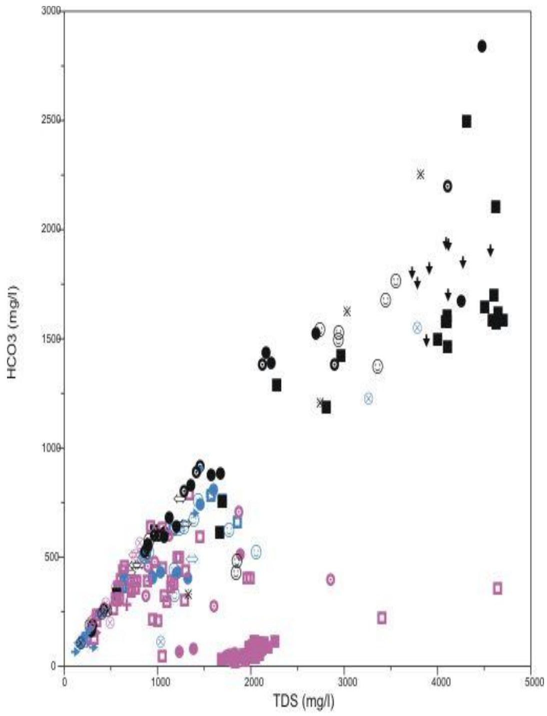

Fig.5

Figure 5: Bicarbonate Vs TDS(Concentation in ppm)

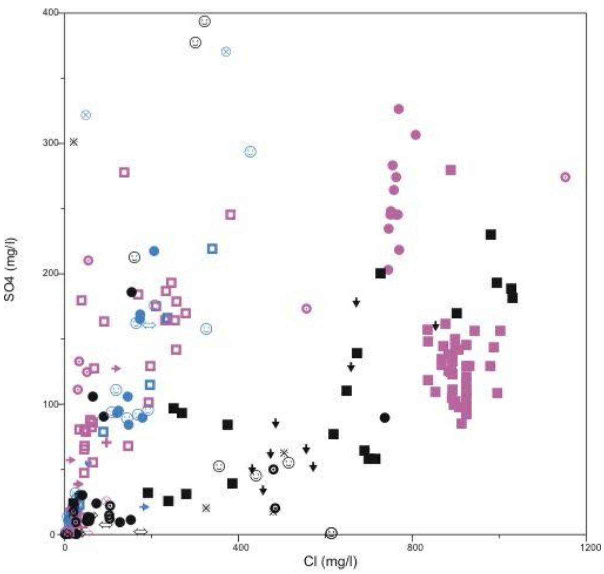

Fig. 6

Figure 6: Sulphate V Chloride

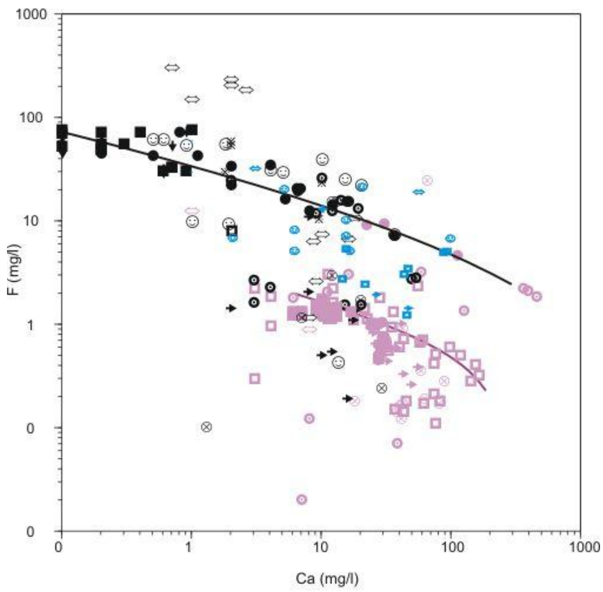

Fig.8

Figure 8: Floride Vs Calcium

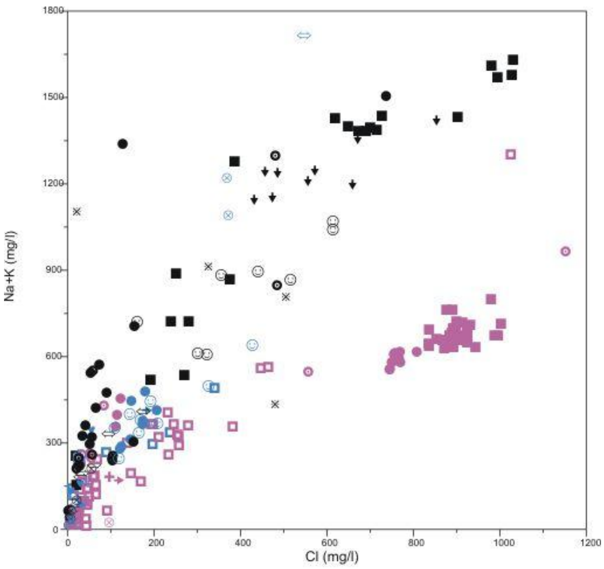

Fig.7

Figure 7: K+Na Vs Chloride (Concentation in ppm)

4. ISOTOPE

Besides the chemical data, the environmental isotopes are essential in defining the recharge area and in observing the degree of water-rock interaction in geothermal environment. Figure 9 shows δD vs. $\delta^{18}O$ for the considered waters excluding the lakes and rivers. In this figure the data is plotted relative to two lines: that of the mean world meteoric water line (MWML $\delta\ D=8\ \delta^{18}O+10$) and a local meteoric water line (LML = $\delta\ D=5.6\ \delta\ ^{18}O+5$). This LML is very similar to that suggested in Panichi's report, and a significant number of data-points well aligned to it; and the Northern Afar waters depict a value of $\delta\ D > 0$.

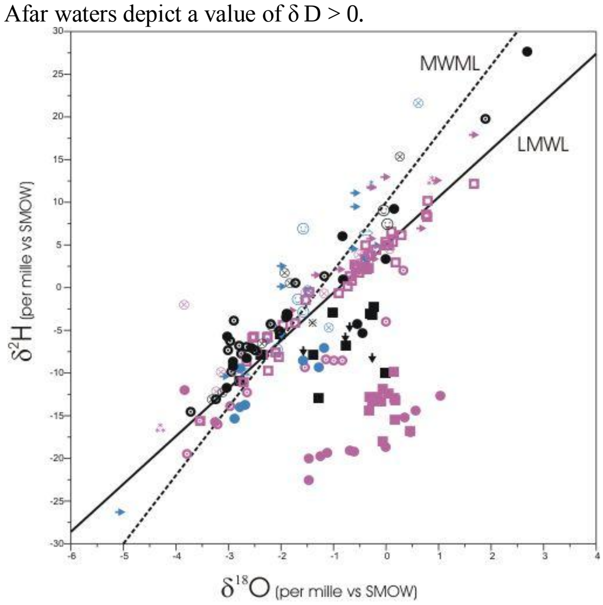

Fig.9

Figure 9: δD vs. δ18O

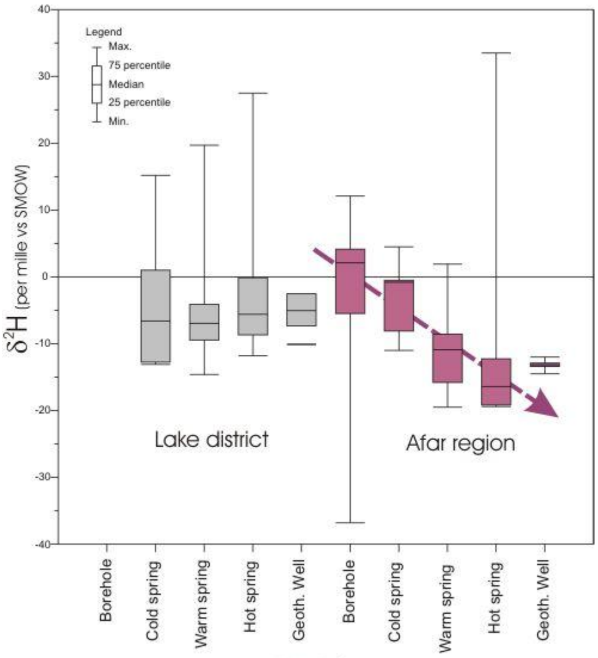

Fig.10

Figure 10: comparison of Lake District and Northern Afar regions

The horizontal shift shows that both the geothermal water groups are affected by a significant oxygen shift. This oxygen shift also characterized by the Allalobeda hot springs which, have the most negative deuterium content, has a trend towards the waters of the Tendaho geothermal waters. It is also worth noting that three samples from well TD2 match the isotopic composition of this group of spring suggesting a possible link between the Tendaho geothermal reservoir and the springs. However, the Aluto Langano geothermal waters show deuterium content greater than that of the Tendaho geothermal wells.

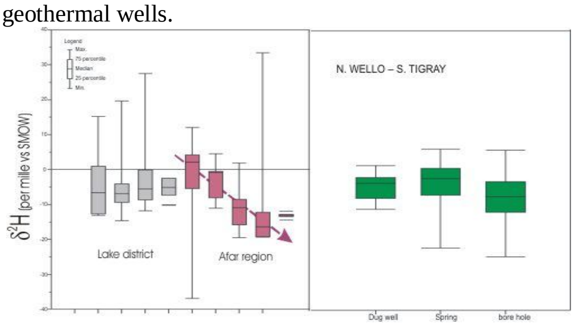

Fig. 11

Figure 11: Comparison of the Lake District and Northern Afar characteristics with those of Northern Wello and Southern Tigray

Figure 10 shows the comparison between Lake District and Northern Afar regions. Unfortunately only 14 data are available for wells and springs of the Southern Afar which is insufficient for a statistical approach.

The waters from the Lake District show a deuterium content generally in the range of -12 to 0 with practically a constant value of the median. The Northern Afar region groundwater circulation exhibits a clear trend which is characterized by decreasing deuterium content with the increasing supposed depth. It is worth noting once again that the water from Tendaho geothermal wells like those of the hot springs of Allalobeda have a deuterium significantly lower than all the other considered groundwaters.

Useful indications derived by comparing the Lake District and Northern Afar characteristics with those of Northern Wello and Southern Tigray are highlighted in Figure 11. The deuterim content of Tendaho and Alalobeda springs are similar to a minority of the samples found in these two regions suggesting possible recharge from these areas. However, as indicated in Figure 12 no relationships between the deuterium content and elevation are distinguishable at the present.

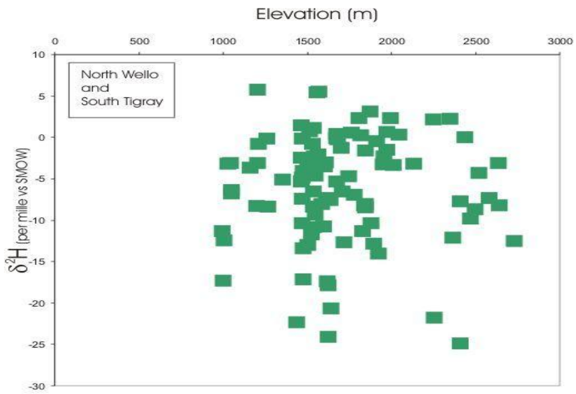

Fig. 12

Figure 12: Relationship between the deuterium content and elevation

5. CONCLUSION AND RECCOMANDATION

In view of the chemical and isotopic data, the waters of the Lakes District have no imprint of genetic relation with the waters of Northern Afar. However further and more detailed studies are recommended.

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