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ISOTOPIC AND GEOCHEMICAL STUDY FOR RECHARGE IDENTIFICATION OF TENDAHO GEOTHERMAL FIELD, ETHIOPIA

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ABSTRACT

Isotopic and geochemical investigations have been carried out in order to identify the recharge area of the Tendaho geothermal field. Tendaho was one of the geothermal fields recommended for development by UNDP, (1973). The Awash River, which is one of the largest rivers in the country, flows from the highland to this large plain lowland area. Therefore, the Awash River makes the area attractive for agricultural development mainly for irrigating of cotton, and the energy demand is growing strongly. It is believed that developing the geothermal resource can solve the energy problem and therefore four wells were drilled and a permeability problem was observed. To study the hydrology the area between latitudes N 8°36'30" and N11°10'00" and between longitudes E39°5'30" and E 41°17'30" which encompasses Southern Afar, part of Northern Afar and the Western Escarpment was selected. Deuterium ^{2}H,^{18}O and geochemical investigation of the study area proved that there exists a regional underground flow, which starts from Lakes District and through the Southern Afar reaches the Tendaho graben. During this process waters evolve towards "mature", water dominated by chloride ions. Similarly the large ^{18}O shift in the Tendaho waters indicates that they have undergone more water-rock interaction process than the more recent waters in the Lakes District. From isotopic study it was also possible to observe that the Mojo-Nazreth-Welenchiti area (south of Southern Afar) might be the source of recharge to the Tendaho geothermal field. Strong oxygen-18 shift was observed in the deep wells drilled in the Tendaho geothermal field. All hot and cold springs as well as the deep geothermal wells sampled during this survey discharge waters near neutral to mildly alkaline pH, with the exception of some which are highly alkaline. Three water types are identified namely, Na-K-Cl, Na-K-HCO_3 and Na-K-SO_4.

1. INTRODUCTION

Thermal waters in Ethiopia have been used for balneological purposes for a long time (Negussie et al 1987). However, the idea of investigating geothermal resources for electric power development originated in the 1960s and investigations started in 1970 with a Joint Ethiopian Government and the United Nations venture. This survey proved the presence of high heat flow in the Rift as a whole and identified numerous geothermal areas (Fig. 1).

The Tendaho geothermal field is located at about 800 km. north east of Addis Ababa. It lies in a northwest trending structural trough in the Afar region, about 50 km wide and more than 100 km long from northwest to southeast (Fig 1). The graben floor at about 480 m.a.s.l. is a barren almost level plain (UNDP, 1973). The graben and surrounding region has an arid climate. Occasional rain, usually as storms, falls mainly during summer (June-Sept.). The lower course of Awash meanders through the graben, and is used for irrigation of cotton plantations at Tendaho, Det Bahari, Dubti and Aysaita. A total of 175,000 hectares is projected for cotton growing. Tendaho Graben, bounded by Loggia Fault on the west and Gamor Fault on the east, is a northwest part of the Afar triangle, Mohr, (1970). Near the intersection of three trends of the East African Rift System i.e. the Ethiopian Rift, Red Sea and Gulf of Aden Rift. In the Tendaho geothermal field northwest and north-north-east trending faults also exist.

Tendaho was one of the geothermal fields recommended for development by UNDP, (1973). The Tendaho cotton plantation enterprise demands energy for its cotton dressing plant and from time to time the energy demand of the region is becoming very crucial. Therefore, in order to solve the energy problem of the area, four geothermal wells were drilled, and two failed to produce steam, which is a hydrological problem.

The Italian Company, Aquater, (1995) performed the drilling and conducted isotope measurements both in the Tendaho and in the western escarpment to study the recharge area after the first well fail to produce steam. The main conclusions were as follows:

1) The complete absence of tritium has been noticed which implies the existence of a long-term circulation of fluids (more than 40 years) from the recharge area.
2) The $\delta^{2}H$ and $\delta^{18}O$ show the effect of water-rock interaction processes at high temperature on the recharge water and the possible presence of a component of different origin, such as magmatic water with an isotopic composition yet to be determined.

The aim of the present study is to identify the recharge area of Tendaho geothermal field. In order to achieve this objective 49 water samples were collected for chemical and isotopic analyses starting from Mojo (south of Southern Afar), up to Tendaho (south of Northern Afar) and the Western Escarpment highland, more to the south than it was done by Aquater. This study was performed during 1995 at the IAEA Isotope Hydrology Section Vienna, Austria. Elevation variation of the study area is very large ranging between 375m a.s.l. in the Tendaho graben to about 3000 m a.s.l. in the Western Escarpment highland.

The physiographic set-up of the area controls the surface run off, therefore rivers, streams, and creeks originating from the highland areas and western escarpment flow to the Rift

Valley where some of them infiltrate and some join the Awash river as tributaries.

2 SAMPLING AND ANALYTICAL TECHNIQUES

2.1 Sampling techniques

The 49 water samples include 23 boreholes, 7 hot springs, 5 cold springs, 4 dug wells, 4 rivers, 2 deep geothermal wells, 2 lakes and 2 precipitation samples.

The borehole samples were collected from hand, electric, or Diesel pumped ones, which are 45 to 190 meters deep and are believed to tap shallow groundwater aquifers. The river samples were collected at the central portion of the channel and are supposed to reflect the accumulated flow from several tributaries and seepages from groundwater. Spring samples were collected from relatively strong flows that remain constant throughout the year and have high temperature in the case of hot springs. Lake samples were collected by deepening the sample vessel to approximately 50 cm and at a distance of 10 metres from the lake shore. Dug wells, which are 6 to 12 metres deep, were sampled from the water level using plastic bucket tied to a nylon rope.

One of the geothermal wells, (ETH-94) was sampled from the water level just like the dug well, since it does not produce any steam, but the second one (ETH-115) was sampled from the weir box while it was discharging. The sample size depends upon the type of constituents to be determined (Giggenbach and Goguel 1989). The samples were stored in polyethylene double capped bottles of 50ml for stable isotopes and 500ml for major chemical analyses. Electrical conductivity and pH were measured in the field.

2.2 Analytical method

The samples collected were analyzed for oxygen–18 and deuterium at the Isotope Hydrology Laboratory, IAEA, Vienna. The isotopic results are reported in per mil deviation from the Vienna Standard Mean Ocean water (VSMOW) with uncertainty levels of ± 0.1‰ and ± 1.0 ‰ for ^{18}O and ^{2}H, respectively, I.A.E.A. (1981)

The chemical analyses for major ionic composition were done at the Chemical Laboratory of the Ethiopian Institute of Geological Surveys and are reported in parts per million (ppm). The pH and electrical conductivity (μs/cm at 25°C) were determined in situ.

3. ANALYTICAL RESULTS

Thermal and cold water chemistry assessment helps in recharge identification. The flow rate of the thermal springs sampled is lower than the cold springs. The hot springs sampled both in the Rift valley and the western escarpment have similar content of cations and anions and also similar conductivity ranging from 1300μs/cm - 1500μs/cm. The depth of the geothermal wells ranges from 1894 to 2000 metres with maximum temperature of 200°C and have relatively high chloride contents of 747 and 805 ppm. The waters have conductivity close to 2800μs/cm, and a comparatively high silica content (640-ppm). The cold springs sampled in the western escarpment highlands have conductivity ranging between 600 and 800μs/cm with the exception of one sample having 81 μs/cm. The cold springs have similar pH values in the range of 6.5 to 7, and low Na, K and relatively high HCO_3 content. The dug wells show higher Na, HCO_3 and Cl content than the hot springs. The conductivity is also relatively high ranging from 1454 to 6387μs/cm with the exception of one sample having only 864μs/cm.

Hot and cold springs as well as the deep geothermal wells sampled during this study discharge waters near neutral to mildly alkaline pH. The scattering of the plots reveals the wide range in composition of these waters in the Piper trilinear diagram (Fig. 2). Therefore, the thermal and cold waters can be grouped into three water types according to the milli equivalent percentages of cations Na, K, Ca, Mg and the anions HCO_3, Cl, SO_4. These include:

1) Na-K-Cl type: these are the deep geothermal well waters, which are perfectly of Na-K-Cl type. The chloride content of the deep geothermal well waters is more than 80 percent and the HCO_3 content is less than 10 percent.

2) Na-K-HCO_3 type: eighty five percent of the waters samples collected in the Rift Valley and in the Western escarpment highland are of Na-K-HCO_3 type. The chloride and sulphate content of these samples mostly varying between 10 to 30 and 10 to 20 percent respectively.

3) Na-K-SO_4 type: these are not common water types either in the Rift Valley or in the Western escarpment highland. Only four percent of the water samples collected are of Na-K-SO_4 type. One is a dug well with a temperature of 30°C in the Rift Valley and the other is a hot spring with a temperature of 68.5°C in the western escarpment highland. The dug well and the hot spring have 12 and 39 percent content of HCO_3 and 38 and 12 percent content of chloride, respectively.

4. RESULTS OF ISOTOPIC ANALYSIS

4.1 Isotopic composition of precipitation

Since 1963 the International Atomic Energy Agency (IAEA) in cooperation with the World Meteorological Organization (W.M.O.) is collecting monthly composite samples of precipitation at Addis Ababa, which is one of the IAEA/WMO precipitation network stations. The samples are analyzed for ^{3}H, ^{2}H and ^{18}O, where the record was not complete but continuous, from March 1965 to December 1993.

The ^{2}H versus ^{18}O plot (Fig. 3) for Addis Ababa performed using the precipitation isotope data which was available from 1965 – 1971, shows deuterium (^{2}H) excess of 15‰ which is about 5‰ enriched in ^{2}H with respect to the global meteoric water line (GMWL), $\delta^{2}H = 8\ \delta^{18}O + 10$.

Therefore, the equation for the local meteoric water line (LMWL) is given as:

$$\delta^2H = 8\,\delta^{18}O + 15$$

With slope of 8, and an intercept of 15.

The weighted mean isotopic composition of Addis Ababa precipitation was determined to be –1.4‰ for ^{18}O and +4.0‰ for ^2H (Craig, 1977).

In the present study an attempt has been made to establish a new meteoric water line using the distribution of precipitation at Addis Ababa for the period 1965-1993. The annual variation of precipitation is very strong. Unfortunately monitoring for isotopes has not been continuous at this station.

The local meteoric water line for Addis Ababa is drawn using the available monthly isotope data of precipitation (Fig 4). Lower slope and higher deuterium excess as compared to the global meteoric water line (GMWL) characterize the line. The equation is given as:

$$\delta^2H = 7.5\,\delta^{18}O + 13$$

With correlation coefficient (R^2) = 0.92 and slope of 7.5. Normally meteoric water lines are fixed to a slope of 8. Therefore to do this, the deuterium excess ($d = \delta^2H - 8\,\delta^{18}O$) was calculated for each precipitation values of ^{18}O and ^2H and the mean was found to be 12.35, thus a new LMWL for Addis Ababa was established to be as:

$$\delta^2 H = 8\delta\,^{18}O + 12.35$$

With slope of 8 and an intercept of 12.35.

4.2 Isotopic composition of surface and groundwater

The 49 samples collected from different features consist of rivers streams, lakes and groundwaters encountered in cold and hot springs, boreholes and deep geothermal wells.

The Awash River sample shows unequal enrichment in ^{18}O and ^2H being shifted to the right of LMWL, due to evaporation which takes place in the Koka dam reservoir up stream. This effect becomes less pronounced down stream due to the contribution of unevaporated surface runoff waters originating from the eastern escarpment that join the Awash River.The isotopic composition of the ground-water samples ranges from –5.84‰ to +3.4‰ for ^{18}O and from +4.37‰ to –22.4‰ for ^2H. The isotopic composition of the deep geothermal wells show clearly "^{18}O –shift" due to exchange of ^{18}O with rocks having higher $^{18}O/^{16}O$ ratio in relation to the original source waters (Fig. 5). ETH-115 shows a well defined "^{18}O –shift" in the order of 3.75‰ whereas the "^{18}O –shift" of ETH-94 is only 2.17‰ indicating relatively shorter circulation time and/or lower water - rock interaction. The isotopic composition of Lake Beseka shows strong surface evaporation effect, resulting in dis-equilibrium enrichment in ^{18}O and ^2H content. Moreover, it can clearly be seen (Fig. 5) that the isotopic composition of the groundwater samples from Mojo, Nazreth and Welenchiti (areas in the Southern Afar) are depleted compared to those collected from Awash area. The hot springs in the Western escarpment and in the Rift Valley show similar isotopic composition in the range between -3.85‰ and -2.99‰ for ^{18}O and -18‰ and -20‰ for ^2H. The geographic distribution of bore holes, dug wells, cold springs and hot springs is highly scattered and the elevation difference is significant and therefore the isotopic composition shows strong variation ranging from –1.7‰ to +3.15‰ for ^{18}O and from +1.4‰ to –16.1‰ for ^2H.

5. DISCUSSION AND CONCLUSION

An attempt has been made to identify the possible recharge area to the Tendaho geothermal field by comparing the stable isotope content of the geothermal wells (ETH 94 and ETH 115), with those of the different feature samples from the Rift Valley and the Western Escarpment highland. This has been done using ^{18}O versus ^2H plot by categorizing the different water features into three groups. From the plots it can be observed that: taking the ^2H content as an indicator, the Mojo-Nazreth-Welenchiti area (South of Southern Afar) might be the source of recharge to the Tendaho geothermal field. As can be seen in Fig. 5, the ^2H content of the starting point of the geothermal well water of ETH 115 corresponds well with the cloud of the samples collected in Mojo-Nazreth-Welenchiti area.

The ^{18}O content is similar on both geothermal wells but the ^2H content varies significantly. ETH 94 is enriched in ^2H (-10‰) than ETH 115 (-24‰). The ^{18}O shift is however stronger in ETH 115 (3.75‰) than ETH-94 (2.17‰). ETH-94 might represent a mixture of groundwater in Tendaho area with other sources enriched in isotopic composition, which might indicate that there is some contribution from local infiltration.

As far as the chemical composition of cold and thermal waters is concerned, significant differences between the three regions namely (Lakes District, Southern Afar, and Northern Afar) might be revealed (Panichi 1995).

- Waters in the Lakes District are, except for very few samples, HCO_3 dominated.
- Waters in the Southern Afar show greater variability, ranging from almost pure bicarbonate waters to 60% chloride waters. In the Northern Afar the bicarbonate component appears to be less important, in favor of increasing relative concentrations of both SO4 and Cl ions to reach pure chloride water type. The above observation might help to deduce that there exists a regional underground flow, which starts from the Lakes District and through the Southern Afar reaches the Tendaho Graben geothermal field. During this underground flow from south to north, waters starting, as HCO_3 waters finally become "mature" waters, dominated by chloride ions. Similarly, Tendaho waters appear to be paleowaters. So that a long time has been available for oxygen isotope exchange compared with the waters in the Lakes District, which appear to be of recent origin.

The piezometric surfaces of the Ethiopian Rift (Fig. 6) clearly indicate the main direction of the groundwater flow is from Lakes District to Awash and Danakil Depression basins (UNDP, 1973).

Therefore:

1. The water type of the Tendaho geothermal field is dominantly of Na-K-Cl neutral to alkaline geothermal water.

2. Taking into consideration the isotopic diagram in Fig 5, the hypothesis of the chemical evolution and observing the Piezometric surface and the main direction of groundwater flow of the Ethiopian Rift Valley, it might be possible to conclude that the Mojo-Nazreth-Welenchi area is the source area to the Tendaho geothermal field.

To tackle the complex problem of identifying recharge area to Tendaho geothermal field a preliminary isotopic and chemical study has been used. For future investigation it can be recommended an interdisciplinary study (geochemistry, hydrogeology, meteorology, geology and geophysics) is needed to assess recharge mechanism and regional groundwater movement in the area under research.

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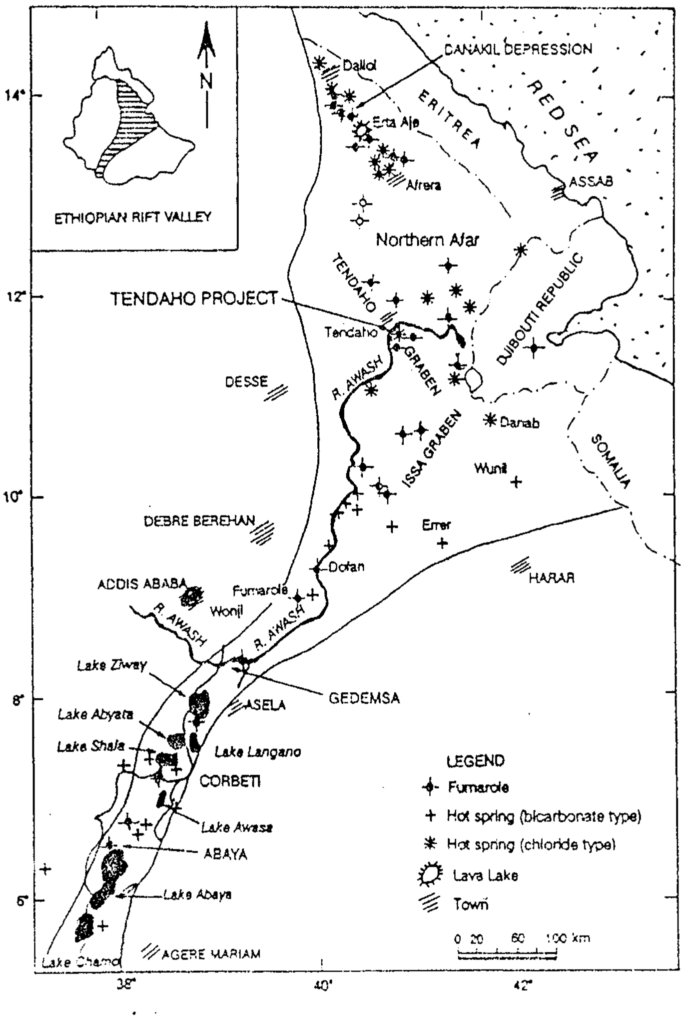

Figure 1. Location of the Rift Valley and the geothermal resource area.

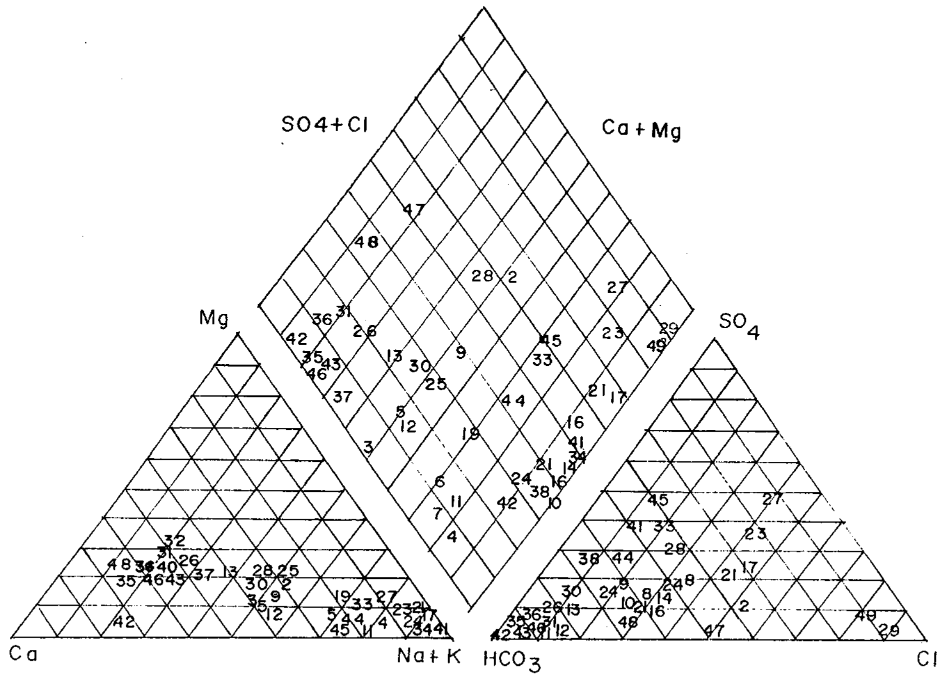

Figure 2. Piper diagram of the chemical analysis of the water samples from the Rift and western Escarpment.

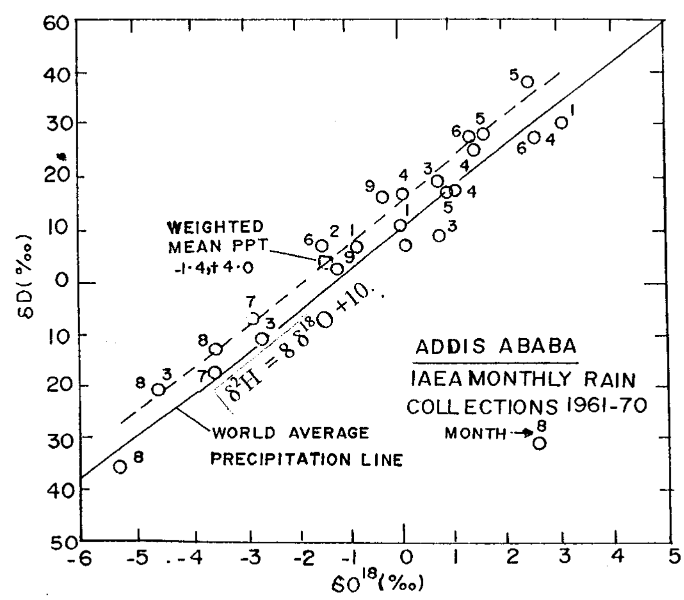

Figure 3. ^{2}H versus ^{18}O plot for Addis Ababa using precipitation data from the period 1965-1971, after Craig (1977)

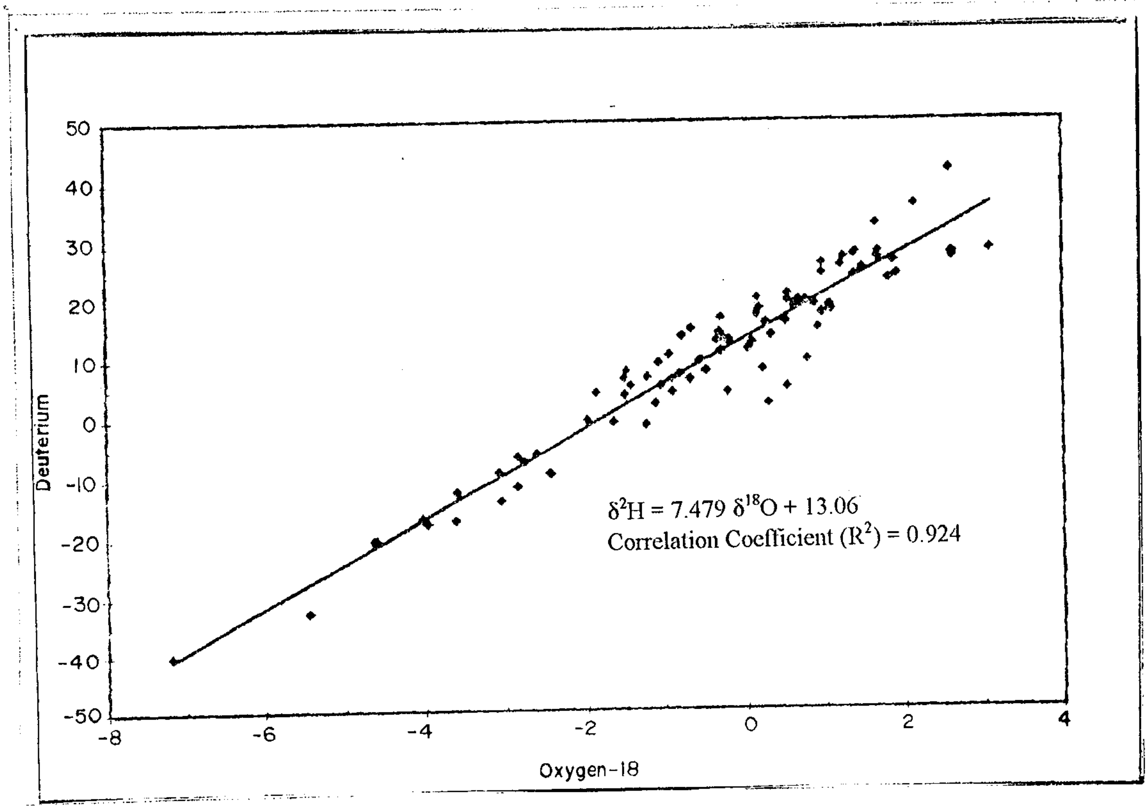

Figure 4. ^{2}H versus ^{18}O plot for Addis Ababa using precipitation data from the period 1965-1991.

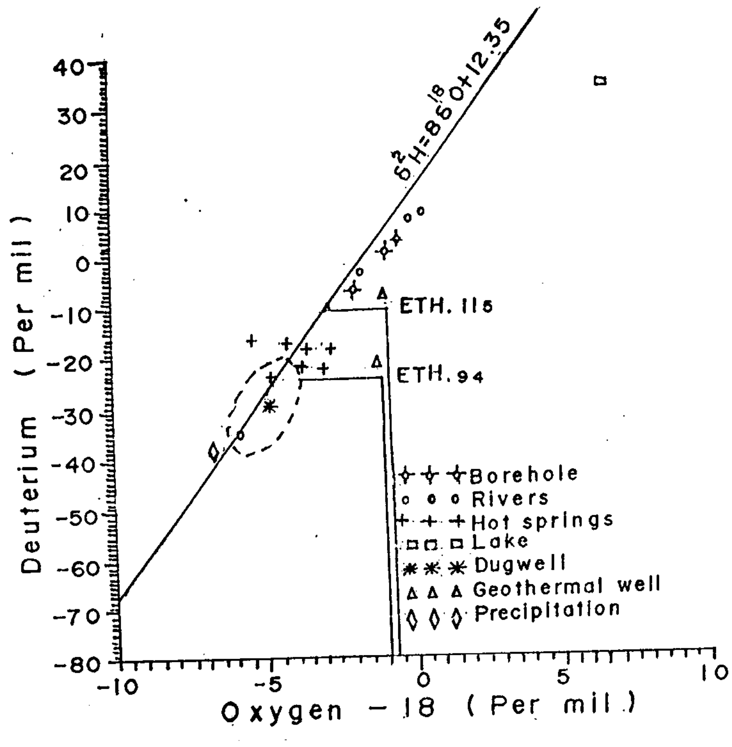

Figure 5. ^{2}H and ^{18}O plot for the samples collected from Mojo upto Awash area together with the hot, cold and geothermal wells.

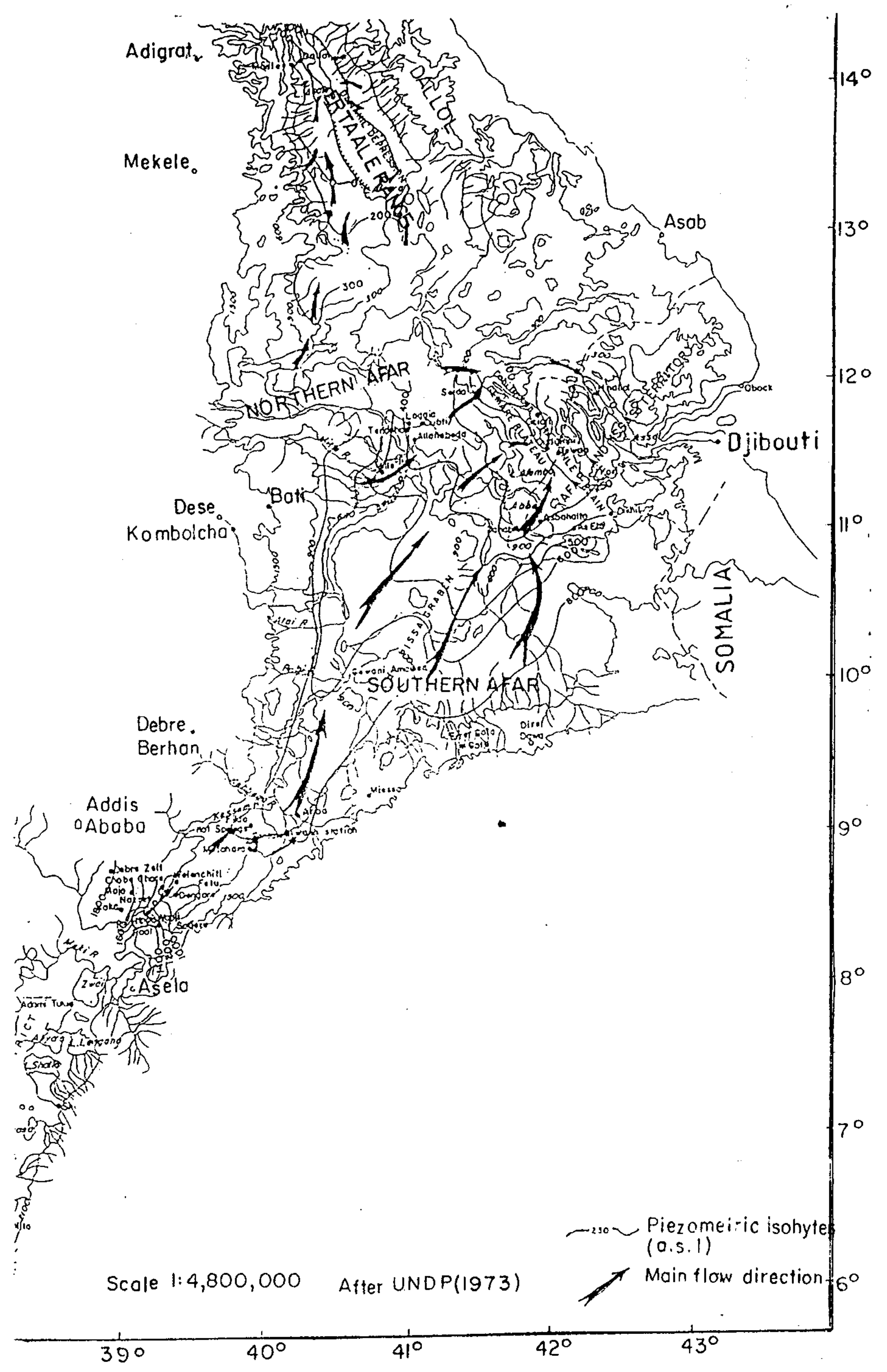

Figure 6. Piezometric surface of the Ethiopian Rift and main directions of groundwater flow, (south to north). From UNDP (1973).