Geochemical Studies of the Tendaho Geothermal Field

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ABSTRACT

The Tendaho geothermal field is located in the Afar triangle (Northern Afar) about 650km northeast of Addis Ababa within 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.

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 objective of the present study is to assess the genetic relationship of the deep and shallow Tendaho geothermal wells with the hot springs present in and around the project area.

A plot of Cl-HCO_3-SO_4 has indicated that waters from the deep Tendaho geothermal wells are a Na-Cl, neutral-to-alkaline geothermal water, whereas the waters from Alalobeda hot springs have similar composition with slightly higher content of SO_4.

Application of various solute geothermometers has demonstrated that the average reservoir temperature of the deep Tendaho geothermal wells is in the range of about 220°C-270°C. Similarly, the temperatures of Alalobeda hot springs are in the range 150°C-220°C. The waters from the deep Tendaho wells were found to be in equilibrium with the reservoir rocks at a relatively higher temperature of about 240°C compared to the Alalobeda hot springs.

1. Introduction

1.1.Background

Exploration of geothermal resources for electric power development startedin 1969 under a joint Ethiopian Government - United Nations development program. The survey proved the existence of a high heat flow that could be harnessed for electric power generation, and identified numerous geothermal prospects (Fig.1). Tendaho was one of the selected prospect areas for further studies(UNDP,1973). The Tendaho geothermal field covers an area of 4000 km^2 in the NE part of Ethiopia, some 650 km 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 two phases. Three deep wells, to a depth of 2200 m. and one shallow well, to a depth of 500 m 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. This work is mainly focussed on the chemical and physical behavior of the recently drilled shallow wells TD-5 and TD-6 and also attempts to define the genetic relations between these wells and the hot springs of Alalobeda. Alalobeda is located about 20 km SW of the Tendaho exploratory wells, and is characterised by the presence of spectacular hot springs with temperatures quite close to the boiling point.The springs cover an area of approximately one km. Samples were collected for chemical and isotopic analyses in 1999,2000 and 2003 for monitoring the wells.

1.2. General Geology of Tendaho

Rifting in the Afar began during the Lower Miocene on a continental arc where important basaltic activity was probably in progress. The Afar depression is believed to have reached its present geological setting during the Pleistocene, with the determination of the axial ridge. 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,1996).

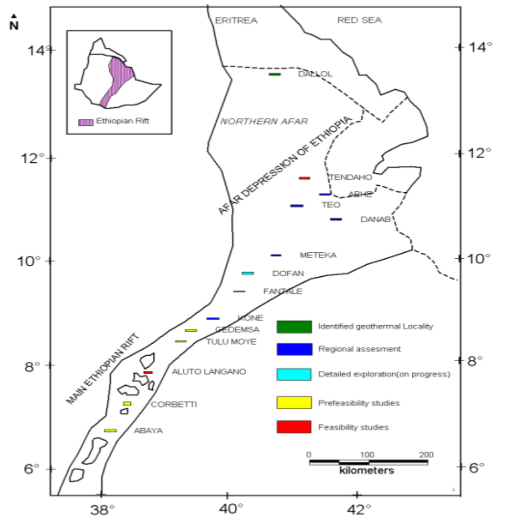

Fig.1 Location Map of the Geothermal Prospect Areas with in the Ethiopian Rift Valley

1.2.1. Lithology of TD-5 and TD-6

The main formations crossed in the upper part of wells TD-5 and TD-6 are sedimentary units with minor basaltic layers. The primary mineral content of the sedimentary rocks are: clay, glass, quartz, calcite, pyroxene and plagioclase, whereas the basaltic rock is made up of glass (ground mass), olivine, plagioclase, pyroxene and iron oxide. Both wells show similar alteration mineral assemblages; these high-temperature indicative minerals are located towards the bottom of the wells (Gebregziabher,1998).

1.3. Previous work

Geothermal exploration in Ethiopia began in 1969 with a regional geological-volcanological mapping and inventory of its manifestations as part of a joint project of the United Nations Development Program and the Ethiopian Government (UNDP, 1973). This regional assessment covered the entire Ethiopian Rift valley and the Afar depression of Ethiopia (Fig.1). During this time (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 ^{18}O, D, tritium, ^{4}He, ^{14}C and ^{13}C were analysed and interpreted. Craig confirmed the presence of a high temperature deep circulating geothermal fluid that could be used for electric power generation. On the basis of different exploration activities, which included geological, geophysical and geochemical investigations, three prospecting areas were selected: (i) Dallol in the Afar Depression; (ii) Tendaho in Northern Afar; and (iii) the Lakes District (Aluto-Langano, Shalla-Corbetti and Lake Abaya) (Fig. 1). Tendaho was the second to be drilled after the Lakes district. In 1980 an Italian company, Aquater, began a 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 above 2000 m), and excludes local recharge. The absence of tritium confirms a long residence time. The main hot springs in Alalobeda have similar isotopic composition to that of the Tendaho wells, which suggests that the Alalobeda geothermal waters are very likely connected to reservoirs linked to hydrological circuits similar to that ofTendaho.

Panichi (1994) reviewed all the available isotopic and chemical data, starting from UNDP(1973), during his mission as an IAEA project expert. He interpreted chemical, ^{18}O, D and tritium data from all of the Ethiopian rift and suggested that the Lakes District in the south region is recharging 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. His main interest was to determine the recharge zone of the Tendaho geothermal field. His conclusion was not far from that of Panichi (1994), and he has recommended further studies on the identification of the recharge area of the Tendaho geothermal field.

1.4. objectives

The main purpose of present study is to:

Obtain further information about the chemical and physical characteristics of the shallow reservoir fluid.

Define the genetic relations between the fluid of the Tendaho geothermal wells and the hot springs of Alallobeda.

3.SAMPLING METHODS

The reliability and usefulness of geochemical data depend on the methods used and the care taken in the collection of samples. The water samples from the deep geothermal wells were taken from a weir box and samples from thermal manifestations were taken as near as possible to the outlet. Water samples for major cations, and (SO_4, Cl) were collected in 125 ml polyethylene bottles and were filtered with a 0.45µm filter membrane using a hand syringe and the cations were acidified with 1:1 HCl while the $SO_{4,}$ Cl were treated with zinc acetate. Water samples diluted (1:5) for SiO_2 were collected in 125 ml polyethylene. Two 500 ml untreated samples were taken for tritium, major anions and boron and 50 ml untreated samples were also taken for ^{18}O and D. All sampling was done after rinsing the bottles with the sampled water and labelling them with the date, feature name, and location.

4. LABORATORY ANALYSIS

All major cations and anions were analyzed by the Central Laboratory of the Geological Survey of Ethiopia (CLGSE). Isotope analyses for δ^2H and $\delta^{18}O$ were performed by the Isotope Hydrology Section, International Atomic Energy Agency (I.A.E.A), Vienna, Austria.

All major cations were analyzed by atomic absorption spectroscopy. Carbonate and bicarbonates were determined by HCl acid titration. Chloride was determined by the Mohr method. Sulphate was determined by turbidimetry and gravimetry depending on whether sample concentrations are low or high, respectively. Fluoride was determined by specific ion electrode. Silica and boron were determined by spectrophotometery, using molybdate blue and carmenic acid methods respectively.

5. RESULTS

The results of the study will be discussed below in terms of (i) water type; (ii) geothermometery; (iii) water rock interaction; and (iv) steam fraction.

5.1. Water type

The major cations are sodium and potassium while chloride; carbonate and sulfate are the main anions as observed from the chemical data analyzed in the CLGSE(Table 1). The water types have been classified in a ternary diagram relative to Cl, SO4 and HCO3(Fig.2). Using the anionic components of a given anion is a convenient means of distinguishing water types and helps us to assess rapidly the water compositions of the fields, as these anions are the most abundant solute components of the fluid. The diagram shows that the discharge fluids of wells TD-5 andTD-6 and also the water of Alalobeda hot springs belong to a typical chloride- type mature geothermal water similar to that produced in other wells at Tendaho. However, the Alalobeda hot springs have a slightly higher about (20%) SO4 concentration. Inorder to verify the hot springs in Alalobeda hydrologicaly connected to that of Tendaho wells their average atomic ratio (Tab.2) are also given. This some similarity of their ratio

could suggests, that they have a common origin.

6. GEOTHERMOMETERY

Knowledge of the sub surface and reservoir temperature is crucial in field management. In order to obtain the reservoir temperature and also to assess the degree of attainment of fluid-rock equilibrium, solute (cation and quartz) geothermometry has been applied(Table 2) and the Giggenbach diagram (1988) has been plotted using relative Na/1000, K/100, √Mg value (Fig. 3).

TD-5: - The temperatures obtained with the quartz geothermometer, assuming conductive cooling, and

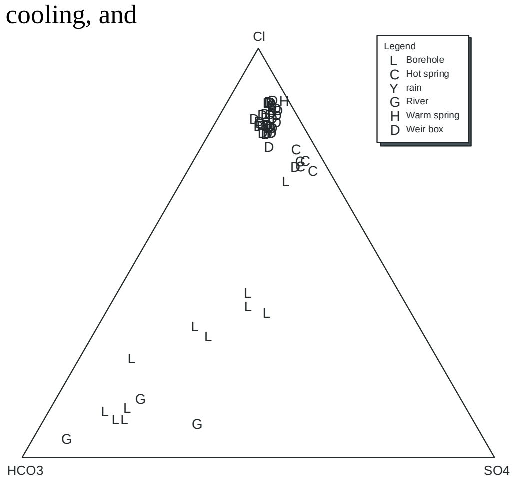

Figure-2 Ternary for waters of Tendaho wells And the surroundings

chalcedony geothermometer, are very similar, giving an average of 274°C and 273°C, respectively, however the quartz adiabatic temperature is lower at an average average temperature of 243°C.

The temperatures obtained using cation geothermometers generally fall in to two sets of values. The values given by Na/K (Giggenbach, 1983) and (Fournier, 1983) which is 270.5°C and 258.5°C are in the same order with the quartz conductive cooling values and slightly higher than the

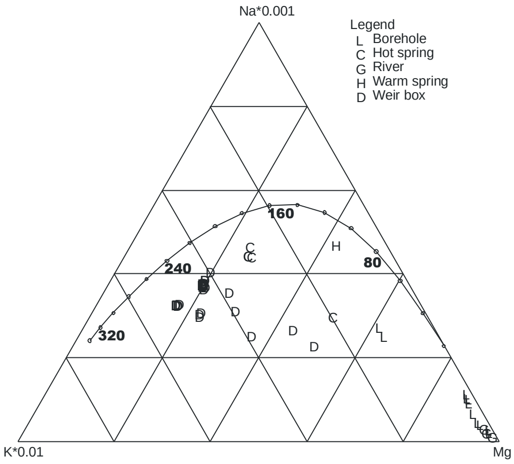

Figure-3 Giggenbach for water of Tendaho wells and the surroundings

measured in-hole temperature. Other Na/K values are in the range 241-253°C, with an average of 246°C, which are in close relation to the quartz adiabatic and measured temperature 248°C.

The TD-6 reservoir temperature, using the SiO_2 and Na-K geothermometers and the Giggenbach triangular diagram varies from 220^0C to 250^0C. These values are in good agreement with in-hole temperature logs.

Alalobeda springs: - The temperatures calculated for Alalobeda springs consist of three distinctive average temperatures 153°C, 182°C and 205°C. The first two values obtained using cation geothermometry while the third is a quartz and Na/K value of Giggenbach, (1983). The first two values are lower than the previous results while the latter one is comparable. At present the reason for these temperature differences is not clear.

7.GIGGENBACH DIAGRAM

In order to assess the degree of attainment of water- rock equilibrium in natural systems within a given temperature, chemical data have been plotted with the relative value of the Na, K, Mg contents, using the ternary diagram of Giggenbach, (1988)(Fig. 3). The extent of water rock interaction is high as is evident in the ternary diagram, since the trend is towards full equilibrium. All the water samples plotted within partially equilibrated zone. The water sample from TD-6 (sampled in 2000) shows a dilution trend that could indicate possible mixing with hot steam. However, it shows the presence of two trends of equilibration temperature toward the reservoir rock, which reveals that the TD-5, TD-6 waters have higher equilibration temperatures, of 270°C and 240^0C than the Alalobeda springs. Furthermore, the data fall into three distinct clusters, suggesting different environments of water- rock interactions and degrees of attainment of water-rock equilibrium.

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8. STEAM FRACTION

The steam fraction of well TD-5, calculated from chemical geothermometry is 29 %, but the result obtained from in-hole measurement indicate 35 %.

The steam fraction of well TD-6, calculated and measured values indicate 23 %.

9. ISOTOPE

The 1999 isotope data are plotted in fig. 4. Most of the water samples are plotted along the World Meteoric Water Line, with a few of them are far from the line. This small ^{18}O shift is the result of a water- rock interaction of the Tendaho geothermal water.

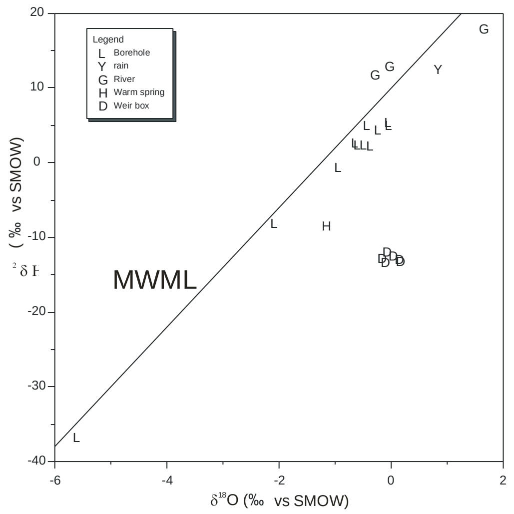

Figure-4 D Vs 18O for water of Tendaho wells and the suroundings

10. DISCUSSION

The waters of the wells and the hot springs are the sodium-chloride type, as in other Tendaho deep wells, but the Alalobeda springs exhibit a higher SO_4 content than the deep Tendaho wells. This high sulphate content could come from the sediments, which contain gypsum and anhydrite. The data plots on the triangular diagram of Giggenbach (1988) show that the above-mentioned waters are partially mature water that did not attain full chemical equilibrium with the host rock. However, the TD-5 water attains hotter temperature and more water-rock equilibria than the Td-6 and the Alalobeda springs. The average TD-5 reservoir temperature, computed using different chemical geothermometr is 246°C, which is in good agreement with the actual in-hole temperature log. The TD-6 reservoir temperature computed using different chemical geothermometers (220-250°C), is in good agreement with the actual in-hole measured temperature. The average reservoir temperatures of Alalobeda springs, using different cation geothermometers and the quartz geothermometers are in the range 148°C to 215°C. The higher value gained from the quartz geothermometers should be taken as a minimum reservoir temperature of a boiling hot spring. TD-5 well shows a higher temperature and higher steam fraction than TD-6, which could also lead to an up flow zone. These shallow wells produce geothermal waters that are as mature as the deep Tendaho wells and have comparable temperatures.

11. SUMMARY OF RESULTS

- The water of wells TD-5 and TD-6 is a neutral to alkaline Na-Cl type mature geothermal water.
- The waters of Alalobeda springs are also of the Na-Cl type with slightly high content of SO_4.
- **The deep reservoir temperature of TD-5 and TD-6 are in the range 240°C - 270°C**
- The temperature of Alalobeda springs are in the range 150-220°C
- The highest steam fraction of the well is 29**%.**
- The well waters and the hot springs do not exhibit similarities in origin although this result should be reconfirmed by isotopic data of the wells and springs.
- These shallow wells produce geothermal waters that are as mature as the deep Tendaho wells and have comparable temperatures.

REFERENCES

Aquater, (1995). Surface geochemical monitoring final report, H 9802.

Aquater, (1995h). Regional isotopic survey final report, H9564.

Abbate. E. et al., Strike-Slip faults in a rift area: a transect in the Afar Triangle, East Africa, Tectonophysics 241 (1995) 67-97, 1994.

Ali, S. (1998). Chemical and isotopic studies of the Northern Afar, Ethiopia. International Institute for Geothermal Research, Pisa, Italy. Unpublished report. Department

Arnorsson, S., Sigurdsson, S., Svavarsson, H. (1982). The chemistry of geothermal waters in Iceland I. Calculation of aqueous speciation from 0 to 370ºC. Geochim. Cosmochim. Acta, 46, pp. 1513-1532

Craig, H. (1977. Isotopic geochemistry and hydrology of geothermal waters in Ethiopian Rift Valley. Isotopic laboratory scripps institution of oceanography, report, ref.no. 77-14. Department

Fournier,R.O. (1983) A method of calculating quartz solubilities in aqueous sodium chloride solutions. Geochim. Cosmochim. Acta, 47, 579-586.

Giggenbach, W.F (1988). Geothermal-solute equilibria: Derivation of Na-K-Mg-Ca geo-indicators. Geochem. Cosmo. Acta. 52, 2749-2765.

Gonfiantini, R., Borsi, S and Ferrara, G. (1973). Isotopic compositions of waters from the Danakil Depression, Ethiopia. Earth and Planetary Science letter, 18, 13-21.

Panichi C., (1994). Isotopic investigation in Geothermal Hyddrology, International Atomic Energy Agency, Report of an Expert Mission, 1995.Reference number 77-14, 1977

Teclu, A. (1995). A preliminary isotopic and geochemical study for recharge identification of Tendaho geothermal field. Ethiopia. International Atomic Energy Agency. Unpublished report. Department
UNDP (1973). Geology, geochemistry and hydrology of hot springs of the East African Rift System within Ethiopia. UNDP, December report DD/SF/ON/11, N.Y. Library

Zewde G/Egzaber. (1998). Geology and Alteration mineralogy in TD-5 and TD-6, UNU G.T.P. Iceland, Report pp

Annexes

Table-2 average atomic ratio of Tendaho and Alallobeda

	Na/K	Na/Ca	Na/Mg	Na/Cl	Cl/B
Allalobeda	15	18.5	4490	0.7	357
Tendaho	8	63.4	5086.7	0.66	211

Table-3 average cation temperatures of the wells and Alalobeda hot springs

sample id	Na/K(1)*	Na/K(2)	Na/K(3)	Na/K(4)	Na/K(5)	Na/K(6)	Na/K(7)	Na/Ca(8)
TD6,99	201.5	185.4	207.9	225.4	227.8	214.4	242.3	217.7
TD6,00	205.9	189.7	212.1	228.6	231.2	217.7	245.5	220.9
TD5,03	242.0	224.2	245.8	253.7	258.8	244.7	270.9	246.4
AL1,00	141.6	127.9	150.9	180.7	179.2	166.9	196.9	173.6
AL73	150.4	136.3	159.4	187.5	186.6	174.1	203.8	177.0
AL3	148.7	134.8	157.8	186.3	185.2	172.8	202.6	176.0
AL2	148.7	134.8	157.8	186.3	185.2	172.8	202.6	176.6
AL1	150.4	136.3	159.4	187.5	186.6	174.1	203.8	177.3

1 Truesdell(1976) 3Arnorsson(1983)(25-250°C)
2 Tonani(1980) 4Arnorsson(1983)(250-350°C)
5Fourner(1983) 7Giggenbach et al.(1983)
6Nieva and Nieva(1987) 8Fournier and Truesdell(1973)

Table-4 average silica temperature of the wells and Alalobeda hot springs

	TQC	TQA	TCH	TAM
TD6,99	244.4	219.6	235.5	120.1
TD6,00	255.4	228.1	249.0	131.5
TD5	274.303	242.594	272.5733	151.5867
AL-1(00)	221.1	201.2	207.2	96.3
AL-1(03)	215.9	197.1	200.9	91.1
73(03)	215.9	197.1	200.9	91.1
AL-2(03)	214.6	196.1	199.5	89.9
AL-3(03)	209.4	191.9	193.2	84.7

Table-1Water Chemical analysis of (1999,2000,2003) (ppm)

Location	Feature type	Feature	Date	Temp	Cond	pH	Na	K	Mg	Ca
Tendaho	TD-6	Weirbox	36224	95	3020	9.23	590	68	0.1	10.9
Tendaho	TD-6	Weirbox	36225	96	3111	9.03	600	70	0.1	11.4
Tendaho	TD-6	Weirbox	36226	95	3201	9.08	620	68	0.1	12.1
Tendaho	TD-6	Weirbox	36227	94	3110	9.03	590	68	0.1	11.7
Tendaho	TD-6	Weirbox	36228	95	3012	9.16	600	70	0.1	16.7
Tendaho	TD-6	Weirbox	36230	95	3010	9.2	580	68	0.1	11.6
Tendaho	TD-6	Weirbox	36231	95	3100	9.13	595	68	0.1	11.3
Tendaho	TD-6	Weirbox	36235	96	3231	9.16	600	68	0.1	11.8
Tendaho	TD-6	Weirbox	36241	95	3211	9.21	600	70	0.1	10.3
Tendaho	TD-6	Weirbox	36251	95	3100	7.05	600	70	0.1	10.4
Tendaho	TD-6	Weirbox	36258	95	3131	9.2	605	66	0.2	12.1
Tendaho	TD-6	Weirbox	36262	95	3121	9.18	600	68	0.1	12
Tendaho	TD-6	Weirbox	36263	95	2895	9.23	645	64	0.1	11.8
Tendaho	TD-6	Weirbox	36269	95	3193	9.23	610	70	0.1	12.8
Tendaho	TD-6	Weirbox	36270	96	3132	9.24	620	68	0.1	13
Loggya	cold	River	36234	33	313	8.76	35	4	4	26
Adaitu (Weira)	cold	Borehole	36248	25	800	8.16	133	7	11.1	24
Upper Mille	cold	Borehole	36248	36	821	7.9	107	4	18.7	42
Mille	cold	River	36248		386	8.08	26	4	11.1	42.5
Lower Mille	cold	Borehole	36248	37	666	8.13	81	5	19	31
Harsis	cold	Borehole	36279	41	886	8.11	179	6	6.5	9.7
Soja	cold	Borehole	36248	41	1156	8.18	184	10	16.6	34
Awash(Tendaho)	cold	River	36250	28	486	8.81	68	5	5.9	19
Tendaho plantation	cold	Borehole	36250	34	2815	8.3	555	6	19.3	27.5
Dubti Tele	cold	Borehole	36250	36	1603	8.21	324	5	8	9.9
Logyya No.1	cold	Borehole	36252	47	1397	8.2	252	5	6.4	17.3
LogyyaNo.3	cold	Borehole	36252	48	1518	8.01	286	4	6.7	23.5
Dobi	cold	Spring	36256	52	11355	7.37	2125	49	3.8	355
Dobi	cold	Borehole	36256	37	5417	8.5	1110	51	8.1	54
Dichoto	cold	Borehole	36256	38	1451	8.2	308	13	0.5	4
Tendaho		rain	27/03/1999							
Tendaho	TD-6	Weir box	36608	96.2	3171	9.5	635	77	2	10
Tendaho	TD-6	Weir box	36609	96	3019	9.51	600	68	1	10
Tendaho	TD-6	Weir box	36610	93.8	3052	9.53	585	69	0.1	9
Tendaho	TD-6	Weir box	36612	93.5	3074	9.58	590	68	0.1	13
Tendaho	TD-6	Weir box	36614	93	3054	9.49	600	69	0.1	10
Tendaho	TD-6	Weir box	36616	93	3049	9.49	585	68	0.1	10
Tendaho	TD-6	Weir box	36619	93	3061	9.49	585	68	0.1	10
Tendaho	TD-6	Weir box	36621	93	3052	9.45	585	68	0.1	11
Tendaho	TD-6	Weir box	36623	93.5	3016	9.42	565	66	0.1	12
Tendaho	TD-6	Weir box	36626	94	3035	9.45	610	70	0.1	12
Tendaho	TD-6	Weir box	36633	94	2955	9.52	570	73	0.3	9
Tendaho	TD-6	Weir box	36635	94	3121	9.46	560	67	0.1	11
Alalobeda1	hot spring	geyser	36625	89	2973	9.01	580	36	0.1	29
Tendaho	TD-5	weir box	25/3/03	95.7	3632	7.98	580	91	0.7	7
Tendaho	TD-5	weir box	25/3/03	93	3790	9.4	580	93	0.2	6

Tendaho	TD-5	weir box	26/3/03	93.5	3600	9.4	620	97.5	0.1	7
Tendaho	TD-5	weir box	28/3/03	96	3699	9.39	600	94.5	0.1	7
Tendaho	TD-5	weir box	31/3/03	95	3630	9.39	600	92.5	0.1	6
Tendaho	TD-5	weir box	37684	95	3754	9.37	600	94	0.1	6
Tendaho	TD-5	weir box	37776	95	3688	9.39	620	98	0.1	6
Tendaho	TD-5	weir box	37868	95	3677	9.38	600	94	0.2	7
Tendaho	TD-5	weir box	37959	95.5	3697	9.41	600	92	0.2	6
Alalobeda1	hot spring	geyser	37625		3460	8.85	540	37	0.1	30
Alalobeda	73	hot spring	37625		3460	8.75	540	37	0.1	31
Alalobeda	AL-2	hot spring	37625	99.5	3310	9.07	520	35	0.8	27
Alalobeda	AL-3	hot spring	37625	98	3370	8.5	520	35	0.1	29

Chemical Analyeses Data of (1999,2000,2003)

Location	Feature type	Feature	HCO3	Cl	SO4	NO3	F	Si	B	O18	2H
Tendaho	TD-6	Weirbox	51.8	851	109	0.89	1.22	223.5	4.29	-0.11	-13.
Tendaho	TD-6	Weirbox	64.6	922	129	1.77	1.22	223.5	4.34	0.03	-12.
Tendaho	TD-6	Weirbox	60.6	922	145	1.33	1.25	211.4	4.58		
Tendaho	TD-6	Weirbox	64.5	922	116	1.77	1.2	208.6	4.34	-0.17	-12.
Tendaho	TD-6	Weirbox	47.8	922	94	1.3	1.3	226.8	3.94		
Tendaho	TD-6	Weirbox	51.7	922	92	1.33	1.19	208.1	4.32		
Tendaho	TD-6	Weirbox	45.7	922	106	0.89	1.22	207.2	4.29		
Tendaho	TD-6	Weirbox	48.7	922	109	0.44	1.23	217.9	4.56	0.14	-1
Tendaho	TD-6	Weirbox	52.7	985	143	0.04	1.2	219.3	4.86		
Tendaho	TD-6	Weirbox	109.4	922	108	1.77	1.16	208.6	4.46	0.16	-13.
Tendaho	TD-6	Weirbox	39.6	993	108	0.89	1.2	211.4	4.65		
Tendaho	TD-6	Weirbox	44.7	922	98	1.33	1.15	221.7	4.11		
Tendaho	TD-6	Weirbox	39.6	929	129	1.33	1.11	206.3	4.30		
Tendaho	TD-6	Weirbox	40.6	922	121	1.33	1.17	207.2	4.65		
Tendaho	TD-6	Weirbox	45.7	922	99	1.33	1.16	206.3	4.60	-0.08	-1
Loggya	cold	River	102.1	14	57	1.8	0.65	7.0	0.04	-0.29	11.
Adaitu (Weira)	cold	Borehole	341.5	43	80	26.6	0.97	41.1	0.08	-0.93	-0.
Upper Mille	cold	Borehole	382.7	47	78	1.3	0.72	25.7	0.04	-0.03	4.
Mille	cold	River	236.6	12	19	0.44	0.33	15.4	0.04	-0.03	12.
Lower Mille	cold	Borehole	296.2	43	47	5.3	0.6	27.5	0.04	-0.04	5.
Harsis	cold	Borehole	356.5	60	82	13.7	1.3	35.9	0.39	-2.07	-8.
Soja	cold	Borehole	386.5	144	68	1.8	0.93	35.5	0.04	-0.22	4.
Awash(Tendaho)	cold	River	148.2	31	39	1.8	0.83	13.5	0.29	1.65	17.
Tendaho plantation	cold	Borehole	399.0	461	450	0.44	1.76	25.7	0.51	-0.63	2.
Dubti Tele	cold	Borehole	371.5	251	164	0.44	1.74	28.9	0.39	-0.42	4.
Logyya No.1	cold	Borehole	210.4	231	186	0.44	1.09	26.6	0.29	-0.59	2.
LogyyaNo.3	cold	Borehole	203.5	255	178	8	1.01	25.7	0.53	-0.48	2.
Dobi	cold	Spring	48.7	3687	505	3.1	2.2	50.4	2.79	-1.16	-8.
Dobi	cold	Borehole	218.1	1418	472	21.3	2.31	31.3	1.58	-0.36	2.
Dichoto	cold	Borehole	321.5	208	175	0.9	0.96	28.5	0.96	-5.59	-36.
Tendaho		rain								0.85	12.
Tendaho	TD-6	Weir box	109.8	1000	156	1.68	1.57	253.9	3.98		

Tendaho	TD-6	Weir box	102.7	890	136	0.82	1.65	245.5	4.07
Tendaho	TD-6	Weir box	83.4	886	124	0.79	1.53	233.3	4.27
Tendaho	TD-6	Weir box	87.5	896	149	1.37	1.44	247.3	4.17
Tendaho	TD-6	Weir box	83.4	890	122	1.34	1.42	230.1	4.09
Tendaho	TD-6	Weir box	87.5	890	132	1.42	1.4	228.2	4.07
Tendaho	TD-6	Weir box	78.3	865	130	1.39	1.43	228.2	4.29
Tendaho	TD-6	Weir box	78.3	865	134	1.6	1.38	279.1	4.35
Tendaho	TD-6	Weir box	80.3	890	134	1.54	1.4	223.1	4.27
Tendaho	TD-6	Weir box	85.4	886	279	1.49	1.38	228.2	4.02
Tendaho	TD-6	Weir box	109.8	833	157	0.5	1.34	269.7	3.70
Tendaho	TD-6	Weir box	85.4	869	144	1.39	1.4	233.3	4.14
Alalobeda1	hot spring	geyser	40.3	805	306	1.12	0.76	162.4	1.89
Tendaho	TD-5	weir box	81.0	905	97	18.16	1.3	301.9	4.04
Tendaho	TD-5	weir box	107.0	881	125	1.77	1.3	292.1	4.17
Tendaho	TD-5	weir box	107.0	911	85	1.77	1.3	299.6	4.28
Tendaho	TD-5	weir box	98.0	889	104	1.77	1.3	294.5	4.18
Tendaho	TD-5	weir box	98.0	890	111	1.77	1.2	289.8	4.55
Tendaho	TD-5	weir box	98.0	893	99	1.77	1.3	292.1	4.39
Tendaho	TD-5	weir box	72.0	897	102	1.77	1.2	294.5	4.57
Tendaho	TD-5	weir box	79.0	922	111	1.77	1.2	287.0	4.31
Tendaho	TD-5	weir box	77.0	896	142	1.77	1.2	292.1	4.33
Alalobeda1	hot spring	geyser	40.0	747	245	0.89	0.75	152.1	2.07
Alalobeda	73	hot spring	59.0	748	247	0.89	0.67	152.1	2.24
Alalobeda	AL-2	hot spring	44.0	742	202	0.89	0.63	149.8	2.31
Alalobeda	AL-3	hot spring	52.0	743	234	0.89	0.7	140.0	2.15