THE CHEMISTRY OF GEOTHERMAL FLUIDS IN GEOTHERMAL AREAS OF THE LAKES DISTRICT, ETHIOPIAN RIFT VALLEY

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ABSTRACT

Data on the chemical composition of water and gas as well as isotopic data from five geothermal areas in Lakes Destrict, Ethiopia, were integrated and studied for better understanding of the geothermal systems. The waters are mostly of the sodium bicarbonate type, with near neutral pH. Intermediate to acidic volcanic rocks dominate in all the areas studied. Mixing of the hot water with cold waters is common in the upflow. Partial re-equilibration has occurred subsequent to mixing and as a result the solute geothermometers indicate relatively low temperatures. The geothermometers tend to indicate higher subsurface gas temperatures than the solute geothermometers. CO2-temperatures exceed 300°C for all the fields (no fumarole in Shalla) and CO2/H2-temperatures tend to exceed 200°C. Due to the effects of condensation, CO_2 -temperatures tend to be high, but as a result of reactions in the upflow involving H_2 CO₂/H₂ temperatures are expected to be low. The SiO₂carbonate mixing model was found to indicate better temperature estimates of the hot water components of the geothermal areas in the Lakes District compared to the others. The empirically derived temperature relations of aqueous species concentrations and cation/proton activity ratios, based on Icelandic chemical data, fits well for the Lakes District fluids except for ratios involving Mg.

Subsurface temperature in the four geothermal fields may be as high as 300-340°C for the Aluto-Langano complex, 300°C for Corbetti, 250-300°C for Wondo Genet and 300°C for the Abaya geothermal area. There may be an independent heat source for Shalla area with a minimum temperature of 200°C. The geothermal fluids are calculated to be supersaturated with calcite and close to saturation with fluorite. At depth, they are highly undersaturated with respect to anhydrite.



TABLE OF CONTENTS

	Page
ABSTRACT	3
1 INTRODUCTION	
1.1 Scope of study	8
1.2 Previous geochemical work	9
1.3 Obejective of the study	10
2 GEOLOGY AND DESCRIPTION OF THE GEOTHERMAL AREAS IN THE LAKES DISTRICT	
2.1 Regional setting and geology	11
2.2 Description of the studied areas: Abaya; Awasa-Wondo	
Genet; Corbetti; Shalla and Langano	11
3 SAMPLING AND ANALYTICAL METHODS	15
4 CHEMICAL CHARACTERISTICS OF THE GEOTHERMAL AREAS	16
5 GEOTHERMOMETRY	
5.1 Solute geothermometry	19
5.2 Solution-mineral equilibria	22
5.3 Gas geothermometry	24
6 MIXING PROCESSES	
6.1 Evidence for mixing	29
6.2 Mixing models	32
6.2.1 Silica-enthalpy mixing model	33
6.2.2 Silica-carbonate mixing model	33
7 SUMMARY	36
8 RECOMMENDATIONS	38
ACKNOWLEDGEMENTS	40
REFERENCES	41

LIST OF FIGURES

1.	Geological map of the Lakes District	45
2.	Comparison between the results of individual solute geothermometers and the mean temperature of all of them	46
3.	Relation between carbon dioxide/fluoride concentra- tions and quartz equilibrium temperature/discharge temperature in the Lakes District geothermal waters	47
4.	Relation between sulfate/sulfide concentrations and quartz equilibrium temperature/discharge temperature in the Lakes District geothermal waters	48
5.	Relation between cation/proton ratios and quartz/- discharge temperature in the Lakes District geothermal waters	49
6.	State of calcite and anhydrite saturation at quartz/- discharge temperature in the Lakes District geothermal waters	50
7.	State of fluorite saturation at quartz/discharge temperature in the Lakes District geothermal waters	51
8.	D/H and 0-18/0-16 variations in thermal and cold waters from the Lakes District	52
9.	Relationship between chloride concentrations and boron, $0-18$, SiO ₂ and SO4 in cold and thermal waters from the Abaya area	53

10.	Relationship between chloride concentrations and boron,	
	0-18, SiO2 and SO4 in cold and thermal waters from the	
	Awasa-Wondo Genet area	54
11.	Relationship between chloride concentrations boron,	
	0-18, SiO ₂ and SO4 in cold and thermal waters from	
	the Shalla area	55
12.	Relationship between chloride concentrations boron,	
	0-18, SiO2 and SO4 in cold and thermal waters from the	
	Langano area	56
13.	Silica-enthalpy mixing model	57
14.	Silica-carbonate mixing model	58

LIST OF TABLES

1.	Chemical compo	sition of	waters in the	Lake Abaya area.	59
2.	Chemical compo Genet area			Awasa-Wondo 	59
3.	Chemical compo	sition of	waters in the	Shalla area	60
4.	Chemical compo	sition of	waters in the	Langano area	60
5.	Isotopic composigeothermal area			Lakes District	61
6.	Calculated tem	peratures	from solute ge	othermometers	62
7.	Temperature fu	nctions fo	or solute geoth	ermometers	63
8.	-			betti and Abaya	64
9.	Estimated temp Langano, Corbe			rmometers for	65
10.	Temperature fu	nctions fc	or gas geotherm	ometers	66

1 INTRODUCTION

1.1 Scope of work

Ethiopia was the second country in Africa to start geothermal exploration for power development. Scientific and technical know-how is essential to explore and utilize this energy resource. Training in countries with experience in geothermal exploration, development, and utilization is probably the best resolution to build up relevant know-how. In line with this approach the author was accepted as a United Nations University Fellow in the 1985 UNU Geothermal Training Programme in Iceland and specialized in the chemistry of thermal fluids.

Introductory leactures covering the various scientific, engineering, and economic aspects in geothermal exploration and exploitation were given. In addition, study tours were arranged to see both high- and low-temperature geothermal fields in Iceland. Greenhouses, factories and farming places which are directly inter-related with geothermal utilization were also visited.

The specialized training in the chemistry of thermal fluids included water and steam sampling from natural thermal manifestations and production wells in high- and lowtemperature fields, analyses of water and steam samples, computer work for speciation calculations, lectures on chemical thermodynamics as basis for geochemical interpretation, interpretation methods for geochemical data based on excercises and problems and computer approach to the interpretation of chemical data. The specialized training supervision of Dr.Stefan was performed mainly under the Arnorsson of the University of Iceland, but also Dr.Jon Orn Bjarnason of the National Energy Authority and Dr.Einar Gunnlaugsson of the Reykjavik Municipal District Heating Service.

This report describes the author's research project which was a part of the training programme. The project was carried out during the last two months of the training period. Data from reports describing previous scientific work in Lakes District, Ethiopia were used. Chemical and isotopic data from water and steam (including chemical data of Shalla cold spring) were taken from UN (1973), Glover (1976), and Craig (1977), respectively.

The chemical data were re-arranged to use the computer programmes of Arnorsson et al.(1982). Hence total carbonate species were calculated and reported as carbon dioxide and HBO₂ as B.

1.2 Previous geochemical work

Chemical data on hydrothermal waters in the Ethiopian Rift and probable deep water temperatures deduced from silica and Na-K geothermometers were reported by UN (1973). Glover (1976) reported gas analyses results and gas-gas equilibrium temperatures (tCH4, tNH3). Isotopic and chemical data including the sulfate-water isotopic temperatures in and around the Rift is reported by Craig (1977). Futhermore, geochemical work of the Langano geothermal area which include the first four deep exploratory wells were described by Melaku Abebe (1983) and Negussie Mekuria (1983).

There are considerable differences in the data from the same springs in the reports of UN (1973) and Craig (1977). Craig's statement concerning this is that "the estimates of subsurface temperatures cannot be considered useful until the question of reality of these compositional differences and/or the reliability of the two sets of data can be resolved." The discrepancy may be due to poor analytical precision. The present author considers that the compositional variation affects little the geothermometry results.

Three areas have been selected for exploration and development in the Lakes District, Langano in the north, Abaya in the south and Corbetti in the middle of the district. In all of these fields subsurface temperatures of more than 180°C have been estimated (UN, 1973; Glover, 1976; Melaku, 1983). Drilling started in one of these fields (Aluto-Langano) in 1981. Eight deep exploratory wells were completed in 1985. The maximum temperature encountered in a drillhole is 318°C in LA-6. Five holes are productive (water dominated). Detailed exploration involving geological, geophysical and geochemical work is still in progress in the remaining two fields.

1.3 Objectives of the present work

Previous geochemical studies in the Lakes District have been focused mainly on the estimation of subsurface temperatures. However, the interpretation did not consider the effect of mixing of the hot water in the upflow on the results. Geothermometry results are anomalous for mixed waters. Therefore, it is necessary to evaluate if mixing has occurred. Recently proposed gas and cation geothermometers have been applied to the existing geochemical data to asses subsurface temperatures. Gas geothermometers are especially useful for an area such as Corbetti where the thermal manifestations are restricted to fumaroles and steaming ground.

So far limited attention has been paid to the quantitative evaluation of the solute-mineral equilibria in the geothermal systems. It is the objective of this report to integrate the available geochemical data (Tables 1, 2, 3, 4, 5 and 8), and

- identify and evaluate the mixing processes by chemical means and mixing models;
- (2) apply newly calibrated chemical geothermometers to predict subsurface temperatures;
- (3) study solution-mineral equilibria.

2 GEOLOGY AND DESCRIPTION OF GEOTHERMAL AREAS IN THE LAKES DISTRICT

2.1 Regional setting and geology

The Ethiopin Rift Valley is part of a major tectonic structure that extends for more than 6,000 km from the Middle East in the north to Mozambique in the south, known as the East African Rift System (Fig. 1). The great majority of this system, including the Ethiopian Rift, is the surface expression of diverging lithospheric plate boundaries. A regional heat flow anomaly extends for more than 1,000 km within the Ethiopian Rift (UN, 1984).

The Lakes District is located south of Addis Ababa in a relatively narrow part of the Ethiopian Rift Valley. Its elevation extends from 1,230 m at Lake Shamo in the south to about 1,800 m at the Awash River watershed in the north. Structurally the Lakes District Rift is a broad graben in which Tertiary rocks have been down faulted and filled with Quaternary sediments (UN, 1973). Lakes Shamo, Abaya, Awasa, Shallo, Chittu, Shalla, Abayta, Langano, Zwai, and Gelilla are all found in the Lakes District.

2.2 Description of the studied areas: Abaya, Awasa-Wondo Genet, Corbetti, Shalla and Langano

This report uses the same index numbers for sampling sites as was done in the 1973 UN report. The index numbers for Lake Abaya (including Graha-Quhe springs east of Awasa) are NB-37/6-. For Lake Awasa-Wondo Genet, Corbetti, Lake Shalla and Lake Langano areas the index numbers start with NB-37/2-. Geological map of the areas including thermal manifestations is shown in Fig. 1.

Lake Abaya area

Lake Abaya is located at 1386 m elevation in the rift floor southof Lake Awasa and north of Lake Shamo, 6°15'N; 37° 55'E. Thermal manifestations (fumaroles and springs) are mainly concentrated on the north and northwest shore of the

lake. All of the springs are close to the water level of Lake Abaya and the Bilate River. They occur on the western marginal rift faults near the center of the graben. Many of them are closely related to centers of rhyolitic volcanism (UN, 1973).

The spring discharges range from very small to 20 1/s with temperatures between 37° and 95°C. Spring 6 deposits siliceous sinter while most of the others deposit limonite very near to their outlet. Due to the low amount of inflow in the recent years Lake Abaya receded from its 1980 level and several new boiling springs were exposed along a line south of spring 6 which are compositionally similar to it. Later, the lake recovered to its original level (UN, 1984).

Lake Awasa-Wondo Genet area

Lake Awasa (1,780 m) occupies an unusual tectonic basin completely enclosed by faults south of Corbetti volcanic center (UN, 1973). Wondo Genet is located east of Awasa. southeast of Shashemene very near to Lake Shallo. All the springs are located east of Lake Awasa. Cold wells for which chemical data are available occur in Awasa town near the eastern shore of Lake Awasa. Wondo Genet (40) springs deposit travertine and springs 38 and 39 (not analyzed) deposit limonite close to their vents (UN, 1973). Shallo springs (52, 48) are located by the northeast corner of Lake Shallo. These are the hottest in the area (96°C) but with low flow rate. The author recently visited the lately formed hot springs in this area. The temperature recorded at the edge of a pool was 94°C. Higher temperatures are expected in the center where surface cooling is negligible. These springs are the most vigorously boiling ones in Wondo Genet formed after the earthquake in 1984.

Corbetti Caldera

Corbetti Caldera is located about $38\,^{\circ}27$ ' E, $7\,^{\circ}10$ ' N in the Lakes District Rift. The maximum altitude is about 2300 m (Chebbi volcano) and the flat plains are at about 1700 m. Corbetti caldera, a Quaternary volcano in the rift, has

extensive hydrothermal manifestations. The area comprises sedimentary and volcanic rocks (Elias, 1984).

Corbetti (meaning obsidian) caldera has three volcanoes, namely Chebbi(SE), Urgi(center), and Danshe (N). Fumaroles, steaming and hot ground are very common in these volcanoes. Steaming ground extends to the north outside the caldera.

Lake Shalla area

Lake Shalla, 7°25'N; 38°30'E; is the deepest lake in the district (over 250 m). Except for minor basalts all rocks exposed in the Shalla region are rhyolitic (predominantly ignimbrites and pumice breccias) and lacustrine sediments derived from them. The most recent volcanic eruption was explosive and produced pumice from centers between Lake Shalla and Abayata (UN, 1973).

Hot springs are distributed along the eastern, southern and western shores of the lake. The eastern springs are the warmest in the area and discharge clear water as far as 100 m from the lake. Salt deposition is associated with springs 90 and 91. Springs 87 and 88 emerge from mud. At spring 29, no sinter is deposited, but algae grows in the 1.25 l/s overflow. One km south of spring 29, springs collectively numbered 30, emerge from dark mudstone overlain by superficial alluvium (UN, 1973).

In between Corbetti Caldera and Lake Shalla there is about 1 km diameter lake, Chittu which is 1.5 km south of the southern shore of Lake Shalla. Two groups of springs have been recognized, those emerging at the southeastern part and those discharging clear water at the northeastern shore of the lake. The discharge is about 6.6 l/s at the southern part and 3.3 l/s at the northern point with moderate temperatures $(51-60^{\circ}C)$.

Lake Langano area

Lake Langano (1586 m) is located a few km east of Lake Abayata and Lake Shalla Park. Lake Langano, Aluto Volcanic Center, and Zwai (north of Lake Langano) all lie within a north-northeast aligned tectonic depression bounded to the west by Langano Fault and to the east by a series of faults which form the eastern rift escarpment (UN, 1973).

Hot springs in this area are mostly confined to the northeastern shores of the lake. Vigorous springs in the area are found in the Geyser Island (10-13). The temperature is near boiling (96.5°C) in spring 10 with flow of 11.6 l/s. The name Geyser is probably given to this spring. Goetz (a German settler since 1902 in the area) reported that a geyser suddenly developed in 1906 at the time of the Langano earthquake. He also mentioned that the geyser erupted to a height of about 25-30 m about once every 30 seconds. At present it is a boiling hot spring.

A maximum temperature encountered through deep exploratory drilling in Aluto-Volcanic center is 318°C at about 2000 m in the 2203.4 m deep well, LA6.

3 SAMPLING AND ANALYTICAL METHODS

This report is based on data of previous workers (see section 1.1). Analytical methods adopted are described in the respective reports. Very few springs were analyzed in all of the investigated areas compared to the availability of thermal manifestations. More data would have been of advantage for the application of mixing models. The information given for water sampling is insufficient. It is very difficult to predict whether the samples were treated or not, especially for silica. Filtering, dilution, concentration, and/or acidification processes are not described.

It is essential to analyse unstable constituents (CO2, H2S, pH) at the sampling site right after collection from raw-untreated sample. Samples for Ca, Mg, Na, and K should be filtered and acidified. If the sulfide content is high it is possible that oxidation into SO4 occurs. Therefore, necessary to precipitate sulfide by adding it is Zn(CH₃COO)₂ solution to a sample intended for S04 determination. Samples for SiO2 should be diluted or treated by alkaline solution prior to analysis to avoid silica polymerization which occurs if total dissolved silica exceed about 100 ppm. Appendix (1) summarizes sample treatment and analytical methods adopted for major elements in geothermal fluids in Iceland.

16

4 CHEMICAL CHARACTERISTICS OF THE GEOTHERMAL AREAS

The location of all the samples is shown in Fig. 1. Tables 1-5 show the chemical and isotopic data of selected thermal and cold waters in the Lakes District used for the present study.

Generally, thermal waters in the Lakes District are high in bicarbonate and fluoride. Sodium is the predominant cation followed by potassium. The pH is slightly above neutral, except for few springs in Shalla. The waters are, therefore, classified as dilute near neutral sodium bicarbonate waters. There are also springs which discharge acid sulfate waters. They are steam heated surface waters, the low pH being due to oxidation of H_2S into SO_4-2 . Waters high in bicarbonate often form by mixing of high temperature waters with surface water. The high fluoride most likely results from relatively high fluoride in the associated acid volcanics.

Lake Abaya area

The Abaya spring waters can be divided into two groups on the basis of their composition and distribution. Springs which are located nearest to the northwestern shore of the lake, i.e. 6, 8, 15, and 16 fall into one group and those which are further north (about 33 km from spring 16) constitute the other group. This latter group (19, 20, 22 and 24) is characterized by high F and carbonate and low Cl relative to SO4 as well as high boron content, at least in spring 22, suggesting that they may be steam heated. This was recognized in the UN report (1973).

The first group of springs is very important in the area. Spring 6 which is nearest to the lake and the most vigorous one has the highest discharge temperature and the highest concentrations of Cl, SiO_2 and total carbonate in the Abaya area. The oxygen shift in this spring water is significant compared to others. Springs 8, 15, and 16 have low to moderate temperatures (42-65.5°C), lower SiO_2 and Cl contents but are higher in bicarbonate, Ca and Mg concentrations. These latter spring waters are assumed to be partially steam heated meteoric waters (see sec. 6.1).

Awasa-Wondo Genet area

Springs 4, 40, and 52 emerge on a swampy plain and are relatively mineralized compared to the springs on the eastern escarpment (44 and 46). The temperature of the spring discharges is between 43°C and 96°C. Lake Awasa and cold wells in Awasa are evaporated waters (see chapter 6). In general, these waters are low in Cl (< 129 ppm), boron and fluoride (except 4 and 52) but with considerable concentrations of Ca and Mg. Spring 40 appears to be unique in the group. It has the highest Cl, SO4, bicarbonate and Cl/F ratio but the lowest Na/Li ratio in the district.

Lake Shalla area

Springs in this area emerge at the eastern (29, 30, 31, 35, 36,), southern (90, 91), and the southwestern shore of Lake Shalla (95, 96).

The springs by the eastern shore have similar cation/proton ratios, with pH ranging from 8.35 to 9.7. Spring 30 is more mineralized and apparently somewhat degassed compared with other springs in the group. The eastern springs show a positive Cl-temperature relationship. By contrast, an inverse relation between SiO2 and Cl is observed in the Shalla springs. The analyzed silica concentrations corrospond closely to amorphous silica saturation at 25°C. Although not proved, these analyses are suspect to error. It is possible that the analyzed silica represents monomeric silica at room temperature and not total dissolved silica in the samples.

Springs 90 and 91 have high Cl, low Na/K, low Cl/carbonate ratio and moderate temperatures (62 and 70°C). These springs are very close to the lake shore (less than 1.5 m). The pH of spring 91 (10.1) is very similar to the pH of Lake Shalla (10.15), the most saline lake in the district (3030 ppm). This suggests that these waters are steam heated lake water.

South Shalla springs (87, 88) have similar chemistry as Chittu spring waters (60, 65) the former being slightly more mineralized. These springs are characterized by high SO4 for their Cl, low silica, high carbonate and appreciable concentration of Ca and Mg. This suggests that the Chitu springs may contain steam heated shallow meteoric water.

Lake Langano area

Springs by the shore of the northern bay of the lake (2, 3 and 84) have low flow rates and moderate temperatures $(61-67\,^\circ\text{C})$. The pH is near neutral (8.1-8.3) and the waters are relatively high in Ca, Mg, and with high Cl/SO4 ratio.

The Bole fault springs (5,8A) have high boron, high temperature ,(92°C and 94°C), and low flow rate, low Cl, and low Cl/SO4 ratio . Inspite of their distance from the source (Aluto volcanic center), they are considered to be steam heated.

Springs in the Geyser Island (10,12) are slightly alkaline, low in Ca and Mg, high in Cl and have low Cl/SO4 ratio. Slight oxygen shift was detected in spring 11 (Craig, 1977). These are the least diluted springs in the area.

Spring 16, the coolest and the least mineralized one in the area, has the highest flow, and the highest Ca and Mg concentrations in the group. This spring has a high cold meteoric water component.

Zwai springs (20,23) on the other side of the Aluto Volcanic Center are characteraized by moderate temperatures (60°C, and 78°C), low discharge rates and low Cl (31 and 95 ppm). The Cl/SO4 ratios lie in between those north of the bay and the geyser springs.

5 GEOTHERMOMETRY

Tables 6 and 9 show the calculated temperatures from solute as well as gas geothermometers for Lakes District waters and steam. The equations used for the solute and gas geothermometers are listed in Tables 7 and 10, respectively. The relationship between individual solute geothermometers and the mean of them all is shown in Fig. 2. The relationship between acid molecules concentration and cation/proton ratios and quartz/discharge temperature is shown in Figs.3-5.

The use of chemical geothermometers involves the assumption that equilibrium is attained between fluid and a particular mineral assemblege in the reservoir and that re-equilibrain the upflow is insignificant. The rock tion type, temperature, kinetics and rate of disolution of various chemical constituents from the rock determine which geothermal minerals will form, and how closely this open chemical system approches equilibrium each time. Different reactions may occur in an ascending water at different rates. The apparent last temperature of equilibrium may thus be different for different chemical geothermometers (Arnorsson et al.,1983a; Fournier, 1977). Chemical re-equilibration is favoured when water temperatures are high initially, when rates of water movement towards the surface are slow, when residence times in reservoirs at intermediate and shallow depths are relatively long, and when the water flows through chemically reactive rocks (Fournier et al., 1974).

5.1 Solute geothermometry

Arnorsson et al.(1983b) used data on selected drillhole fluid compositions (Iceland) to calibrate several activity ratios (aNa+/aH+, aK+/aH+, (aCa²⁺)1/2/aH+, (aMg²⁺)1/2/aH+ and acid molecule concentrations (H₂CO₃, H₂SO₄, H₂S, HF, H₄SiO₄) against temperatures. An expansion of such calibration involving 10 solute geothermometers is presented by Arnorsson and Svavarsson (1985). An attempt has been made to apply the calibrated geothermometers for waters in the Lakes District. The equilibrium temperature of various solute geothermometers have been calculated. The reference temperature, quartz equilibrium, at which the calculations were performed was selected on the basis of having the least deviation from the mean temperature (more likely to be the equilibrium temperature). The silica content and alkali ratios may change as the water slowly rises owing to decreased solubilities at lower temperature and water-rock reactions. Silica temperatures often show quicker response to cooling in upflow zones. The Na/K temperatures are not affected by dilution, and evaporation. On the other hand dissolution following mixing tends to cause high Na-K temperatures.

When silica precipitation occurs in the upflow and when have appreciable concentration of Ca, the Na-K-Ca waters geothermometer may give more reliable results than the SiO2 and Na/K geothermometers. Arnorsson et al. (1983a,b) showed that each of the two cation ratios which constitute the Na-K-Ca geothermometer (Na/K and (Ca)1/2/Na) are determined by water temperature alone. Therefore, for equilibrated geothermal waters, which have cooled by conduction in upflow zones, the Na-K-Ca geothermometer may give a better estimation than the Na/K geothermometer as the (Ca)1/2/Na appears to respond faster to cooling than the Na/K ratio. Changes in concentration resulting both from with cold, dilute water will affect boiling and mixing the Na-K-Ca geothermometer. Boiling generally will result in high Na-K-Ca temperatures because of calcite precipitation leads to removal of aqueous Ca+2.

Mixed waters tend to yield low H_2S , Mg-K and Na-Li temperatures but high Na-K temperatures. The geothermometers involving Li, Rb and Mg often yield temperatures differing much from the other geothermometers. Arnorsson and Svavarsson (1985) explained this as being partly due to the low levels of these metals (near detection limit by flameless A.A) for Icelandic waters used for calibration. In some instances the Na-Li geothermometer results are similar to the CO_2 gas geothermometry values.

For the Lakes District waters the temperatures of silica (quartz), H_{2S} , and H_{2SO4} are lower than the mean whereas Na-K-Ca, Na-Li and HF temperatures are higher the CO2, (Fig. 2). Na/K and Mg-K temperatures are highly fluctuating. The low temperatures of silica, H₂S, H₂SO4, Mg-K and higher values of Na/K temperatures are explained by precipitation of silica and reactions following mixing. Whenhigh temperature hot water, which is rich in CO2 mixes with cold underground water, the mixture will initially be acid, but upon reaction with the rock the pH will increase and CO2 will be converted to HCO-3. Leaching of K gives high Na/K temperatures. In contrast leaching of Mg results in lower Mg-K temperatures. In most cases, the Mg-K temperatures are slightly above the measured surface temperatures suggesting intensive leaching/mixing in the upflow.

Almost all the samples plot close to the CaH equilibrium curve at quartz equilibrium temperature (Fig. 5). The concentration of the HF ion pair is slightly higher than expected from the HF "equilibrium" curve at the quartz equilibrium temperature. The reason may be that the HF equilibrium curve is derived from data in basaltic terrain in Iceland but the Lakes District geothermal systems occur in acidic volcanics. Thermal waters associated with such rocks tend to equilibrate with fluorite.

At the measured discharge temperatures samples from all geothermal areas have Na+/H+, K+/H+, and (Mg+2)1/2/H+ ratios both higher and lower than expected at equilibrium (Fig. 5). At the quartz equilibrium temperature the same ratios always plot above the equilibrium curve. This indicates substantial re-equilibration for Mg, Na, K and/or H during cooling in the upflow.

The concentrations of H_{2S} and $H_{2S}O4$ are above the equilibrium curve at discharge temperatures but slightly below it at quartz equilibrium temperatures indicating, as for the cations, partial re-equilibration in the upflow. The concentrations of H_{2CO_3} are higher than indicated by the equilibrium curve both at the measured discharge temperature and quartz temperature.

The most diluted springs (16 in Abaya, 44 in Wondo Genet, 16 in Langano and 23 in Zwai) plot far from the equilibrium curves. This is because of precipitation of minerals from the waters, leaching from the rock, oxidation and/or mixing processes in the upflow zones.

The somewhat large differences between the different solute geothermometres (Table 6) may have resulted from mixing in the upflow. However, if such mixing has occurred it seems likely that substantial re-equilibration has occurred subsequent to mixing. Evaluation of mixing processes are considered in chapter 6.

5.2 Solution-mineral equilibria

Solution-mineral equilibrium studies are one of the best approaches to interpret fluid chemistry. Application of chemical geothermometers is indeed based on the assumption that solution/mineral equilibria are attained in geothermal systems.

The conditions for equilibrium in multiphase systems are described by the Gibbs phase rule. It can be demonstrated that the number of compatible chemical components is equal to the number of phases in the system. Thus, the phase rule may be written in a simplified form as

F = M + 2

where F is the number of independent variables needed to define the system completly and M the number of mobile components. 2 indicates temperature and pressure. Chloride is the only major mobile component in most geothermal waters. The effect of pressure on solution-mineral equilibria in the range occurring in geothermal systems (1-200 bars) is found to be small (Helgeson et al., 1978; Ellis and McFadden, 1972; Arnorsson et al., 1983a). It follows, therefore, that the number of variables required to define the major element chemistry of geothermal waters at equilibrium are two, chloride and temperature.

Physical processes such as boiling and cooling as well as the rate of leaching of various components from the primary rock constituents and the rate of precipitation of alteration minerals tend to shift the geothermal system from equilibrium.

The state of saturation of some geothermal waters with respect to calcite, anhydrite, and fluorite was calculated with a computer programme (Arnorsson et al, 1982) with reference to the measured surface temperatures and quartz temperatures (Fig. 6 and 7). The results indicate calcite saturation at discharge temperatures. Significant anhydrite undersaturation is observed both at discharge and quartz equilibrium temperatures. Some of the waters calculate to be close to fluorite saturation but others are undersaturated at the quartz equilibrium temperatures. No correlation can be seen between the degree of saturation and temperature. At discharge temperatures both supersaturation and undersaturation is observed (Fig.7). It has been found in many geothermal fields in acid volcanic rocks that equilibrium between fluorite and solution is attained in the reservoir. Mixing with cold water will upset equilibrium and this may be the cause of departure from equilibrium for the Lakes District waters.

It has been demonstrated at a given temperature, independent of salinty, that the ratio $(aCa^{2+})1/2/aH^{+}$ is constant for geothermal waters (Arnorsson et al, 1978; Palmason et al., 1979). It follows then that a fixed P CO2 value corresponds to calcite saturation at a given temperature.

 $CaCO_3 + 2H^+ = Ca^{+2} + H_{2O} + CO_2$ $aCa^{+2}/(aH^+)^2 \cdot P CO_2 = K$, when $aH_{2O} = 1$

All the waters considered in this study are supersaturated with calcite at the quartz reference temperature. Except for a few spring waters from Awasa-Wondo Genet area, they are also supersaturated with respect to calcite at the surface. An average deviation from the saturation curve in terms of log Q is 1 and 0.5 at the quartz and the surface discharge temperature, respectively. The apparent supersaturation at discharge temperatures may be due to degassing, either prior to or subsequent to sampling. Whichever reference temperature is selected (quartz, measured, Na/K) Lakes District waters calculate to be highly undersaturated with respect to anhydrite. The degree of undersaturation increases with decreasing chloride Shalla 90, 91 are exceptional because of contamination by the saline lake water. This relation was also seen in Icelandic waters (Arnorsson et al., 1983a). The systematic trend towards increasing anhydrite undersaturation with falling temperature and decereasing salinity may be related to the control of sulfate activity through the reaction

$$H_{2S} + 4H_{2O} = SO4^{-2} + 2H^{+} + 4H_{2}$$

and the buffering effects of iron minerals on the partial pressures of hydrogen and hydrohgen sulfide (Arnorsson et al., 1983a).

The waters are quartz and chalcedony supersaturated at the discharge temperatures resulting from cooling or mixing of the geothermal water in the upflow. The average deviation from the equilibrium curve in terms of log Q is 0.6 and 0.3 for quartz and chalcedony, respectively.

5.3 Gas geothermometry

The gas content in geothermal systems is controlled by temperature dependent equilibria with alteration minerals in the reservoir rock (Giggenbach,1980; Nehring and D'Amore, 1981, 1984; D'Amore and Truesdell, 1980; Arnorsson et al., 1983a; Arnorsson and Gunnlaugsson, 1985). Various equations for gas geothermometers have been proposed (D'Amore and Panichi, 1980; Nehring and D'Amore, 1981, 1984; Arnorsson et al., 1983b; Arnorsson and Gunnlaugsson, 1985) recently.

 CO_2 , H₂S, CH₄, H₂, N₂, and NH₃ constitute the most abundant gases in geothermal systems. The amount of these gases in the steam phase depend on the original gas composition of the aquifer, the distribution coefficients between steam and water phases and the steam fraction. The proposed

temperature functions include both gas concentrations and gas ratios and when applying all the geothermometers together a valuable information can be obtained on subsurface temperature and condensation/steam-separation in the upflow as well as reactions.

The gas geothermometers which are based on gas ratios will give the most reliable results when condensation in the upflow significantly affects the gas concentrations in the steam and reactions with wall rock minerals have relatively less effect on the gas ratio/ratios, whereas geothermometers which use gas concentrations in fumarole steam are advantageous over the gas ratio geothermometers when steam condensation or phase separation in the upflow have less effect than reactions(Arnorsson and Gunnlaugsson, 1985).

In active volcanic vents the cooling of gases takes place quite rapidly and the gas reactions do not adjust completely to the lower temperatures resulting in higher calculated equilibrium temperatures (from gas analysis of the sampled discharge) than the collection temperature, but somewhat lower than the deep temperatures (Glover, 1976).

Gas analysis data (Glover, 1976) were used to apply the newly calibrated gas geothermometers for Lakes District geothermal areas (Table 8). The excess N_2 was calculated assuming all O_2 in the samples is atmospheric. The gas analyses results are tabulated in Table 8 and the estimated equilibrium temperatures using the gas geothermometers of Arnorsson and Gunnlaugsson (1985) are listed in Table 9.

Lake Langano area

Data for eight fumaroles in the Langano geothermal field are shown in Table 8. They include Aluto B (NE), Finkilo (S), and Bobesa (E) fumaroles, all located inside the Aluto Caldera, whereas Auto and Hulo (W), Kure, Gebiba and Feature 18 (S) are all outside the caldera, (Fig. 1).

There is a considerable variation in the estimated temperatures by the different gas geothermometers. The CO2 estimates (275-357°C) are higher than the estimated temperatures from the other gas geothermometers. However, the maximum temperature encountered through deep exploratory drilling inside the caldera is in the range given by the CO2 geothermometer (318°C). As shown in Gebiba fumarole (291-300°C), CO_2-N_2 and $H_{2S}-H_2$ temperatures compare well within +/- 9°C. The available data are limited so comparison for the other fumarols is not possible. H2S temperatures are at maximum at Aluto B, 239°C with an average of 220°C. The temperature estimated from H2 and CO2-H2 gas geothermometers are lower than that of CO2 but higher than the H₂S temperatures (Gebiba Fumarole). Condensation followed by removal of H_2 is the cause of the discrepancy. Oxidation of ${\rm H}_2{\rm S}$ is more pronounced than that of ${\rm H}_2$ in the upflow. The CO_2-N_2 results are inconsistent in most cases whether correction has been made for excess N2 or not.

The CO2-H2S, CO2-NH3, H2-NH3 ratios and the results from gas geothermometry indicate that Finkilo and Aluto B are closer to a major upflow zone than the fumaroles at Auto and Hulo. Finkilo and Aluto B fumaroles are located on opposite sides of the caldera (NW and S), so presumably the upflow would be within the caldera. This is not in line with interpretation in Glover's (1976) report, but in line with the confirmed result through drilling. The estimated temperatures from T CH4 (180°C) and T NH3 (188°C) are similar to that of the solute geothermometers. However, the agreement between the two should not be taken as a good indication of subsurface temperatures since mixing results estimates by the solute geothermometers in low (see chapter 6). The sulfate-water isotopic temperatures show more or less similar results, i.e. 314°C and 346°C for spring 5 and 12 assuming conductive cooling, and 256°C and 280°C assuming cooling by steam loss, respectively (Craig, 1977). It should, however, be noted that mixing which leads to oxidation of H2S causes sulfate-water isotopic temperature to be high.

Lake Abaya area

The thermal manifestations in Lake Abaya area constitute widely scattered hot springs and fumaroles. Abaya F (Abaya fumarole) and Duguna fumaroles (about 30 km north of the Lake) have been used to evaluate subsurface temperatures. Abaya F, located very near to spring 6 and the Lake, is the most vigorous sampled in the Lakes District and the only one at which the "puggy clay" was observed usually associated with sulfuric acid attack caused by oxidation of H_{2S} (Glover, 1976).

The CO₂, H_2S and CO₂- H_2 geothermometers in this geothermal area are the highest in the Lakes District. The average values from CO2, CO2-N2 (without correction for excess N2), H₂S-H₂, H₂ and CO₂-H₂ gas geothermometers are 344°C, 283°C, 263°C, 251°C, 244°C and 205°C, respectively. The differences between individual gas geothermometers can be explained by condensation or steam separation at elevated pressure and reactions in the upflow. As inferred from the gas geothermometers, the hot water body underneath Abaya area is expected to have a temperature in the range of 300-350°C. Abaya F seems to be closest to the hot water source. This area is charactrised by low resistivity anomaly (Ketsela, 1984). The sulfate-water isotopic temperatures for this area shows 325°C assuming conductive cooling (Craig, 1977).

Corbetti

The thermal manifestations in the Corbetti Caldera (Fig. 1) are hot steaming grounds and fumaroles. Surface alteration minerals in the area include kaolin, montmorilonite (smectite) and amorphous silica (Elias, 1984). Since hot springs do not appear at the surface (lower water level), the fumarole gas chemistry is critical for assessing the system.

The gas analysis results and the calculated temperatures from different gas geothermometers are shown in Tables 8 and 9, respectively. $H_{2}S$ and H_{2} were not detected in the fumaroles except in Koka (located north of the caldera at

a relatively low elevation) which make comparison between geothermometers very difficult. This was because of the high percentage of air contamination.

Koka fumarole is unique among the analyzed fumaroles. Air contamination is very small $(1.56\ 0/0)$ in Koka. Moreover, the gas concentrations including methane are higher than in other fumaroles in the area.

Even though the variation is small, the estimated temperatures from CO_2 is higher than those of the other gas geothermometers. All fumaroles indicate a narrow range of temperature when CO_2 equilibrium temperature function is used (311-333°C). H₂S-H₂ temperatures give similar result 312°C at Koka. H₂S-H₂ temperatures and "corrected" CO₂-N₂ temperatures indicate similar results for Koka fumarole (312°C and 286°C). The other geothermometers, i.e. T H₂S, T CO₂-H₂ and T H₂ show lower values. This is presumably mostly due to reactions in the upflow.

All the above results suggest that Koka is the nearest to the source and that the reservoir is situated north of Corbetti Caldera and may have temperatures in excess of $300 \,^{\circ}$ C. The low resistivty (10 Ohmm) in this locality which extends north to the southern shore of Lake Shalla provides additional evidence for the existence of high underground temperature (Mohammedberhan, 1984). The gas equilibrium temperatures estimated by Glover (1976) are rather low (T CH4 = 168 °C and T NH3 = 187 °C).

6 MIXING PROCESSES

Hot water ascending in geothermal systems may cool by conduction of heat to the surrounding rock, boiling, and mixing with cooler water, or by a combination of these processes.

Geothermometers indicate the temperature at the point of last re-equilibration underground. Hence their application to mixed waters, especially when chemical equilibrium is attained after mixing, will give the temperatures of the mixed water rather than the hot water component. The study of mixing processes in the upflow zones is therefore very important. The application of mixing models, rather than solute geothermometers alone is useful in evaluating the temperature of the hot water component in the mixture.

6.1 Evidence for mixing

In most cases geothermal water is higher in dissolved solids than cold water. The mixture lies inbetween the two depending on their proportion in the mixture. Fournier (1979b) and Arnorsson (1985a) discussed the characteristics of mixed waters in detail. Some of these are :

 variations in chloride concentration of boiling springs is too great to be explained by steam loss;

(2) variation in concentrations but not in ratios of relatively conservative elements that do not precipitate from solution during movement of water through rock, such as Cl/B;

(3) variation in oxygen and hydrogen isotopes (especialy tritium);

(4) cool springs with large mass flow rates and much higher temperatures indicated by chemical geothermometers (greater than 50 °C);

(5) systematic variations of spring compositions and measured temperatures;

(6) low pH relative to the water salinity (often in range of 6-7 for Cl concentrations of less than 100 ppm) and high total carbonate, at least if the mixing has prevented boiling, and the temperature of the hot water component exceeds some 200°C;

(7) the tendency of calcite undersaturation; and

(8) low calcium/proton activity ratios.

Mixing in geothermal systems, if it occurs, can be convincingly demonstrated when data on the chemical composition of scattered thermal and cold waters is available. Linear relations between Cl, B, and O-18 constitute the main evidence for mixing. Also similar relations between Cl, SiO_2 and SO4 concentrations may substantiate evidence for mixing (Arnorsson, 1985a).

Lake Abaya area

D/H versus 0-18/0-16 variations in selected thermal and cold waters from the Lakes District geothermal areas are shown in Fig 8. All the Lakes and most shallow wells plot very close or on the line describing D and 0-18 for evaporative lakes in East Africa according to Craig (1977).

Abaya spring 6, the hottest and the most mineralized shows considerable oxygen shift. All the other springs plot very close to the precipitation lines. Spring 6 has the highest hot water fraction as indicated from mixing models. Therefore the oxygen shift should be a result of hot water-rock interaction at higher temperatures but steam loss may also contribute.

Fig. 9 shows the relation between Cl, B, 0-18, SiO₂ andSO₄ for waters from Lake Abaya. Except for spring 6 all the other springs are very low in chloride making it difficult to conclude with certainty about mixing in the upflow.

Lake Awasa-Wondo Genet area

Thermal springs in Lake Awasa-Wondo Genet area show little or no oxygen shift except small shift at Wondo Genet spring 41 (Fig. 8).

The geothermal waters in this area are mixed as indicated by near linear to linaer relations of Cl-B, Cl-O-18 and Cl-SO4 (Fig. 10). The Cl-SiO2 relationship indicates much silica precipitation from sample 40. The sample from spring 40unlike the others in the area has high concentrations of carbonate, chloride, lithium, sodium, potassium and sulfate.

Lake Shalla area

Spring 30, the most vigorous spring in the Shalla area, shows significant 0-18 shift. Craig, 1977 explained this shift as being due to mixing of 50% Lake Shalla water and low chloride groundwater. On the other hand Craig (1977) suggested Shalla 90 (with small oxygen shift but higher in Cl due to contamination) as a more likely source. But spring 90 is steam heated as disscused in section 4. Therefore, the suggestion of spring 90 as a source is unlikely.

Mixing processes are convincingly demonstrated for the Shalla area by the Cl-B relation (Fig. 11). Data on 0-18 are limited to only a few springs, No. 30, Shalla cold spring, and springs which are steam heated or contaminated/evaporated.

The eastern Shalla springs show a positive Cl-temperature relation, but the reverse was obtained for Cl-SiO₂. The analyzed silica in the area is almost equivalent to amorphous silica saturation at the discharge temperature.

Cl-SO4 in this area shows a negative relation. The redox equilibria involving hydrogen, sulfide and pH might be the controlling factor for sulphate mobility

 $H_{2S} + 4H_{2O} = SO4^{-2} + 4H_{2} + 2H^{+}$

Similar relation was seen in Landmannalaugar waters, Iceland (Arnorsson, 1985a).

The solute geothermometers indicate temperature of about 200°C. This is expected to be minimium because mixing prevented the solute geothermometers to give higher values underneath Shalla area. This is a supporting evidence for the oxygen shift of the Shalla spring 30 as being a result of hot water/rock interaction and steam loss rather than mixing of low Cl groundwater with water from Lake Shalla. Hence Lake Shalla is a perched water which is not involved in mixing processes. It attained its concentration through extensive evaporation.

Lake Langano area

Springs with relatively high amount of cold water fraction in the Langano geothermal area lie on the precipitation line. In case of spring 11 in Geyser Island, there is an oxygen shift, but this is explained by Craig (1977) as steam heated perched groundwater. Mixing in the Langano area is evidenced by a near linear relation of Cl-B and Cl-18-0 (Fig.12). The SiO₂-Cl relation is not good, presumably due to some silica precipitation. The same thing applies to the Cl-SO₄ relationship, most likely due to reactions affecting SO₄ in the upflow.

6.2 Mixing models

As evidence exists that the hot spring waters in all the geothermal areas of Lakes District are of mixed origin, an attempt was made to use mixing models to estimate the temperature of the hot water component. Silica-enthaly and silica-carbonate mixing models have been applied (Figs. 13 and 14).

6.2.1 Silica-enthalpy warm spring mixing model

This method is applicable to warm spring waters that have not lost heat before mixing except by steam formation. It is assumed that no loss of heat, nor steam formation occurs after mixing. The initial silica content of the deep hot water is assumed to be controlled by the solubility of quartz, and no dissolution nor deposition of silica occurs before or after mixing.

The silica-enthalpy warm spring mixing model was applied to Lake Abaya, Lake Awasa-Wondo Genet and Langano areas assuming no steam loss and was found togive temperatures for the hot water component of 266°C, 213°C and 223°C, respectively. The chloride-enthalpy mixing model gives similar results for the Langano area, 220°C (Melaku, 1983). temperatutes are lower than both those of gas These geothermometry estimates and those encountered in the high temperature drillholes. For example this temperature for the Lake Langano area is lower than the temperature encountered through drilling by 100°C. This is most likely due to removal of silica from solution in the upflow.

The most vigorous Geyser Island springs which are far from Aluto have the highest hot water component as indicated by their salt content. This must be due to variable mixing in the upflow and that the Geyser Island springs have a better access to deeper, less mixed waters as they are located near vertical fractures.

6.2.2 Silica-carbonate mixing model

If there are sufficient data on warm waters containing an unboiled hot water component, the SiO2-carbonate diagram may be used to evaluate the temperature of the hot water component (Arnorsson,1985a). This model assumes that the total carbonate species will appear as CO_2 which is a satisfactory approximation at temperatures higher than 200°C. In addition to the evaluation of the hot water components, this model gives the opportunity to distinguish boiled and unboiled waters.

The temperature of the hot water components as indicated by this model are 297°C and 284°C for Lake Abaya and Lake Awasa-Wondo Genet, respectively (Fig.14). The SiO₂ values of the reservior fluids underlying Abaya and Wondo Genet areas as inferred from this model correspond to 660 and 610 ppm. The results of this model are in a good agreement with the results of the CO₂ gas geothermometer and, sometimes with that of Na-Li geothermometer and sulfatewater isotopic temperatures.

Assuming the cold water component to have more or less similar Cl and temperature values as the nearby rivers, spring 6 has got the highest hot water fraction (27%) in the area, while all the others are highly diluted. The hot water is estimated to have a chloride concentraion of some 2000 to 2600 ppm. The chloride values of the other springs are lower than would be expected from their temperatures. This is best explained by partial steam heating of these waters.

Even though Lake Abaya is enriched in heavy isotopes as a result of evaporation, its salinity is very low (41 ppm Cl). This may open the possibility of Lake Abaya to be involved in the mixing process.

Temperatures estimated by the SiO2-carbonate mixing model for Awasa-Wondo Genet area is 284°C. The Na/K temperatures for spring 4, 40 and 52 are 220°C, 214.5°C and 212°C, respectively. The Na-Li geothermometer shows 265°C for spring 4, but higher values for the coldest spring, 44 (which has the characteristics of highly mixed water), and to spring 40 (highest Li in the District which might not be in line with the waters used for calibration). Spring 40 lies below the mixing line of the silica-carbonate model, that is the SiO₂ value is low for the carbonate. A possible cause for this is the precipitation of SiO2 in the upflow subsequent to mixing. Sulfate-water temperatures for Wondo Genet (Belle Tebel) springs as reported by Craig (1977) are 255°C assuming cooling with steam loss and 318°C assuming conductive cooling. All this suggests the existance of an independent heat source underneath Wondo Genet with a temperature of 250-300°C.

The correlation of silica and carbonate for waters in the Langano area for which data are available is poor (not shown). Possibly the removal of silica is the main cause.

Since the SiO2 values of Shalla springs are unreliable (show negative correlation with Cl), use of silica-enthalpy and silica-carbonate mixing models are not possible. There are no boiling springs except spring 30. The Cl concentrations in the springs are variable. Thus, an attempt has not been made to use the Cl-enthalpy mixing model. However, Na/Li and Na/K geothermometers, indicate an independent heat source underneath Shalla with temperature in excess of 200°C (see Table 6). It seems unlikely that the Shalla springs are an outflow from Aluto-Langano and Corbetti geothermal areas which are 40 and 25 km away respectively. This is convincing especialy when the results of shallow and/or deep wells between Shalla and the respective fields are considered. The close resemblance between Chittu and South Shalla springs clearly demonstrates that the former springs are an outflow from Shalla. Reliable SiO2 determination of Shalla springs and complete chemical data from shallow wells inbetween Shalla and Corbetti will assist in confirming this result.

7 SUMMARY

1. The waters in the Lakes District have near neutral pH and are primarily of the sodium bicarbonate type. Mixing with cold waters occurs invariably in the upflow. The hot water components underlying the geothermal areas in this district contain dissolved total carbonate in the range of 3000-5000 ppm.

2. The gas geothermometers of Arnorsson and Gunnlaugsson (1985) give probably good picture of subsurface temperatures for Lakes District geothermal systems. Condensation is always strong in the upflow. Hence CO_2 temperatures tend to give high estimates of subsurface temperatures. Sometimes the sulfate-water isotope geothermometer and Na-Li results are similar to the CO_2 temperature. Because of mixing, the solute geothermometers yield low results when surface geothermal fluids are used to estimate the subsurface temperature.

3. The silica-carbonate mixing model seems to give the most reliable results of all the mixing models in the estimation of the reservoir temperatures in Lakes District, where there are few boiling springs in each locality and the temperature distribution is highly affected by mixing.

4. A hot water body exists underneath Aluto-Langano Complex with temperature in between 320°C and 340°C. It flows towards south, southwest, north and east supplying the surrounding springs at lower elevation and fumaroles at higher elevations.

5.Shalla probably has its own heat source with a minimum temperature of 200°C and subsurface flow towards east, south and south west supplying Shalla and Chitu springs.

6. There probably exists a hot water body with temperature in excess of 300°C north of Corbetti Caldera. Flow from the reservoir is probably towards south, southwest and southeast discharging steam at the surface (fumaroles, hot and steaming grounds) in and around the caldera.

7. The springs at Wondo Genet and east of Awasa are possibly fed by a high temperature water of some 250-300°C underneath Wondo Genet.

8. The deep hot water underlying the Abaya area is thought to have silica of about 660 ppm and 2000-2600 ppm chloride with temperatures in the range of 300-350°C. The hot water probably flows to the north, northwest and northeast and mixes with low chloride groundwater.

9. The waters in Lakes District are supersaturated with respect to calcite, nearly saturated with fluorite and highly undersaturated with respect to anhydrite at depth. The waters are somewhat supersaturated with quartz and chalcedony at the surface.

8 RECOMMENDATIONS

1. Special attention should be paid to establishing a data base of reliable chemical analyses of the geothermal and surface waters in the Lakes District. Complete chemical analyses of waters in Shalla and Wondo Genet areas are essential to substantiate or disprove the present interpretation.

2. Both hot springs and fumaroles occur in the geothermal fields of the Lakes District except in the Corbetti geothermal area where there are only fumaroles. It is advantageous to use both fumarolic steam chemistry and hot springs chemistry to predict subsurface temperatures.

3. Fumaroles and shallow wells which are located around Corbetti and inbetween Shalla and Corbetti should be sampled and analyzed to understand the Corbetti and Shalla geothermal systems and to see their interrelationship. It would be advantageous to drill more shallow wells in the same area, and in and around the Corbetti caldera to assist the gas chemistry interpretation.

4. Both geochemical and geophysical results indicate the heat source for the Abaya area to be close to the lake. Therefore, chemical sampling and temperature measurement at the bottom of the lake are important to identify any water flow underneath the lake itself.

5. Special approaches are required for sampling and analyzing geothermal fluids. Therefore, it is advantageous for the Geothermal Division to have its own geochemical laboratory.

6. The following equipment are recommended for the geothermal geochemical laboratory for improving precision and the speed of analysis.

(a) Atomic Absorption spectrophotometer

(b) Automatic dilutor: This instrument increases sample preparation for atomic absorption analysis 3-5 times compared to conventional dilution methods.

(c) Coulombimetric chloride titrator. This instrument will improve both the speed and the precision of the analysis as compared with the Mohr titration.

(d) Glass gas sampling bulbs with septum and pressure check valves.

(e) Automatic pipettes with tip ejectors, and fixed volume micropipette.

(f) Silicone tubing suitable for high temperature fluid sampling as they have good heat and solvent resistances.

(g) Digital balance. This is specially useful for gas analysis in terms of accuracy and speed.

(h) An effective cooling system for collection of samples from wells. A system using a motor vehicle radiator has been fabricated in Iceland.

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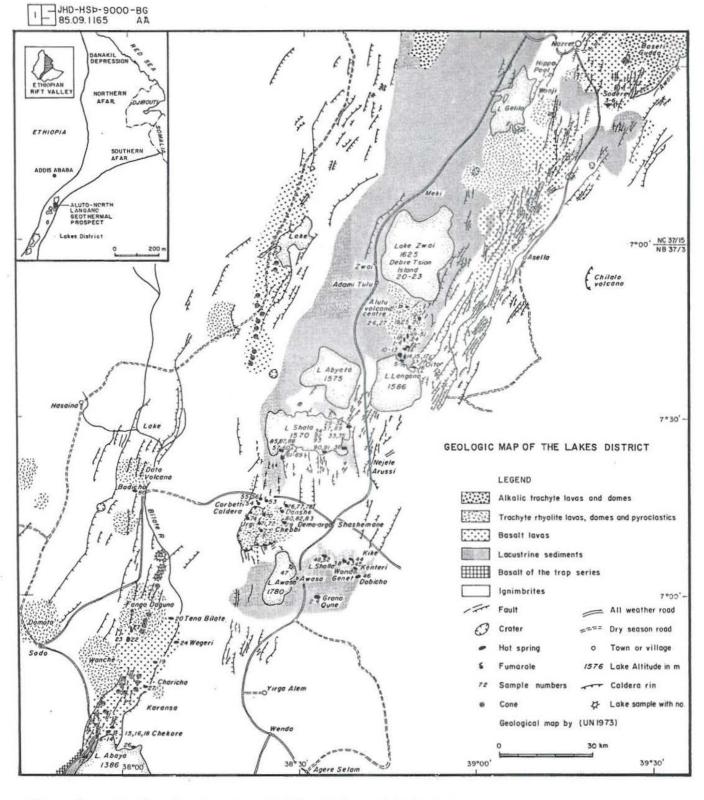
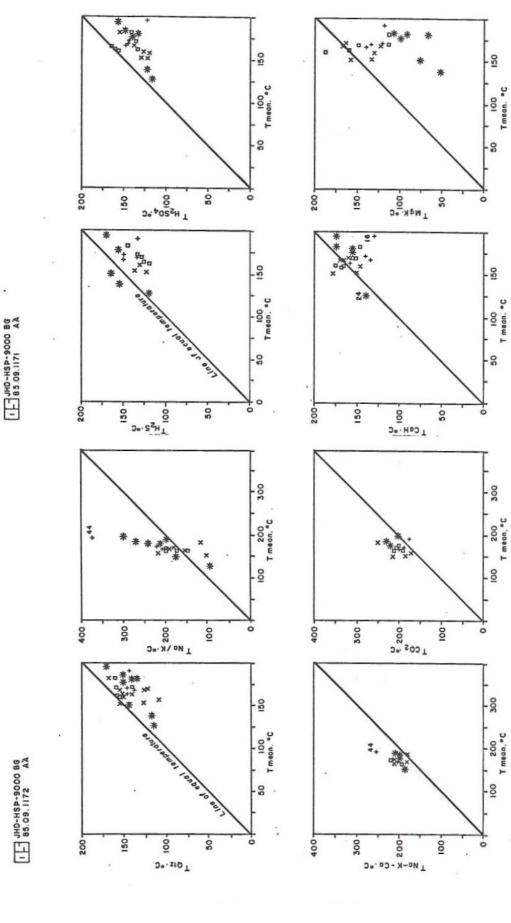


Fig. 1. Geological map of the Lakes District.



+

a Langano

* Abaya + Awasa - Wondo Genet X Shalla



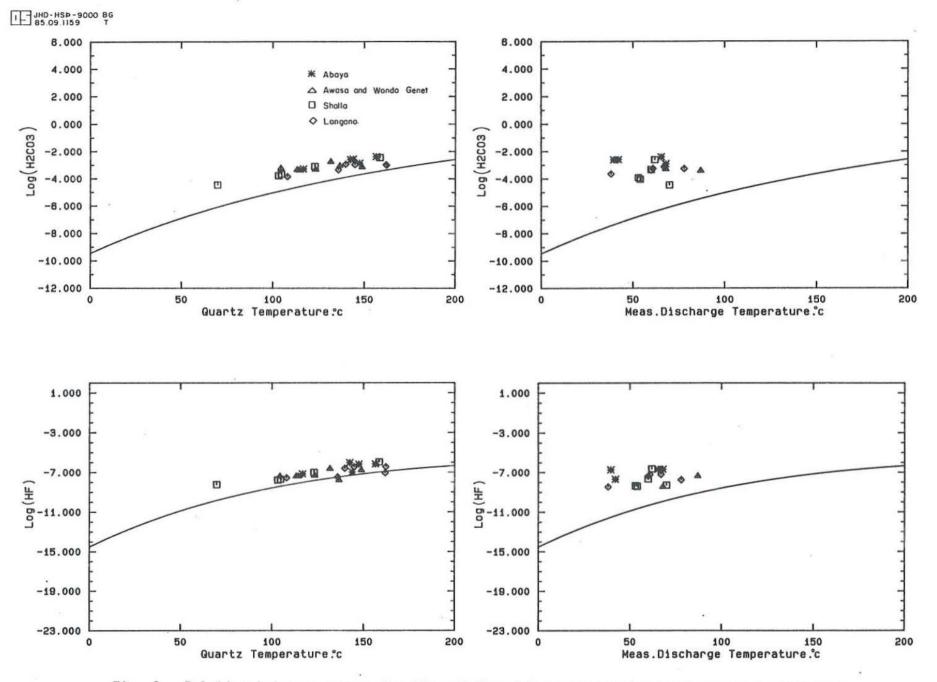


Fig. 3. Relation between carbon dioxide and fluoride concentrations and quartz equilibrium temperature/discharge temperature in the Lakes District geothermal waters.

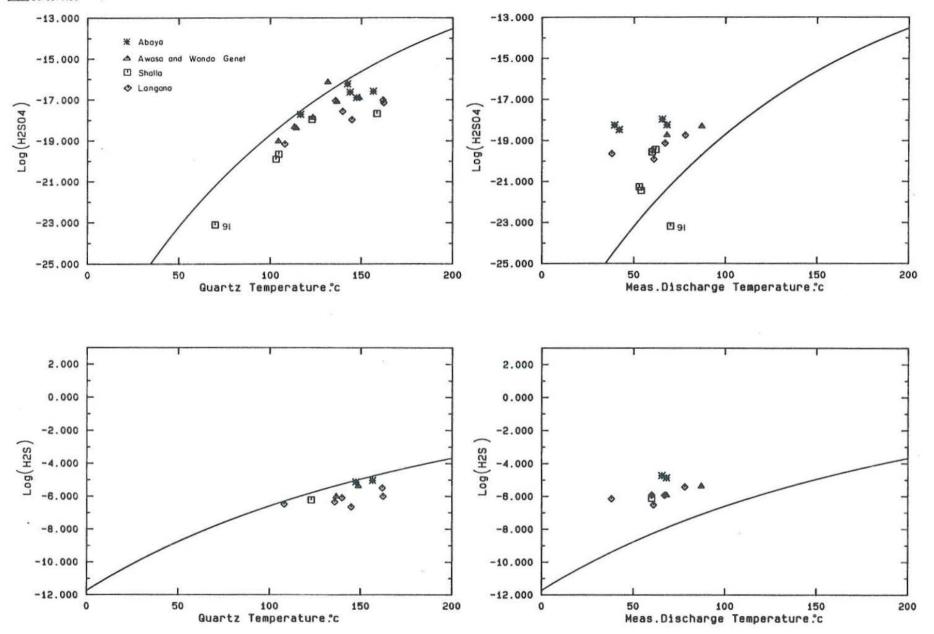


Fig. 4. Relation between sulfate and sulfide concentrations with quartz equilibrium temperature/discharge temperature in the Lakes District geothermal waters.

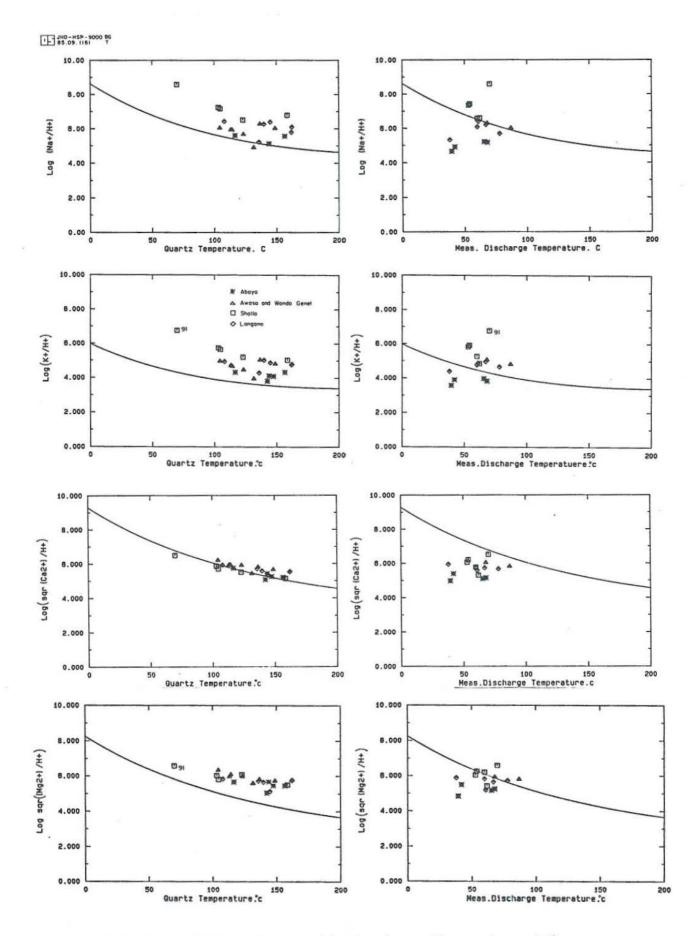


Fig. 5. Relation between cation/proton ratios and quartz/discharge temperature in the Lakes District geothermal waters.

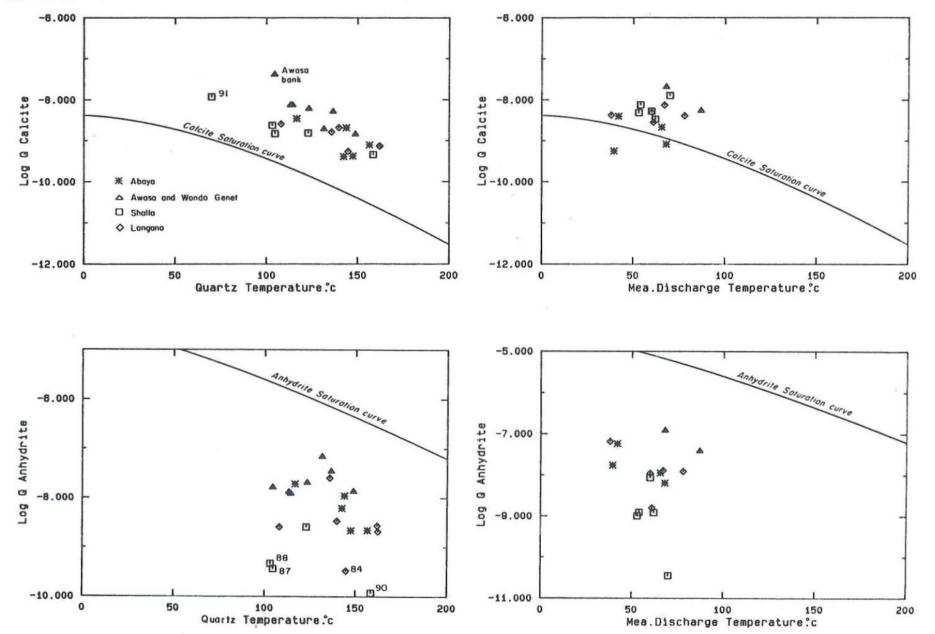
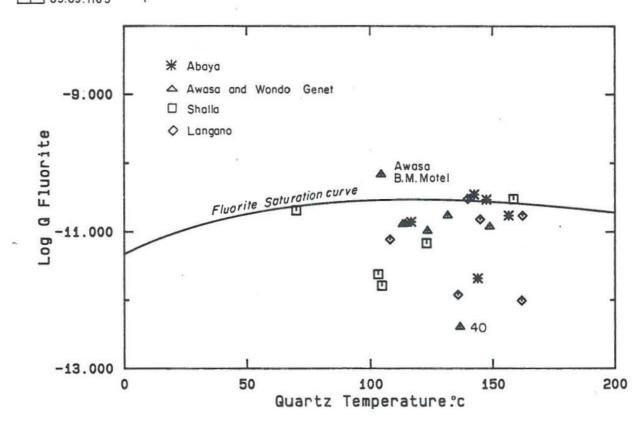


Fig. 6. State of calcite and anhydrite saturation at quartz/discharge temperatures in the Lakes District geothermal waters.

JHD-HSP-9000 BG 85.09.1163 T



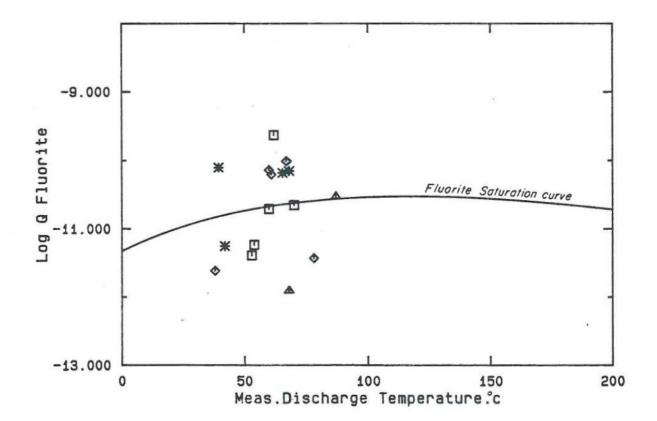


Fig. 7. State of fluorite saturation at quartz/discharge temperatures in the Lakes District geothermal waters.

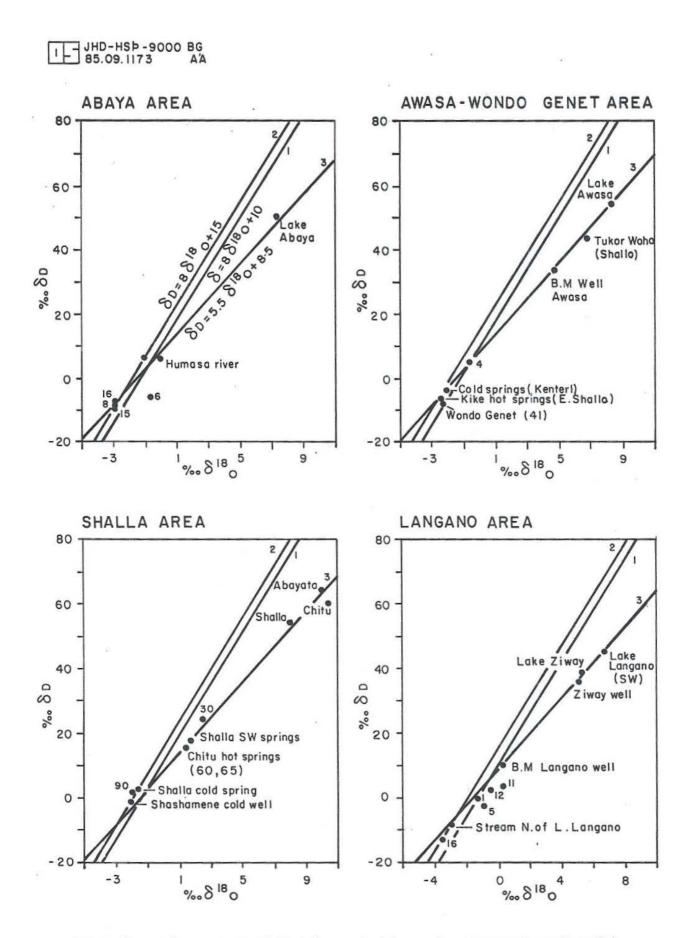


Fig. 8. D/H and 0-18/0-16 variations in thermal and cold waters from the Lakes District.



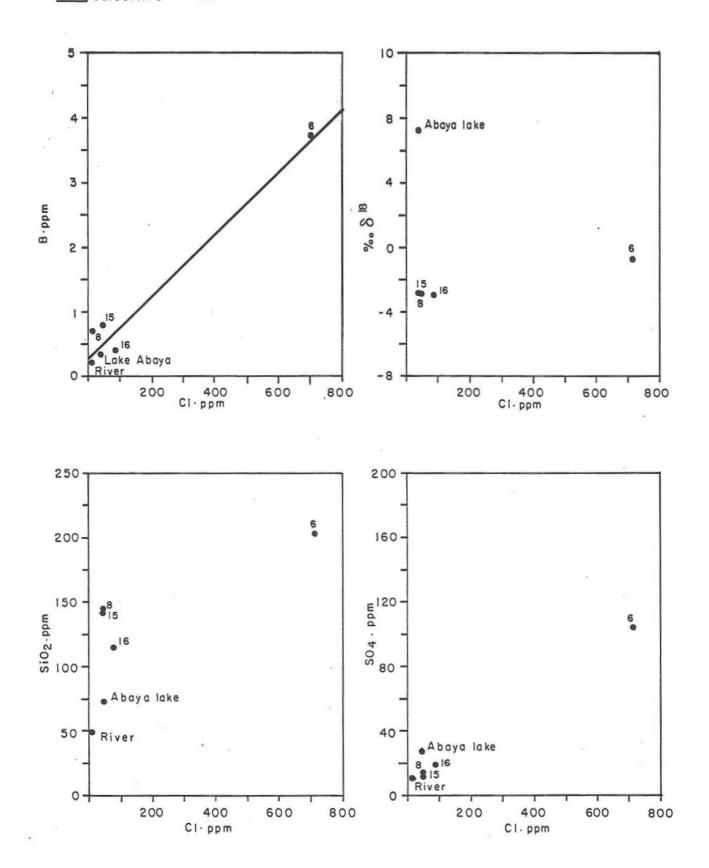


Fig. 9. Relationship between chloride concentrations, boron, 0-18, Si0₂ and SO4 in cold and thermal waters from the Abaya area.



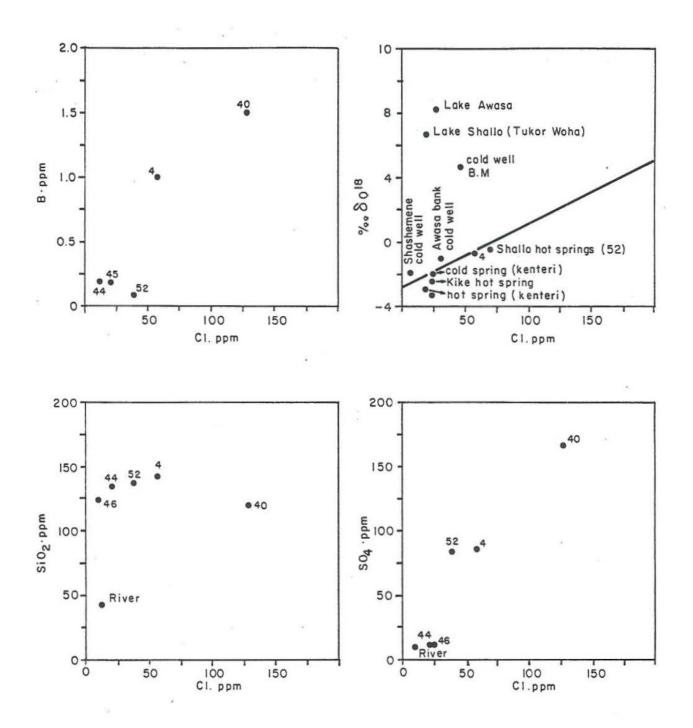
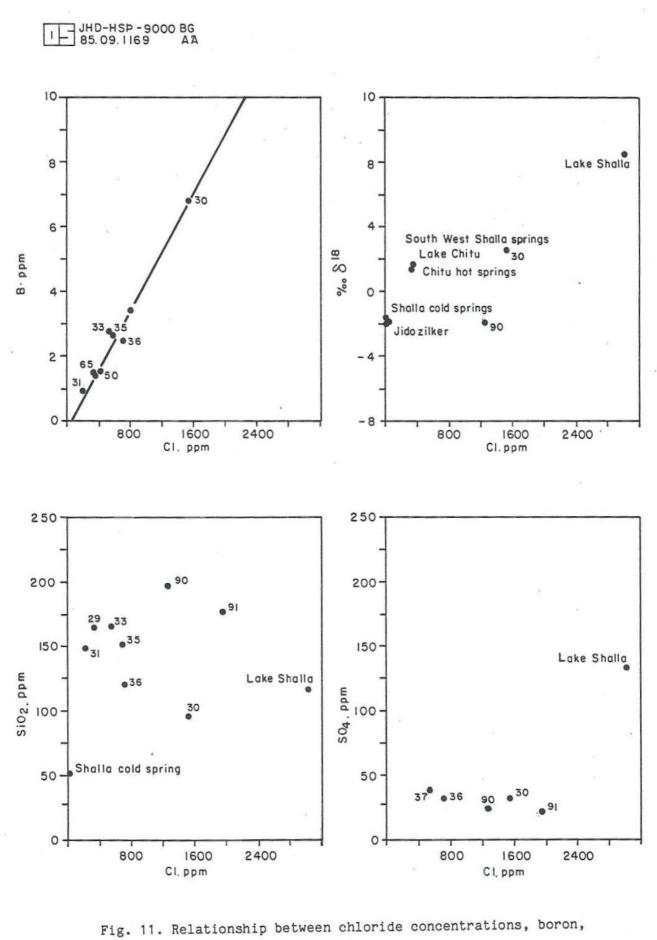
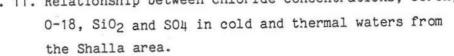
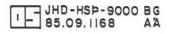


Fig. 10. Relationship between chloride concentrations, boron, 0-18, $Si0_2$ and S04 in cold and thermal waters from the Awasa-Wondo Genet area.







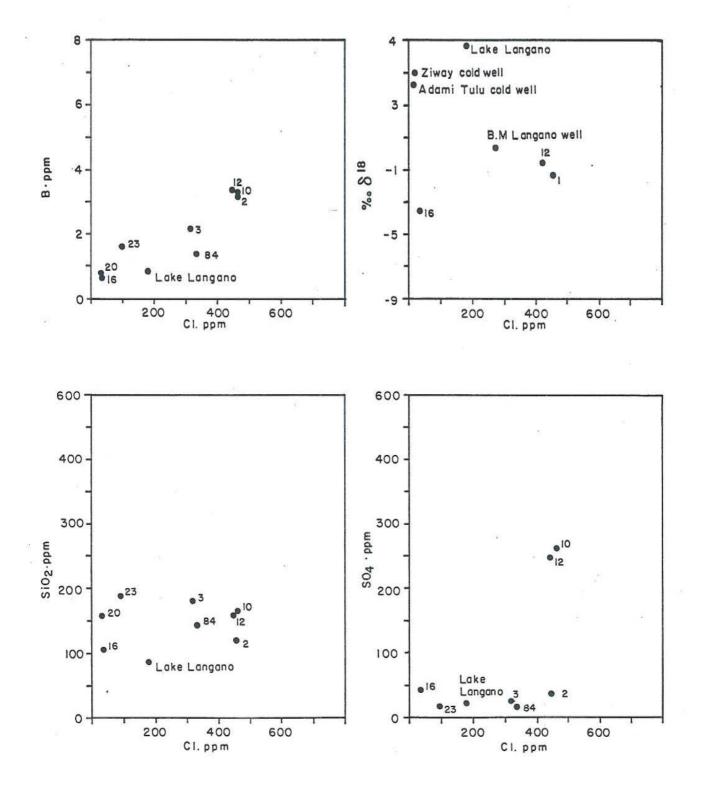
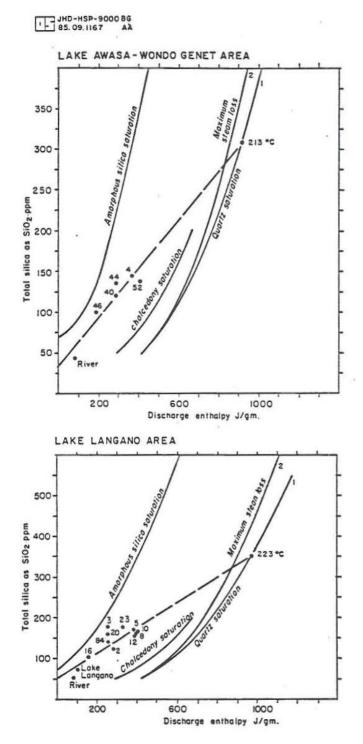


Fig. 12. Relationship between chloride concentrations, boron, $0\text{-}18\,,\,\text{Si}0_2$ and SO4 in cold and thermal waters from the Langano area.



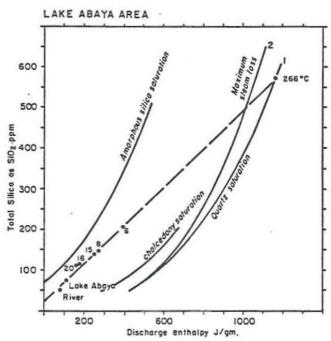


Fig. 13

Silica-enthalpy mixing model. Quartz saturation curves (1 and 2) are based on Fournier and Potter (1982a). Chalcedony and amorphous silica saturation curves are based on Fournier (1981). The broken line represents the silicaenthalpy relationship of the geothermal waters.

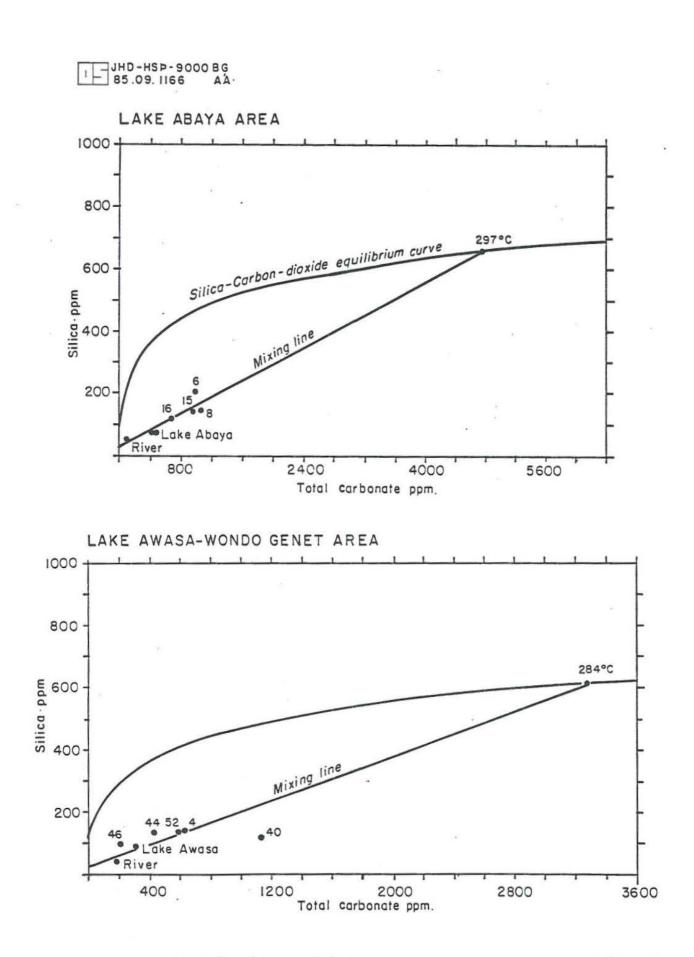


Fig. 14. Silica-carbonate mixing model. The temperature dependence of silica was assumed to be controlled by quartz solubility according to the data of Fournier and Potter (1982).

TABLE 1 Chemical composition of waters in the Abaya Area (ppm)

Location	T (°C)	Flow (1/s)	рH	H ₂ S	Total Carbonate (CO ₂)	NH4	Li	К	Na	Ca	Mg	F	Br	I	Cl	SO4	В	Si02
NB 371616	95	11.6	9.6	7	995.33	1.00	1.80	240	1290	< 3	<2	43	na	0.05	711	104	3.73	204
8	65.5	11.5	7.2	2	1059.72	0.19	0.58	50	500	20	14	13	na	0.01	48	12	0.70	146
15	60	20.0	na	nd	950.70	0.32	0.62	50	530	18	9	14	na	0.01	48	12	0.73	141
16	42	9.0	7.2	nd	671.53	na	0.65	39	230	52	48	2	nđ	0.02	81	18	0.40	116
19	68	1.6	7.4	2	456.47	na	0.07	22	280	8	7	18	nd	0.01	45	11	0.27	126
20	39.5	83.3	7.0	nd	437.18	na	<0.05	27	194	16	5	12	0.4	0.01	18	11	0.12	112
Lake Abaya	-	-	8.0	na	441.99	na	0.05	20	226	18	5	7	0.7	na	41	27	0.31	73
River Abaya turnoff	-	-	8.3	na	63	na	<0.05	8	17	8	2	0.5	0.2	na	<10	<10	0.18	49

TABLE 2 Chemical composition of waters in Lake Awasa-Wondo Genet Area (ppm)

NB 371614	87	1.0	8.4	3	627	na	0.42	43	397	11	5	13	1.1	0.01	57	86	1.0	143
NB 3712140	68	2.1	8.4	0.9	1134	na	2.20	67	655	23	7	2	0.6	0.02	128	166	1.5	119
52	96	small	8.5	3	594.60	na	0.88	44	430	<3	<2	40	nd	0.01	38	83	0.09	137
44	69	6.3	8.15	1	421.90	na	0.09	51	170	11	5	2	0.2	0.01	21	<10	0.19	135
46	43	10.0	7.35	0.2	119.94	na	<0.05	17	50	4	4	2	0.3	0.01	<10	<10	0.19	99
Lake Awasa (47)	26	-	8.4	nd	307.54	na	0.13	43	170	7	7	6	nd	0.01	26	<10	0.19	95
Awasa Chem. Corp.	-	-	7.3	na	519.75	na	0.53	24	124	35	33	6	0.7	0.02	12	87	0.52	93
B.M. Hotel well	-	-	8.6	na	1019.92	na	0.55	60	416	89	55	9	0.7	0.04	90	12	0.34	59
Oasis Hotel well	-	-	8.3	na	469.19	na	0.16	23	220	30	15	5	0.1	0.1	25	24	1.30	85
Afewort Hotel well	-	-	8.4	na	632.96	na	0.17	34	330	22	10	7	0.8	0.01	41	22	0.3	71
Hotel Bellevue	-	-	8.5	na	598.42	na	0.16	28	300	22	15	7	0.7	0.01	40	21	0.76	73
River East of Awasa	-	-	7.6	na	186.40	na	0.08	16	77	10	3	3	na	na	11	<10	na	43

na = not analysed, nd = not detected

waters 1	mposition of waters 1	I composition of waters 1
waters	mposition of waters 1	mposition of waters 1
waters 1	mposition of waters 1	I composition of waters 1
	mposition	1 composition

Location		н	Flow	μd	H2S	Carbonate	NH4	L1	К	Na	Ca	Mg	64	Br	н	Cl	SON	B	S102
		(0.)	(1/s)			(02)													-
IB 3712-																			
ake Shalla ((34)	1	,	10.15	-	6478.43	1.18	0.05	225	6800	\$	<2>	300	pu	0.05	3030	137	24.2	
	29	51	1.2	2.6	0.6	898.64	1.20	<0.05	11	660	<3	<2	20	1.1	0.05	358	<10	1.41	
	30	96	33.3	8.9	-	2177.30	1.85	74.0	69	2340	<3	<2>	60	11.5	0.09	1526	31	6.86	
	31	52	4.5	9.3	-	011.001	na	0.06	11	380	<3	<2	10	1.4	0.04	226	<10	0.91	
	33	53	0.5	9.6	-	1378.62	na	0.07	85	1150	<3	<2	35	1.2	0.05	532	37	2.72	
	35	11	<0.1	8.6		1242.47	na	0.50	62	1100	<3	5	30	2.8	70.07	668	<10	2.62	
	36	80	<0.1	8.35	-	1466.18	na	0.54	98	1280	<3	e	40	2.2	0.07	722	33	2.40	0.5
	90	62	0.1	8.0	pu	3480	na	0.30	80	2600	4	3	56	pu	0.1	1249	24	na	
	91	70	3.0	10.1	pu	6861.80	na	0.50	110	4157	2.4	0.96	150	pu	0.1	1958	22	na	(Mrss)
	87	53	5	9.2	pu	1646.47	na	<0.05	70	1344	1.2	0.50	21	0.9	0.03	569	48	na	
	88	54	9	9.3	pu	1607.04	na	<0.05	70	1284	1.7	0.95	22	0.9	0.03	510	45	na	
	60	51	>6.6	8.7	-	1570.24	na	<0.05	06	1150	<3	e	20	2.2	0.03	11 1 1	61	1.58	68
	65	60	3.3	8.5	1.0	1912.35	0.13	<0.05	83	970	#	5	20	pu	0.03	350	78	1.48	
B.M. Hotel Well	111																		
Shamene Shemene		,	,	8.0	a u	123.34	au	20.05	4	115		~	~	0.4	0.04	<10	01	11 0	5

TABLE 4 Chemical composition of waters in the Lake Langano Area (ppm)

491.37 na <0.05 24 423 4 1 13 0.9 0.03 180 22 0.81 73 675.64 nd 0.20 45 530 9 6 20 1.3 0.04 453 32 3.3 123 675.64 nd 0.20 45 530 9 6 20 1.3 0.04 318 24 2.19 179 7200.33 na 0.37 45 530 9 6 20 1.3 0.04 318 24 2.19 179 7200.33 na 0.45 55 730 9 6 20 1.3 0.04 318 24 2.19 179 559.09 na 0.46 55 735 <2 14 2.6 0.06 449 247 3.38 155 449 val 0.46 55 735 <2 12 1.0 0.04 272 344 3.11 168 429.77 0.50 1.08 22<																
na <0.05																
$\begin{array}{rrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrr$	9.1 na	491.	37	na	<0.05	24	423	4	-	13	0.9	0.03	180	22	0.81	73
nd 0.20 45 530 9 6 20 1.3 0.04 318 24 2.19 na 0.37 45 858 3 0.24 38 0.5 0.04 318 24 2.19 na 0.45 56 750 <3 <2 14 2.6 0.06 460 262 3.30 na 0.45 56 735 <3 <2 14 2.6 0.06 449 247 3.38 0.50 1.00 39 570 <3 <2 12 1.0 0.04 272 384 3.11 0.45 0.84 32 0.25 12 1.0 0.04 272 384 3.11 0.85 0.84 3 2 0.8 0.04 272 384 3.11 0.86 0.81 3 2 0.8 0.04 274 366 2.79 na 0.56	8.1 0.6 1	1117.	19	0.71	0.55	81	826	12	17	24	2.4	0.04	453	32	3.3	123
na 0.37 45 858 3 0.24 38 0.5 0.02 339 15 1.40 na 0.45 56 750 <3	8.2 0.6	67	5.64	pu	0.20	45	530	6	9	20	1.3	0.04	318	24	2.19	179
na 0.45 56 750 <3 <2 14 2.6 0.06 460 262 3.30 na 0.46 55 735 <3 <2 14 2.6 0.06 490 247 3.38 0.50 1.00 39 570 <3 <2 14 2.6 0.06 449 247 3.38 0.50 1.00 39 570 <3 <2 12 1.0 0.04 272 384 3.11 0.85 0.84 32 50 <3 <2 12 1.0 0.04 272 384 3.11 0.85 0.84 32 50 <2 9 0.8 0.01 274 366 2.779 na 0.56 20 17 8 7 nd 0.02 31 410 0.81 na 0.18 25 240 15 18 7 nd 0.02	8.3 0.2 1	120	0.33	na	0.37	45	858	e	0.24	38	0.5	0.02	339	15	1.40	141
na 0.46 55 735 <3 <2 14 2.6 0.06 449 247 3.38 0.50 1.00 39 570 <3	11.6 9.1 0.4 54	54	5.03	na	0.45	56	750	\$	<2	14	2.6	0.06	1460	262	3.30	165
0.50 1.00 39 570 <3	8.9 0.2	55	9.09	na	0.46	55	735	\$	<2	#	2.6	0.06	449	247	3.38	155
0.85 0.84 32 560 <3	8.7 0.6	42	77.6	0.50	1.00	39	570	<3	<2	12	1.0	0.04	272	384	3.11	168
na 0.56 20 100 17 8 2 0.5 0.01 34 37 0.72 na 0.118 25 240 15 8 7 nd 0.02 31 <10	8.7 0.6	-	33.52	0.85	0.84	32	560	\$3	<2	6	0.8	0.04	274	366	2.79	161
na 0.18 25 240 15 8 7 nd 0.02 31 <10 0.81 na 0.18 25 240 15 18 7 nd 0.02 31 <10 0.81 na 0.53 38 400 8 5 5 nd 0.02 95 31 1.58	8 0.2	27	6.30	na	0.56	20	100	17	80	2	0.5	0.01	34	37	0.72	105
na 0.18 25 240 15 18 7 nd 0.02 31 <10 0.81 na 0.53 38 400 8 5 5 nd 0.02 95 31 1.58	7.6 1	5	37.85	na	0.18	25	240	15	8	2	pu	0.02	31	<10	0.81	159
na 0.53 38 400 8 5 5 nd 0.02 95 31 1.58	7.6 1	53	17.85	na	0.18	25	240	15	18	2	pu	0.02	31	<10	0.81	159
	8.15 2	73	31.45	na	0.53	38	400	8	5	ŝ	pu	0.02	95	31	1.58	176

na = not analysed, nd = not detected

Abaya			Langano		
Location	o∕oo &D	0/00 8 ¹⁸ 0	Location	o∕oo &D	0/00 \$ ¹⁸ 0
NB 37161- 6	-5.7	-0.66	NB 37121-		
8	-8.7	-2.88	Lake Langano (SW)	45	6.73
15	-9.4	-2.98	B.M. Langano well	10	0.39
16	-7.1	-2.70	Lake Zwai (Bulbula River) 39	5.29
Lake Abaya	49.6	7.25	Swai well		
Humasa River	6.2	-0.07	Adami Tulu well	32.6	4.28
			1	-0.3	-1.33
			5	-2.2	-0.87
			11	3.6	0.39
			12	2.5	-0.44
Awasa-Wondo Genet			Shalla		
Location	o/oo ≬D	0/00 8 ¹⁸ 0	Location	0/00 &D	0/00 8 ¹⁸ 0
NB 37121-			NB 37121-		
Wondo Genet (41)	-8.0	-2.38	Lake Shalla, surface	54.5	8.49
Kike Hot Springs (45)	-6.2	-2.47	Lake Chittu	60.3	10.48
Shallo Hot Springs (52)	-5.7	-0.47	Shalla cold spring	2.9	-1.62
Graha Quhe (4)	5.3	-0.69	Lake Abayata	64.2	10.00
Kenteri Cold Springs	-3.3	-2.06	Shashemene well	-1.4	-2.05
Kenteri Hot Springs (45)	-7.6	-3.00	30	2.4	2.5
Lake Awasa	54.5	8.25	90	1.9	-1.97

Shalla S-W spring

Chittu hot springs

Jido River

12.78

1.47

-1.89

17.9

15.9

2.1

Lake Shallo

Awasa Bank Well

Awasa B.M. Well

Shashemene Well

44

2.8

34.4

-1.4

6.77

-1.15

4.67

-2.05

TABLE 5 Isotopic composition of waters in the Lake Abaya, Lake Awasa-Wondo Genet, Lake Shalla and Lake Langano areas

Sample no.	Ti	T2*	тз*	Т4	T5*	T6	Т7	т8	т9*	T10	T11*	T12*	T13	м	δ
Abaya:															
NB 37161- 6	171.4	150.0	286.7	-	151	204.5	170	299	305	174	224.5	-	157	196	48
8	151.6	129.2	215.1	201	128.5	218.5	154	212	275	156	100	247	139.5	176	30
15	150.2	127.8	202.8	200	127	227	-	199.5	269.5	175	107.5	-	149.5	183	28
16	138.2	115.2	266.5	208	114	203	-	271	(382)	134.5	66	161	133	181	51
19	144.4	121.6	177.3	185	120.5	182	164.5	175	139	129	75.5	136.5	76	151	36
20	136.7	113.6	242	204	112.5	200	-	241.5	-	156.6	92.5	237	139	180	38
22	118.2	94.2	401.5	-	93.5	147	154	-	-	150	52	145.5	123	138	15
25	115.2	91.1	96.7	-	90.5	167.5	119.5	98.5	187	139.5	70.5	201.5	118.5	126	22
wasa and Won	do-Genet:														
IB 37121- 4	148.8	126.3	222.6	207	125.5	190.5	151	220	265	140.5	120	203	144.5	172	31
40	138.2	115.1	217.3	206	114	201.5	133	214.5	(425.5)135.5	134.5	148	145	168	35
44	144.9	122.2	(332.2)	256	121	178.5	132	375	199	130.5	119.5	146	123.5	191	86
52	146.2	123.5	215	-	122.5	188.5	150.5	212	(342.5)158.5	140.5	-	143	166	25
halla:															
IB 37121-29	155.8	133.6	177.5	-	133	187.5	123.5	175	-	150	132.5	208.5	123.5	152	39
30	126.3	102.7	102.7	-	101.5	215	136	104	135.5	177	157	-	128	152	39
31	150.1	127.7	222.2	-	127	175	131.5	219.5	119	146.5	130	184.5	124	159	35
33	156.3	134.1	193.8	-	133.5	204	135	190.5	78.5	165.5	168.5	-	138	167	27
35	152.3	129.9	158.3	-	129	212	139.5	157	192.5	179.5	130.5	-	133	164	29
36	139.5	116.6	186.5	-	115.5	212.5	138	183.5	185	178.5	164	-	136.5	169	29
90	169.1	147.6	115.7	180	148.5	252	-	117	112.5		157.5	-	154	183	47
91	156.8	134.6	140.8	185	134	218	-	141	143	168.5	205.5	-	124	167	33
87	122.6	98.8	149.3	210	98	198.5	-	148.5	-	173	193	190	124.5	171	31
88	124.6	100.9	154.6	208	100	196.5	-	153.5	-	164.5	177	190.5	123.5	169	30
60	108.7	84.1	185.1	-	83.5	195.5	130	182.5	-	154.5	161	179	120.5	157	29
65	125.8	102.2	196.9	209	101	202.5	129	193.5	-	160	122	199.5	132.5	157	29
angano															
IB 37121- 2	140.4	117.5	212.4	215	116.5	205.5	130	209	221.5	149.5	148.5	237	136	169	36
3	163.4	141.6	199.3	200	142	200.5	133	196	177	153	113	-	144	170	26
84	148.5	125.9	152.1	192	125	210	117	151.5	188	175.5	187.5	-	134.5	161	30
12	154	131.7	177.1	-	131	191	116	174.5	214	167.5	157.5	220	158.5	160	23
10	157.8	135.6	177	-	135.5	190.5	125.5	174.5	211	167	159.5	223.5	160.5	163	20
5	159.1	137.1	164.5	-	137	187.5	131.5	163	321	168	148.5	219	166	162	16
8a	156.4	134.2	147.8	-	133.5	186.5	130.5	147.5	301.5		139	202	163.5	158	17
16	130.9	107.5	283	212	106.5	166	110	293.5	-	120	75	139.5	126.5	166	61
20	155.9	133.7	219.9	192	133	194	138	293.5	230.5		82.5	193.5	133	167	31
23	161.5	139.6	277.2	203	139.5	194	145.5	285.5							48
< 3	101.5	133.0	211.2	203	139.3	191	142.5	200.5	370.5	140	112.5	178.5	140	183	40

TABLE 6	Calculated	temperatures	(°C)	from solute	geothermometers	for	geothermal	waters	in Lakes	District
	by the met	hod of Arnors:	son a	nd Svavarsso	n (1985)					

* - excluded in the calculation of mean and standard deviation for geothermal waters in Abaya, Awasa-Wando Genet and Langano Areas.

* - and Ti excluded in the calculation of mean and standard deviation for geothermal waters in Shalla Area.

TABLE 7 Temperature functions for solute geothermometers

No.	Geothermometer	Temperature functions	Range (°C)	Source
1	Quartz	$t^{\circ}C = \frac{1164}{4.90 - \log S10_2} - 273.15$	180-250	Arnorsson et al. (1983a); SiO ₂ in mg/kg
2	Chalcedony	$t^{\circ}C = \frac{1101}{0.11 - \log S10_2} - 273.15$	25-180	Arnorsson et al. (1983a); SiO ₂ in mg/kg
3	NaK	$t^{\circ}C = \frac{933}{\log Na/K + 0.993} - 273.15$	25-250	Arnorsson et al. (1983a); Na, K in mg/kg
4	Na-K-Ca	$t^{\circ}C = \frac{1647}{\log Na/K + \beta \log/Ca/Na + 2.24} - 273.15$	4-340	Fournier and Truesdell (1973); $\beta = 1/3$ for /Ca/Na <1 and Ty/3 >100°C. Na, K, Ca in moles/1
5	· \$102	logmH4S104 = - 0.588 - 0.00441T - 1515.21/T + 1.3470.1	ogT	Arnorsson et al. (1983b)
6	C02	log ^{mH2CO3} = - 1.794 - 0.00510T - 4469.63/T + 4.1414.1	ogT	Arnorsson et al. (1983b)
7	H ₂ S	log ^{mH2S} = - 1.678 - 0.00355T - 5071.05/T + 3.8889·1	ogT	Arnorsson et al. (1983b)
8	NaK	logaNa+/aK+ = - 1.782 - 2775.5/T + 558780/T ² - 0.0096	9T + 4.104.logT	Arnorsson and Svavarsson (1985)
9	Na/Li	logaNa+/aLi+ = 0.161 + 1201/T		Arnorsson and Svavarsson (1985)
0	CaH	log/aCa+2/aH+ = - 1.733 + 0.01117T + 3890.51/T - 3.997	7·logT	Arnorsson et al. (1983b)
1	MgK	log√aMg+2/aK+ = - 0.00396T + 978.33/T		Arnorsson and Svavarsson (1985)
2	HF	log ^{mHF} = - 5.262 - 0.03511T - 7964.11/T + 12.1022·lo	g T	Arnorsson et al. (1985)
3	H ₂ SO4	log ^{mH} 2 ^{SO} 4 = - 6.436 - 0.03906T - 13335.68/T + 14.7958-	logT	Arnorsson et al. (1983b)

Location	Sample no.	Discharge T(°C)	co2	H ₂ S	NH3	H ₂	02	N2	СНц	Excess ^N 2	Corrected N ₂
Langano	NB 37121-										
Bobesa	28	91.5	683.25	0.12	0.06	nd	496.11	1857.74	0.79	8.81	1848.93
'Gebiba	24	95	344.98	0.30	0.26	0.16	0.09	2.17	0.90	1.82	0.35
*Gebiba	24	95	305.56	0.19	0.24	0.09	0.01	1.76	0.67	1.72	0.04
Finkilo	19	92.5	1547.17	0.13	0.09	trace	8.65	32.46	8.21	0.22	32.24
Kure	49	-	219.44	0.18	0.23	trace	497.37	1870.45	nd	16.30	1854.15
Aluto B	-	85	2499.97	0.67	0.02	nd	4086.74	15780.92	12.98	546.10	15234.82
Auto	27	95	564.57	0.28	0.77	trace	44.82	183.5	4.95	16.62	166.88
*Hulo	26	93	146.67	0.56	2.28	nd	498.44	1880.23	0.63	22.25	1857.98
*Hulo	26	93.5	211.08	0.38	2.11	na	na	na	na	na	-
Corbetti	NB 37121-										
Koka	56	95	1152.78	0.08	0.67	0.13	2.69	28.69	10.28	18.65	10.04
Doredimtu	54	92.5	670.05	nd	0.67	nd	1222.73	4693.04	nd	253.53	4439.51
Chebicha	74	90.5	749.97	nd	na	nd	1567.36	6109.33	nd	264.60	5844.73
Danshe	70	85.5	555.54	nd	na	nd	2002.10	7728.18	1.95	266.45	7461.73
Borama	76	95	519.48	nđ	0.39	nd	51.75	216.71	0.55	23.67	193.04
Borama	76	95	561.20	nd	0.44	nd	112.99	433.14	nd	11.96	421.18
Demo Argo	79	95	605.58	nd	0.22	nd	1380.42	5310.11	nd	165.62	5144.49
Abaya	NB 37161-										
Abaya F	7a	95.5	3572.06	2.38	0.72	0.11	6.42	15.58	10.48	-	-
Digima	22	96.5	738.92	nd	0.09	0.007	0.17	15.43	1.81	14.02	0.61

TABLE 8 Gas analyses results from Lake Langano, Corbetti and Lade Abaya areas (mM/kg)

• and * the same fumarole at different time.

Location	Sample no.	Discharge T(°C)	TC02	TH ₂ S	TC0 ₂ /N ₂	TC0/H2	TH2S/H2	TH2	T ¹ CO ₂ /N;
Langano	NB 37121-								
Bobessa	28	91.5	318	205	124	-	-	-	124
Gebiba	24	95	300	223	295	246	293	260	337
Gebiba	24	95	296	214	297	241	241	255	361
Finkilo	19	92.5	341	207	260	-	~	-	261
Kure	49	-	287	213	105	-	-	**	105
Aluto B	-	85	357	239	109	-	•	-	110
Auto	27	95	313	222	178	-	÷		180
Hulo	26	93	275	235	100	**	-	-	100
Hulo	26	93.5	286	228	-	-	-	*	-
Corbetti	NB 37121-								
Koka	56	95	333	333	255	229	312	259	286
Doredimtu	54	92.5	318	318	107	-	-	-	108
Chebicha	74	90.5	321	321	105	-	-	-	106
Danshe	70	85.5	313	313	99	-	-	-	-
Borama	76	95	311	311	171	-	-	-	-
Borama	76	95	313	313	154	-	-	-	*
Demo Argo	79	95	315	315	104	-	-	-	**
Abaya	NB 37161-								
Abaya F	7a	95.5	369	369	305	213	251	257	-
Duguna	22	96.5	320	-	261	198	-	232	-

TABLE 9 Estimated temperatures from gas geothermometers for the Lake Langano, Corbetti and Lake Abava areas (°C)

- and * The same fumarole at different time

othermometer	Temperature function	Restriction
C0 ₂	$-44.1 + 269.25Q - 76.88Q^2$	All waters
-	+ 9.52Q ³	
H ₂ S	+ 246.7 + 44.81Q	All waters
H ₂	+ 277.2 + 20.99Q	above 300°C
C02/H2	+ 341.7 - 28.570	and waters in
H2S/H2	+ 304.1 - 39.48Q	the range 200-300°C
		if chloride >500 ppm

TABLE 10 Temperature function for gas geothermometers

Source: Arnorsson and Gunnlaugsson, 1985

Component	Sample treatment	Method
рH	Raw, untreated, cooled	Instrumental (pH-meter)
c0 ₂	Raw, untreated, cooled	Titration with HCl (using
		pH-meter to mark end point)
H ₂ S	Raw, untreated, cooled	Titration with Mercuric Acetate
		(using dithizone as indicator)
Cl	Filtered, untreated	Chloride meter
F	Filtered, untreated	Selective electrode
S102	Raw, untreated,	Diluted UV/VIS spectrophotometer
		(Silico-molybdate complex)
В	Filtered, untreated	UV/VIS Spectrophotometry
		(Methylene blue complex)
SO4	Raw, untreated	(Sulfide titration with Barium
	should be precipiteted	perchlorate by zinc acetate)
Na and K	Filtered, acidified	A.A. Spectrophotometery
		(with lanthanum as inhibitor
		to interference)
Dissolved	Raw, untreated	Evaporated residue
solids		
Gases	Raw, untreated	Gas chromotography, titration
	(alkaline condensation	
	and/or without condensation)	
Isotope	Raw, untreated	Mass Spectrophotometer

Appendix I Sampling and analytical methods adopted for geothermal fluids

APPENDIX II Equations describing the temperature dependence of mineral solubilities.

MINERAL	REACTION	TEMPERATURE FUNCTION (°K)
401 ADULARIA ^C	$KAlSI_{3}O_{8} + 8H_{2}O = K^{+} + Al(OH)_{4}^{-} + 3H_{4}SIO_{4}^{0}$	+38.85 -0.0458T -17260/T +1012722/T ²
402 LOW-ALBITE	$NaAlSi_{3}O_{8} + 8H_{2}O - Na^{+} + Al(OH)_{4}^{-} + 3H_{4}SiO_{4}^{0}$	+36.83 -0.0439T -16474/T +1004631/T ²
403 ANALCIME	NaAlS1206 H20 + 5H20 = Na ⁺ + Al (OH) + 2H45104	+34.08 -0.0407T -14577/T +970981/T ²
404 ANHYDRITE	$Caso_4 - Ca^{+2} + so_4^{-2}$	+6.20 -0.0229T -1217/T
405 CALCITE ^d	$c_{aco_3} - c_{a}^{+2} + co_3^{-2}$	+10.22 -0.0349T -2476/T
406 CHALCEDONY	$sio_2 + 2H_2O - H_4 sio_4^{o}$	+0.11 -1101/T
407 Mg-CHLORITE	$Mg_{5}Al_{2}Si_{3}O_{10}(OH)_{B} + 10H_{2}O - 5Mg^{+2} + Al(OH)_{4}^{-} + 3H_{4}SiO_{4}^{0} + 8OH^{-}$	-1022.12 -0.3861T +9363/T +412.461ogT
408 FLUORITE	$CaF_2 = Ca^{+2} + 2F^{-1}$	+66.54 -4318/T -25.471ogT
409 GOETHITE	FeOCH + H_2O + CH^- = Fe (CH) $\frac{1}{4}$	-80.34 +0.099T +20290/T -2179296/T ²
410 LAUMONTITE	$CaA1_{2}S1_{4}O_{12} \cdot 4H_{2}O + BH_{2}O - Ca^{+2} + 2A1(OH)_{4}^{-} + 4H_{4}S1O_{4}^{\circ}$	+65.95 -0.0828T -28358/T +1916098/T ²
411 MICROCLINE	$KAISI_{3}O_{8} + 8H_{2}O - K^{+} + AI(OH)_{4}^{-} + 3H_{4}SIO_{4}^{0}$	+44.55 -0.0498T -19883/T +1214019/T ²
412 MAGNETITE	$Fe_{3}O_{4} + 4H_{2}O = 2Fe(OH)_{4}^{-} + Fe^{+2}$	-155.58 +0.1658T +35298/T -4258774/T ²
413 Ca-MONTMOR	${}^{6Ca}_{0.167}Al_{2.33}Si_{3.67}O_{10}(OH)_{2} + 60H_{2}O + 12OH^{-}$ - $Ca^{+2} + 14AL(OH)_{4}^{-} + 22H_{4}SiO_{4}^{-}$	+30499.49 +3.5109T -1954295/T +125536640/T ² -10715.661og
414 K-MONTMOR	${}^{3K_{0.33}Al_{2.33}Si_{3.67}O_{10}}(CH)_{2} + {}^{3OH_{2}O} + {}^{6CH^{-}}$ - $K^{+} + 7AL(CH)_{4}^{-} + 11H_{4}S10_{4}^{\circ}$	+15075.11 +1.7346T -967127/T +61985927/T ² -5294.72logT
415 Mg-MONTHOR	$^{6Mg}_{0.167}$ $^{A1}_{2.33}$ $^{S1}_{3.67}$ $^{O}_{10}$ $^{(OH)}_{2}$ + $^{6OH}_{2O}$ + 120H - Mg + 14AL $^{(OH)}_{4}$ + 22H ₄ SiO ⁶ ₄	+30514.87 +3.5188T -1953843/T +125538830/T ² -10723.711og
416 Na-MONTMOR	$^{3Na}_{0.33}$ ^{Al} _{2.33} ^{Si} _{3.67} ^O ₁₀ ^(OH) ₂ + $^{3OH}_{20}$ + $^{6OH}_{10}$ - Na ⁺ + 7AL (OH) + $^{11H}_{4}$ S10 ^o ₄	+15273.90 +1.7623T -978782/T +62805036/T ² -5366.181ogT
417 MUSCOVITE	$KAL_{3}SI_{3}O_{10}(OH)_{2} + 10H_{2}O + 2OH^{-} = K^{+} + 3AL(OH)_{4}^{-} + 3H_{4}SIO_{4}^{0}$	+6113.68 +0.6914T -394755/T +25226323/T ² -2144.77logT
418 PREHNITE	$Ca_2Al_2Sl_3O_{10}(OH)_2 + 10H_2O = 2Ca^{+2} + 2Al(OH)_4^- + 2OH^- + 3H_4SlO_4^-$	+90.53 -0.1298T -36162/T +2511432/T ²
419 PYRRHOTITE	$8Fes + so_4^{-2} + 22H_2O + 6OH^{-} = 8Fe(OH)_4^{-} + 9H_2S$	+3014.68 +1.2522T -103450/T -1284.861ogT
420 PYRITE	$8FeS_2 + 26H_2O + 10OH^- = 8Fe(OH)_4^- + 5O_4^{-2} + 15H_2S$	+4523.89 +1.6002T -180405/T -1860.331ogr
421 QUARTZh	$SiO_2 + 2H_2O = H_4SiO_4^{\circ}$	+0.41 -1309/T (0-250°C); +0.12 -1164/T (180-300°C)
422 WAIRAKITE	$CaA1_2S1_4O_{12} \cdot 2H_2O + 10H_2O = Ca^{+2} + 2A1(OH)_4^- + 4H_4S1O_4^0$	+61.00 -0.0847T -25018/T +1801911/T ²
23 WOLLASTONIT	$E Casio_3 + 2H^* + H_2O = Ca^{+2} + H_4 sio_4^{\circ}$	-222.85 -0.0337T +16258/T -671106/T ² +80.68logT
424 ZOISITE	$Ca_2Al_3Sl_3O_{12}(OH) + 12H_2O = 2Ca^{+2} + 3Al(OH)_4^- + 3H_4SlO_4^0 + OH^-$	+106.61 -0.1497T -40448/T +3028977/T ²
25 EPIDOTE	$Ca_2 FeAL_2Si_3O_{12}(OH) + 12H_2O = 2Ca^{+2} + Fe(OH)_4^{-1}$ + 2AL(OH)_4^{-1} + 3H_4SiO_4^{-1} + OH^{-1}	-27399.84 -3.8749T +1542767/T -92778364/T ² +9850.381ogT
426 MARCASITE ¹	$8Fes_2 + 26H_2O + 10OH^ 8Fe(OH)_4^- + 5O_4^{-2} + 15H_2S$	+4467.61+1.5879T-169944/T -1838.45logT

alf not otherwise specified data for minerals and aqueous species are from HELGESON et al. (1978) and HELGESON (1969). ^bData on Al(OH) and Fe(OH) are from ARNORSSON et al. (1982a) and GURNLAUGSSON and ARNORSSON (1982) respectively. ^CThermodynamic data on adularia are from HELGESON (1969). ^dData on the enthalpy and entropy of calcium ion at 25°C are from ROBIE et al. (1978). ^CARNORSSON et al. (1982b). Their empirical solubility function is very similar to the experimental solubility data of FOURNIER (1977). ^ENORDSTROM and JENNE (1977). ^SLANGMUIR (1971). ^MMOREY et al. (1962), KENNEDY (1950). ¹NAUMOV et al. (1971).

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Appendix III: Samples of computer printout of the WATCH 2 programme.

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DRKNSTOFHUN JHD abaya 1985-07-29 berhan

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IRENGTH = 0.02465 TONICE BM ANICE 1 CATIONS (MILL, E9.1)-0.02506614 EFFH EFF EFFH EFFH EFF EFFH EFF EFFH			. SCH		0.0	0.0	0.0		-HO2H	0.00	-7.821	FEH	0.00
RENGIN = 0.02483 IDHIC BALANCE: 1.01105 ICHIDIS ICHIDIS <th< td=""><td></td><td></td><td></td><td></td><td>•</td><td>,</td><td></td><td></td><td></td><td>8.50</td><td>-1.053</td><td>11131</td><td>0.00</td></th<>					•	,				8.50	-1.053	11131	0.00
Its (FPN) Difference (Z) 11.40 Constrained CL 7.54 2.317 FE(M)3-4 146.01 CD2 1059-72 C07 0.40 KB 497-18 1.64 2.311 FE(M)3-4 146.01 CD2 1059-72 C07 0.40 KB 497-18 1.64.31 FE(M)3+4 500.00 H2 2.00 H2 0.40 H2 0.403 FE(M)3+4 500.00 H2 2.00 H2 0.40 H2 0.405 FE(M)3+4 500.00 H2 0.00 H2 0.400 H2 0.2014 H172 3.101 FE(M)3+4 500.00 H2 0.00 H2 0.400 H2 0.406 FE(M)3+4 FE(M)3+4 FE(M)3+4 500.00 H2 0.00 H2 0.406 H2 0.407 FE(M)3+4 FE(M)3+4 50.00 H2 0.00 H2 0.000 H2 FE(M)3+4 FE(M)3+4 FE(M)3+4	IONIC SIRENG	C8420*0 = H1	IONIC BALANCE :		BL. E9. JO. 02508614				¥ 3	10.0	-4.169	FEOH	0.00
IER (FFN) REF SIEM (FFN) GAS FRESSIRES (BASS ABS.) Hit 497.18 -1.AA3 FE(HI)1+ 144.01 C02 1059.72 C07 0.40 H/3 0.4115-13 FE(HI)1+ 500.00 H/2 2.00 H/3 0.400 H/3 0.4175-13 IFC(HI)1+ 500.00 H/2 0.00 H/3 0.4175-13 IONIC SINENGIN 0.4192 -3.411 FE(HI)1+ 500.00 H/2 0.00 H/2 0.00 H/3 0.4175-13 IONIC SINENGIN 0.21373 IONIC SINENGIN FE(HI)1+ 7000 H/2 0.00 H/2 0.00 H/3 0.4175-13 IONIC SINENGIN FE(HI)1+ 7000 H/2 0.00 H/2 0.00 H/3 0.000C H00 IONIC SINENGIN IONIC SINENGIN FE(HI)1+ FE(HI)1+ 713.00 H/2 0.00 H/3 0.000C H00 IONIC SINENGIN IONIC SINENGIN IONIC SINENGIN IONIC SINENGIN IONIC SINENGIN IONIC SINENGIN IONIC SINENGIN <td< td=""><td></td><td></td><td></td><td>ANTONN IN</td><td>191/5770*01*02*10</td><td></td><td></td><td></td><td></td><td>47.66</td><td>-2.871</td><td>FECONDA-</td><td>00.00</td></td<>				ANTONN IN	191/5770*01*02*10					47.66	-2.871	FECONDA-	00.00
ICM (FPH) REF 9163M (FPH) GAS PRESSIRES (BARS ABS.) Ki 47.90 -7.894 FE(IM):H 146.01 C02 10537.72 C02 0.00 H2 0.414 4.72 -3.911 FE(IM):H 350.00 H2 0.00 H2 0.00 H2 0.00 H2 -3.911 FE(IM):H 300.00 H2 0.00 H2 0.00 H2 0.00 H2 -3.911 FE(IM):H 300.00 H2 0.00 H2 0.00 H2 0.00 H2 -3.911 FE(IM):H 300.00 H2 0.00 H2 0.00 H2 0.001:H0 H2 -3.911 FE(IM):H			-	ALL PRIME	1				HQ4	499.18	-1.663		0.00
146.01 CD2 1059-72 CO2 0.60 CD2 0.581:400 CAH 4.72 -3.1911 FE(101)24 500.00 H2S 2.00 H2S 0.60 H2 0.60 H2 0.6117 H 4.72 -3.1911 FE(101)24 500.00 H2S 0.00 H2S 0.60 H2 0.60 H2 H 4.72 -3.1911 FE(101)24 50.00 H2 0.00 H2 0.60 H2 0.60 H2 H 4.72 -3.1911 FE(101)24 70.00 H2 0.00 H2 0.60 H2 0.60 H2 HA HA H	DEEP WATER G	(HJd		DEEP	SIEAN (PPN)	GAS PRE	SSURES (BARS ABS.	-	Kł	49.90	-2,894	FE (DH) ++	00.0
146.01 UZ 0.02 0.0815440 IONIC SINENGIH 0.02335 IDNIC FALANCE 1 500.00 H2 2.00 H2 0.00 H2 0.02335 IDNIC FALANCE 1 500.00 H2 0.00 H2 0.00 H2 0.005400 IDNIC SINENGIH 0.02335 IDNIC FALANCE 1 70.00 H2 0.00 H2 0.00 H2 0.005400 IDNIC FALANCE 1 70.00 H2 0.00 H2 0.00 H2 0.005400 IDNIC FALANCE 1 13.00 H2 0.00 H2 0.00 H2 0.005400 IDNIC FALANCE 1 13.00 H3 0.00 H2 0.00 H2 0.005400 IDNIC FALANCE 1 13.00 H3 0.00 H2 0.005400 IDNIC FALANCE 1 IDNIC FALANCE 1 13.00 H3 0.00 H2 0.005400 IDNIC FALANCE 1 IDNIC FALANCE 1 0.00 H3 0.10 H2 0.000 H2 IDNIC FALANCE				-					CAH	4.92	-3.911	FE(UH) 24	00.00
300.00 H/2 0.00 H/2 0.0 H/2 0.00 H/2 0			201	202	0.00	2002	0.5815490		TANTE CTU	Cuttu - A	20176	TOUT BALANCE	
20.00 N2 0.000 N2 0.006 H0 N3 0.00 N3 0.00 N3 0.00 N3 0.00 N3 0.006 H0 N3 0.00 N3 0.00 N3 0.00 N3 0.00 N3 0.00 N3 0.00 N3				22	0010	C72	Po-3/1610		NIC ATUAT		P 10-94	TOUR PUPPerson	
13.979 CH 0.00 CH 0.006 CH <				20	0010	2 5	0.0005100						MILEN
12.00 N2 0.00 N2 0.00 N2 0.00 N2 0.000 N2 0.000 N3 0.123E-04 GEOTHERMONE LEAS DEGREES C 46.00 NH3 0.18 NH3 0.00 NH3 0.123E-04 GUNRTZ 156.6 13.00 NH3 0.123E-04 CUNRTZ 156.6 0.000 H2 0.0546F401 CH4.CEOUNT 127.8 0.000 H2 0.024F401 NMK 1978.6 0.0979 H2 0.00 0.00 0.0979 H2 0.00 0.00 OXIMITON POLENTIAL (VOLTS) 1 EH K/S= -0.481				CHA	0.00	CH4	0.000F400						P111C
48.00 NH3 0.18 NH3 0.00 NH3 0.12/35-04 GUARTZ 156.6 13.00 HZ0 0.5665401 GUARTZ 156.6 0.000 HZ1 0.6241401 CH4.CEDUNY 127.8 NMX 198.6 0.000 HZ1 0.00 OC NATION 198.6 0.000 B011.1M5 PURTION 0.00 OXIDATION POTENTIAL (VOLTS) 1 EH K/S= -0.481				HZ		2H	0.000E100		CHENICAL	GEOTHERMONI	ELERS DEGRE	ES C	1/0001
13.00 H20 0.5646101 DUARTZ 156.6 0.00 H20 0.5248101 D.A.C. 156.6 0.000 H20 (2) 0.6999 H20 (2) 0.00 H20 (2) 0.00 H20 (2) 0.00 0.00 0.00 H20 (2) 1 EH H26 -0.481 0.000 BUILING PURTION 0.00 D.C.00 DUCIDATION POLENTIAL (VOLTS) 1 EH H25 -0.481				NH3	0,00	EHN	0.1235-04						
0.00 T01AL 0.624E401 CHALCEDINY 127.8 0.0000 NAK 127.8 0.66999 H20 (X) 0.00 0.00 NAK 198.6 0.00000 B01LANG PURTION 0.00 0.00 0.00 0X.0ATION POTENTIAL (V0LIS) 1 EH N25= -0.481		13.00				HZO	0.5666401		DUARTZ	156.6			
0,0000 H2N (Z) 0.00 0,6999 H2N (Z) 0.00 O.6999 DXIDATION POLENTIAL (VOLIS) ; EH H2S= -0.481 0,0000 BOILING PURTION 0,00 DXIDATION POLENTIAL (VOLIS) ; EH H2S= -0.481		0.00			10	TOTAL	0.6248.401		CHAIL CEDON				
0.6999 HZD (Z) 0.00 0.000 BOILING PURTON 0.00 0.000 DATORITON POLATION POLA		0000*6							NAK	198.6			
0.0000 BOILING FURITON 0.00 DIXINGTION FORTION 0.00		2.6999		H20 C		0.00							
And		0000*0		11108	PORTION	0.00			DXIDATION	PRIENTIAL	(VOL.TS) :	EH NZS= -0	481 EH
		71								the new Assessment	and the second		1

1.44.5 99,999 99,999 99,999 99,999 99,999 99,999 99,999 EH NH3= 99.999 0.811 0.218 0.458 0.458 0.815 0.815 0.815 0.815 0.458 0.458 0.458 0.415 0.414 0.415 1508. -17.074 -2.452 -2.452 -2.433 -25.254 -77.497 -35.800 -7.634 -35.442 FECL+ ALTH+ ALTH+ ALTH+ ALTH+ ALTH+ ALTH+ ALT+ ALT+ ALT+ ALT+ ALT+-ALT+-ALT+-EH H2= 99.999 ANALCINE CHALCEIONY GOETHITE MAGNETTIE MG-HONTNGR, FREHNITE UUMARTZ ZOISITE FE (0H) 3 FE (0H) 4-FE (2H) FE (2H) F IONS (MUL.E9.)0.02447368 MIS (MOL.E0.)0.02178138 EXENCE (Z) 11.64 T DEGREES KELVIN = 2,33 0.467 0.218 0.818 0.818 0.452 0.452 0.452 0.452 0.452 0.452 0.452 0.452 0.452 0.452 0.452 H CH4= 99,999 CALC. 99.999 99.999 99.999 99.999 99.999 99.999 7.746 7.746 FEH FEHH FEHH FEOH FEOH3-FEOH3-FEOH34-FEOH34-FEOH34-FEOH34-FEOH34-FEOH34-FEOH34-FEOH34-FEOH34-FEOH34-FEOH4 -3.418 -5.032 -5.032 -5.032 -5.040 -5.050 -5 1EBR, -14,931 -10,539 -10,576 -10,576 -10,599 -106,890 9,314 9,314 -86,497 AL BITE LUW CALCITE FLUIRITE NICKOLLINE K-MININOS. K-MININOS. FURTE PTRITE MARCASTE OG SOLUBIL.I"Y PRODUCIS OF MINERALS IN DEEP VATER CAL C. 99.999 99.999 99.999 99.999 99.999 99.999 TERK. -15.513 -6.473 -6.473 -80.163 -76.133 -76.133 -76.133 -76.133 -76.50 -71.240 -71.240 -71.240 -71.240 ADNI.ARTA AMHYORJTE NG-CH.ORTIE NG-CH.ONTIE CA-NONTHOR. PYRSHOTTE WATRAGTTE EPIDOTE

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Final wetter Easi is a second of the second of	00370021 . AMA	ANASA+CHEN.COR		LAKES	B	ETHIOPIA	ACTIVITY C	OEFFICIENTS	ACTIVITY COEFFICIENTS IN DEEP WATER	65
N MILLO. FEMA SMPL FEMA SMPL <th< th=""><th></th><th></th><th></th><th></th><th></th><th></th><th>Ŧ</th><th>0.883</th><th>KS04-</th><th>0.871</th></th<>							Ŧ	0.883	KS04-	0.871
Circle STAN SAME S	PRUUKAN WAICH2.						-8-	0.863	ب ل	0.863
$ \left[\begin{array}{cccccccccccccccccccccccccccccccccccc$	WATER SAMPLE (PPN)	STEAN SAMPLE					H35104	0.577	- ŧ	0.865
$ \begin{array}{cccccccccccccccccccccccccccccccccccc$							H2B03-	0.859	K 1	0.861
174.00 REI (2): (2): (2): (2): (2): (2): (2): (2):		-		REFERENCE TEMP.	DEGINEES		HC03-	0.865	CA++	0.583
1,7,00 1,5,00<		200					-203	0.568	4+9H	
57.00 102 131200000 10000000 1000000 10000		57H		SAMPLING PRESSUR	-		HS-	0.863	COHCUS	
33.00 Cit NUMBER Control Contro Control Contro	5	2 5		DISCHARISE ENIMAL			1-0	5/510	neruusa execut	
31/30 0 CM MEAGREFT THEFEANURE ERECES 0.00 0.00 CM 0.000 0.00 CM 0.000 0.00 CM 0.000 0.00 0.000 0.000 0.00 0.00		3		DISCHARISE.	K6/SE		-+054	198.0	HUH	18/8
$ \begin{array}{cccccccccccccccccccccccccccccccccccc$		CHA					504	0.562	+HOSH	6.879
$ \begin{array}{cccccccccccccccccccccccccccccccccccc$	100	M2		MEASURED TEMPERA	TURE DEGREES		-ensen	0.871	++HN	668.0
17.00 CONCRETENT INTERNAL MATCHAR MATCHAR <thmatchar< th=""> MATCHAR <thmatcha< td=""><td></td><td></td><td>ų.</td><td>RESISTIVITY/TEAP</td><td>ā</td><td><</td><td>CUENTCAL C</td><td>DIADRAUTIC 1</td><td>N DEED UATED</td><td>UI UNV MODI</td></thmatcha<></thmatchar<>			ų.	RESISTIVITY/TEAP	ā	<	CUENTCAL C	DIADRAUTIC 1	N DEED UATED	UI UNV MODI
1115 2000 LITENS GAE FER IG 0.0000 RESIMEN DAMMER FIPA LILITD INFLUE RESIMEN DAMMER FIPA LILITD INFLUE 0.000<					UV/ PCB		H4 LACT.1	0.00	-7.930	110 Mar 110
L115 0.00 Condensation Results Results 14.13 2.25 0.0000 EVENESC NESTIM- 0.00 0.0 0.0 0.0 0.0 0.00 14.13 2.25 4.23 4.24 4.23 4.24 4.23 4.24 4.24 4.24 4.24 4.24 4.24 4.24 4.24		LITERS GAS PER KG					-HP		-4.515	NACI
0.0000 CRERES C/NETERS REPTH (NETERS) RESIGN- 0.330 C330 -<		CONDENSATE/DEG.C		MEASURED DOWN	HOLE TEMP.	FLUED INFLOW	HASTOA		-7.874	XCI
0.5000 0.0000 Existint 0.00 <td></td> <td></td> <td></td> <td>DEGREES C/</td> <td>METERS</td> <td>DEPTH (HETERS)</td> <td>H3SI04-</td> <td>4.22</td> <td>-4.343</td> <td>NASO4-</td>				DEGREES C/	METERS	DEPTH (HETERS)	H3SI04-	4.22	-4.343	NASO4-
0.0000 CUMBEISSIE (FPM) 0.0 0.0 0.0 MARSING 0.0 0.0 0.0 MARSING 0.0<							H2S104	0.00	-7.863	KS04-
0.0000 PM/IGE.C 0.0 <th< td=""><td></td><td>CONDENSATE (PPM)</td><td></td><td>0.0</td><td>0.0</td><td>0.0</td><td>NAH3SIDA</td><td>0.28</td><td>-5.627</td><td>CAS04</td></th<>		CONDENSATE (PPM)		0.0	0.0	0.0	NAH3SIDA	0.28	-5.627	CAS04
C02 0.0 <td></td> <td>PH/DEG.C</td> <td></td> <td>0.0</td> <td>0*0</td> <td>0.0</td> <td>H3B03</td> <td></td> <td>-4.328</td> <td>MGS04</td>		PH/DEG.C		0.0	0*0	0.0	H3B03		-4.328	MGS04
HZ 0.00 0.00		C02		0.0	0.0	0.0	H2B03-		-5.943	CACO3
Mit 0.00 0.00		HZS		0.0	0.0	0*0	H2C03		-2./52	RECOS
0.0 0.0 <td></td> <td>NA</td> <td></td> <td>0.0</td> <td>0.0</td> <td>0.0</td> <td>HC03-</td> <td></td> <td>-2.025</td> <td>CAHCO3+</td>		NA		0.0	0.0	0.0	HC03-		-2.025	CAHCO3+
0.0 0.0 <td></td> <td></td> <td>ł</td> <td>0.0</td> <td>0.0</td> <td>0.0</td> <td>E03</td> <td></td> <td>-4,844</td> <td>HIGHC034</td>			ł	0.0	0.0	0.0	E03		-4,844	HIGHC034
CINNERKATE WITH MAIN (FPH) 0.0 <th0< th=""></th0<>				0.0	0.0	0*0	H2S	0.00	0000	CAOH+
COMPENSATE MITH Math (FPN) 0.0 0.0 0.0 5 0.00 -6.01 -7.288 COR 0.0 0.0 0.0 0.0 0.0 0.0 -6.01 -7.288 RENGTH = 0.01423 IGNIC BALANCE I: CATIONS (INL.ED.)0.01022537 F 0.0 0.0 -6.00 -6.00 -5.135 RENGTH = 0.01423 IGNIC BALANCE I: CATIONS (INL.ED.)0.01022537 F 0.00 -5.01 -5.238 RENGT IGNIC BALANCE I: CATIONS (INL.ED.)0.01022537 F -0.01 -7.238 -5.01 -5.205 RER (FPN) DIFFEKENCE (Z) -19.322 F -6.00 -5.205 -5.01 -5.205 97.00 HZ3 DIFFEKENCE (Z) -19.322 HT F 0.01 -5.236 97.00 HZ3 DI DIFFEKENCE (Z) -19.3223 DI DI -5.137 -7.238 97.00 HZ3 DI DI <td></td> <td></td> <td>and the</td> <td>0.0</td> <td>0.0</td> <td>0"0</td> <td>-SH</td> <td>0.00</td> <td>0000*0</td> <td>HIGHH</td>			and the	0.0	0.0	0"0	-SH	0.00	0000*0	HIGHH
C22 0.0 0.0 0.0 0.0 0.0 15.15 RK6FH = 0.01423 TONIC FMLANCE I CATIONS (ML.EP.).0.010223.37 0.0 0.0 0.0 15.15 RK6FH = 0.01423 TONIC FMLANCE I CATIONS (ML.EP.).0.010223.37 FF 0.0 -5.501 RFMF DIFFERENCE (2) -19.39 FF 0.00 -5.501 RFM DIFFERENCE (2) -19.39 FF 0.00 -5.501 RFM DIFFERENCE (2) -19.39 FF 5.00 -5.501 RFM DIFFERENCE (2) -19.39 FF 5.00 -5.501 37.01 CD7 319.75 CD2 0.00 H2 0.01194 10N1 23.40 HZ 0.00 HZ 0.000 HZ -5.316 -5.316 35.50 HZ 0.00 HZ 0.000 HZ -5.316 -5.316 37.00 HZ 0.00 HZ 0.000 HZ -5.316 <td></td> <td>CONDENSAIE ULTH N</td> <td>(HAA) HIN</td> <td>0.0</td> <td>0.0</td> <td>0.0</td> <td>1,</td> <td></td> <td>0*000</td> <td>NH40H</td>		CONDENSAIE ULTH N	(HAA) HIN	0.0	0.0	0.0	1,		0*000	NH40H
H2S 0.0 0.0 0.0 0.0 0.0 -7.28 TRENETH = 0.01423 TOWIC BALANCE I CATIONS (MIL.EP.)0.01022A37 ER 0.01 -7.28 TRENETH = 0.01423 TOWIC BALANCE I CATIONS (MIL.EP.)0.01022A37 ER 54.4 0.01 -5.48 TRENETH = 0.01423 TOWIC BALANCE I CATIONS (MIL.EP.)0.01022A37 ER 50.00 -5.49 TRENES (MIL.ED.)0.0122A37 TOWIC STREAM ANTON SCALED. 0.01 -5.50 -5.47 TREP STEAM (PPN) ERF STEAM (PPN) EAS FRESSURES (BARS ABS.) H 2.4.00 -5.50 T24.00 H2S 0.00 H2S 0.00 H2 -5.134 24.00 H2S 0.00 H2S 0.00 H2 -5.134 24.00 H2S 0.00 H2 0.00 H2 -5.134 24.00 H2 0.00 H2 0.00 H2 -5.134 24.00 H2 0.00 H2 0.00 H2 -5.134 <td< td=""><td></td><td>C02</td><td></td><td>0.0</td><td>0.0</td><td>0*0</td><td>H2504</td><td></td><td>16.145</td><td>NH4+</td></td<>		C02		0.0	0.0	0*0	H2504		16.145	NH4+
REMETH = 0.01423 IONIC BALANCE 1 CATTONS (ML.ED).0.01224221 S0.11 -5.283 REMETH = 0.01423 IONIC BALANCE 1 CATTONS (ML.ED).0.01234221 Fr 0.00 -6.49 REMETH = 0.01423 IDNIC BALANCE 1 CATTONS (ML.ED).0.01234221 Fr 0.00 -6.49 REMETH = 0.01423 IDNIC BALANCE 1 -19.39 EFF SEAM (PPN) EAS FRESSURES (BARS ABS.) Hr 123.30 -3.249 93.01 CO2 519.75 CO2 0.00 HZS 0.00 -3.349 93.01 CO2 519.75 CO2 0.00 HZS 0.01174 1011 124.00 HZS 0.00 HZS 0.00 HZS 0.01174 1011 35.00 HZ 0.00 HZS 0.000 HZS 0.01174 1011 35.00 HZ 0.00 HZ 0.000 HZ 0.01174 1011 35.00 HZ 0.00 HZ 0.000 HZ 0.01174 1011 35.01 <t< td=""><td></td><td>HZS</td><td></td><td>0.0</td><td>0.0</td><td>0*0</td><td>HS04-</td><td></td><td>-7.258</td><td>E#+</td></t<>		HZS		0.0	0.0	0*0	HS04-		-7.258	E#+
IREMENT = 0.01423 TONIC FRAME: 1 CATTONS (FILL-EL).0.0122231 PER (FPH) PER FRENCE: (21) -19.39 FRENCE: (21) -10.00 FRENCE: (21) -0.00 FR							S04		-3,283	FE+++
MMUNS HML.LGL.JO.01242221 F- 6.00 -5.501 TEFFEGENCE (IX) -19.39 CL- 11.30 -5.471 TEFFEGENCE (IX) -19.39 CL- 11.30 -5.471 37.01 CD2 319.75 CD2 0.00 Hz 23.70 -5.349 37.01 CD2 319.75 CD2 0.00 HZ 0.319.44 10.1194 1001 37.01 CD2 319.75 CD2 0.00 HZ 0.01194 1001 214.00 HZ 0.00 HZ 0.0016+00 1011C 5.378 -5.378 35.00 CH 20.00 HZ 0.000 HZ 0.01194 1010 35.00 CH NH3 0.0006+00 HZ 0.01194 1010 35.00 CH NH3 0.0006+00 HZ 0.01194 1010 35.00 CH NH3 0.0006+00 HZ 0.00194 10114 1010 1	IONIC STRENGTH = 0.01423		CATIONS (HOL	L.EQ. JO. 01022637			生		-6.649	FEOH
DIFFERENCE (1) -19,-39 CL- 11,98 -5,-47 R(PM) DEP SIEAN (PPN) 6AS PRESSURES (BARS ABS.) K+ 23,-70 -2,-289 93,01 C02 319,75 C02 0,00 H2 23,-13 -3,-249 93,01 C07 319,75 C02 0,00 H2S 0,01194 ION 124,00 H2 0,00 H2S 0,000 H2S 0,01194 ION 25,00 U2 0,00 H2S 0,000 H2 0,01194 ION 35,00 U2 0,00 H2S 0,000 H2 0,01194 ION 35,00 U2 0,00 H2 0,000 H2 0,01194 ION 35,00 U2 0,00 H2 0,000 H2 0,01194 ION 35,00 U2 0,00 H2 0,000 H2 0,01194 ION 37,00 U2 0,00 U2 0,000 U2			ANTONS CHOL	L.EQ.)0.01242221			Ť		-3.501	FE(0H)2
TER (FPN) DEEP STEAM (FPN) GAS PRESSURES (BARS, JAS, JAS, 2.3.29 MAP 123.70 -2.3.39 33.01 C07 519.75 C02 0.00 H2S 0.01194 10H1 33.01 C07 519.75 C02 0.00 H2S 0.01194 10H1 23.00 H2 0.00 H2S 0.00 H2S 0.01194 10H1 23.00 U2 0.00 H2S 0.000 H2S 0.01194 10H1 35.00 U2 0.00 H2 0.000+00 H2 0.01194 10H1 35.00 U2 0.00 H2 0.000+00 CH4 0.01194 10H1 35.00 U2 0.00 H2 0.000+00 D 10H1 STERURIAL GEOTHERMONETERS BEEREES C 35.00 W3 0.00 H2 0.000+00 D 10H1 10H1 10H1 12.00 M3 0.00 H2 0.000+00 D 10H1 10H1 10H1 1			DIFFERENCE	8			เ -		-3.471	FE (0H) 3-
ICA VETU DREP STEAM (PPN) GAS PRESSURS GAAS ABS.) K1 Z3.78 -5.216 73.01 CD2 0.00 H2 0.000 H2 23.73 -5.216 73.01 CD2 0.00 H2 0.000 H2 0.01194 10N1 24.00 H2 0.00 H2 0.000 H2 0.01194 10N1 35.00 H3 0.00 H2 0.000 H2 0.01194 10N1 35.00 H3 0.00 H3 0.000 H3 0.01194 10N1 17.00 M3 0.00 H3 0.0	PULL INVESTIGATION						NA+		-2.269	FE(0H)4
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0.00 ENTERS ENTERS 1550.00 LITERS FAS FER KIS NEASINEL DEG.C 0.0000 CUNUENSATE/DEG.C NEASINEL 0.0000 CUNUENSATE/DEG.C NEASINEL 0.0000 CUNUENSATE/DEG.C NEASINEL 0.0000 CUNUENSATE (FPH) 0.0 0.0 0.0000 PM/DEG.C 0.0 0.0 0.0 0.0000 CUNUENSATE VITH HAIN 0.0 0.0 0.0 0.0 125 NUL CC2 0.0 </td <td>0.00 ENTERS ENTERS 1550.00 LITERS EAS FEX KG REASINEL 1550.00 LITERS EAS FEX KG REASINEL 0.0000 CUNCLISSIE REASINEL 0.0000 CUNCLISSIE REASINE 0.0000 PLUTERS 0.00 0.0000 PLUESSIE 0.0 125 0.0 0.0 125 0.0 0.0 125 PLUESSIE 0.0 125 0.0 0.0 125 0.0 0.0 127.01 1001C RALANE 0.0 127.01 <</td> <td>-</td> <td>22.00</td> <td></td> <td></td> <td>REST</td> <td>STIVITY/TENP.</td> <td></td> <td></td>	0.00 ENTERS ENTERS 1550.00 LITERS EAS FEX KG REASINEL 1550.00 LITERS EAS FEX KG REASINEL 0.0000 CUNCLISSIE REASINEL 0.0000 CUNCLISSIE REASINE 0.0000 PLUTERS 0.00 0.0000 PLUESSIE 0.0 125 0.0 0.0 125 0.0 0.0 125 PLUESSIE 0.0 125 0.0 0.0 125 0.0 0.0 127.01 1001C RALANE 0.0 127.01 <	-	22.00			REST	STIVITY/TENP.		
1558.00 LITERS EAS FEX KG REASINER DOWNIALE 150.000 LUTERS EAS FEX KG NEASINER DOWNIALE 0.0000 CUNDENSATE/REG.C DESKEES C/AFETER 0.0000 CUNDENSATE (PPN) 0.0 0.0 0.0000 CUNDENSATE (PPN) 0.0 0.0 0.0 0.0000 CUNDENSATE (PPN) 0.0 0.0 0.0 0.0 0.0000 CUNDENSATE UTTH MADH (PPH) 0.0 <td< td=""><td>IFSB.00 ITTERS EAS FEX KG REASINET DOWNIALE 0.0000 CUNTENSATE/PEG.C DESSEES CARETER 0.0000 CUNTENSATE/PEG.C DESSEES CARETER 0.0000 CUNTENSATE/PEG.C DESSEES CARETER 0.0000 CUNTENSATE (FPN) 0.0 0.0 0.0000 CUNTENSATE (FPN) 0.0 0.0 0.0 0.0000 CUNENSATE (FPN) 0.0 0.0 0.0 0.0 0.0000 CUNENSATE (FPN) 0.0</td><td></td><td>0.00</td><td></td><td></td><td>E1/H3</td><td>ENP.</td><td>NU/BEB.</td><td></td></td<>	IFSB.00 ITTERS EAS FEX KG REASINET DOWNIALE 0.0000 CUNTENSATE/PEG.C DESSEES CARETER 0.0000 CUNTENSATE/PEG.C DESSEES CARETER 0.0000 CUNTENSATE/PEG.C DESSEES CARETER 0.0000 CUNTENSATE (FPN) 0.0 0.0 0.0000 CUNTENSATE (FPN) 0.0 0.0 0.0 0.0000 CUNENSATE (FPN) 0.0 0.0 0.0 0.0 0.0000 CUNENSATE (FPN) 0.0		0.00			E1/H3	ENP.	NU/BEB.	
155.00 LITERS 645 FEX KIS REASINCE TO DAMHIALE 0.0000 CUNTERS 645 FEX KIS NERSIES CATTER 0.0000 CUNDENSATE (FPM) 0.0 0.0 0.0000 CUNDENSATE (FPM) 0.0 0.0 0.0 0.0000 CUNDENSATE (FPM) 0.0 0.0 0.0 0.0 0.0000 PH/DEG.C 0.000 0.0 <td< td=""><td>150.00 LITERS 645 FER KIS REASINGE DOWNHALE 0.0000 CUNUENSATE/DEG.C NERSINGE DOWNHALE 0.0000 CUNUENSATE/DEG.C NERSINGE DOWNHALE 0.0000 CUNUENSATE (FPN) 0.0 0.0 0.0000 PL/DEG.C 0.0 0.0 0.0 0.0000 PL/DEG.C 0.0 0.0 0.0 0.0 0.0000 PL/DEG.C NA 0.0</td><td></td><td>1958.00</td><td></td><td></td><td></td><td></td><td></td><td></td></td<>	150.00 LITERS 645 FER KIS REASINGE DOWNHALE 0.0000 CUNUENSATE/DEG.C NERSINGE DOWNHALE 0.0000 CUNUENSATE/DEG.C NERSINGE DOWNHALE 0.0000 CUNUENSATE (FPN) 0.0 0.0 0.0000 PL/DEG.C 0.0 0.0 0.0 0.0000 PL/DEG.C 0.0 0.0 0.0 0.0 0.0000 PL/DEG.C NA 0.0		1958.00						
LIDS 0.00 CONTRATE/PEG.C NEGSIREE DOWHINLE 0.0000 0.0000 PM/Y DIS.C 0.0 0.0 0.0 0.0000 PM/PIES.C 0.0 0.0 0.0 0.0 0.0 0.0000 PM/PIES.C 0.0 0	LIDS 0.00 CONTRATE/PEG.C NEASIMET DOWNHALL 0.0000 PLUTES.C DEFERSES CATERS 0.0000 PLUTES.C 0.0 0.0 0.0000 PLUTES.C 0.0 0.0 0.0 0.0000 PLUTES.C 0.0 0.0 0.0 0.0 0.0000 PLUTES.C 0.0 0.0 0.0 0.0 0.0 REMENSATE UTH MADH (PPH) 0.0		150.00		LITERS GAS PER KG				
0.0000 CONCRETER 0.0000 DESREES C/METER 0.0000 CONDENSATE (FPM) 0.0 0.0 0.0 0.0000 PIL/TEG.C 0.0 0.0 0.0 0.0 0.0000 PIL/TEG.C 0.0 0.0 0.0 0.0 0.0 173 CD2 CD2 0.0 <td< td=""><td>0.0000 ERSRES C/METER 0.0000 PIL/DEG.C 0.00 0.0 0.0000 PIL/DEG.C 0.0 0.0 0.0000 PIL/DEG.C 0.0 0.0 0.0 0.0000 PIL/DEG.C 0.0 0.0 0.0 0.0 0.0000 CD2 CD2 0.0 0.0 0.0 0.0 H25 COURDENSATE WITH HAUH (PPH) 0.0<</td><td>S61.105.80</td><td>0.00</td><td></td><td>CONDENSATE/DEG.C</td><td>×</td><td>EASURED DOWNHO</td><td>LE TEMP.</td><td>FLUID INFLOW</td></td<>	0.0000 ERSRES C/METER 0.0000 PIL/DEG.C 0.00 0.0 0.0000 PIL/DEG.C 0.0 0.0 0.0000 PIL/DEG.C 0.0 0.0 0.0 0.0000 PIL/DEG.C 0.0 0.0 0.0 0.0 0.0000 CD2 CD2 0.0 0.0 0.0 0.0 H25 COURDENSATE WITH HAUH (PPH) 0.0<	S61.105.80	0.00		CONDENSATE/DEG.C	×	EASURED DOWNHO	LE TEMP.	FLUID INFLOW
0.0000 0.0000 PH/JEIS.C 0.0000 PH/JEIS.C 0.00 0.0 0.0 0.0 0.0 0.0 0.0	0.0000 0.0000 PH/DESC 0.0000 PH/DESC 0.00 0.0 0.0 0.0 0.0 0.0 0.0 0		0.0000				DEGREES C/NE	TERS	DEPTH (METERS)
0.0000 CUNDENSATE (FPH) 0.0 0.0 0.0 0.0000 PN/DES.C 0.0 0.0 R12 R23 R3 R3 R4 R53 R4 R54 R4 R646TH = 0.30714 IOMIC BALANCE : CATTONS (HRL, FRL.)0.18264779 0.0 0.0 CC2 R646TH = 0.30714 IOMIC BALANCE : CATTONS (HRL, FRL.)0.18264779 R52 R52 R52 R52 R52 R52 R52 R52	0.0000 CUNDENSATE (PPH) 0.0		0.0000						
0.0000 PM/PIES.C 0.0 0.0 0.0 CI22 CI23 0.0 0.0 0.0 0.0 0.0 H25 NA CI22 0.0	0.0000 PH/PIES.C 0.0 0.0 0.0 CI22 CI23 0.0 0.0 0.0 0.0 0.0 H25 N N N 0.0 <td></td> <td>0.0000</td> <td></td> <td>CONDENSATE (PPH)</td> <td></td> <td>0.0</td> <td>0.0</td> <td>0.0</td>		0.0000		CONDENSATE (PPH)		0.0	0.0	0.0
CD2 H25 H25 H25 H25 H25 H25 H25 H25 H25 H2	CI22 0.0 <td>-</td> <td>0.0000</td> <td></td> <td>PH/DEG.C</td> <td></td> <td>0*0</td> <td>0.0</td> <td>0.0</td>	-	0.0000		PH/DEG.C		0*0	0.0	0.0
H25 0.0 <td>H25 H3 0.0 H3 0.</td> <td></td> <td></td> <td></td> <td>C02</td> <td></td> <td>0.0</td> <td>0.0</td> <td>0.0</td>	H25 H3 0.0 H3 0.				C02		0.0	0.0	0.0
MA 0.0	MA 0.0				H25		0.0	0.0	0.0
177.01 CO2 0.0<	RENGTH = 0.30714 IDMIC BALANCE CANBENSATE WITH HARM (PPH) 0.0				NA		0.0	0.0	0.0
0.00 0.0 <td>COMPENSATE WITH HAIM (PPM) 0.0<!--</td--><td></td><td></td><td></td><td></td><td></td><td>0.0</td><td>0.0</td><td>0.0</td></td>	COMPENSATE WITH HAIM (PPM) 0.0 </td <td></td> <td></td> <td></td> <td></td> <td></td> <td>0.0</td> <td>0.0</td> <td>0.0</td>						0.0	0.0	0.0
Iteleficient 0.0 <t< td=""><td>CONVENSATE VITH HADH (PPH) 0.0<!--</td--><td></td><td></td><td></td><td></td><td>+1</td><td>0.0</td><td>0.0</td><td>0.0</td></td></t<>	CONVENSATE VITH HADH (PPH) 0.0 </td <td></td> <td></td> <td></td> <td></td> <td>+1</td> <td>0.0</td> <td>0.0</td> <td>0.0</td>					+1	0.0	0.0	0.0
CONDENSATE WITH HARM (PPM) 0.0 </td <td>CONDENSATE WITH HAIM (PPM) 0.0<!--</td--><td></td><td></td><td></td><td></td><td></td><td>0.0</td><td>0.0</td><td>0.0</td></td>	CONDENSATE WITH HAIM (PPM) 0.0 </td <td></td> <td></td> <td></td> <td></td> <td></td> <td>0.0</td> <td>0.0</td> <td>0.0</td>						0.0	0.0	0.0
CO2 CO2 0.0 <td>CO2 CO2 0.0 1177.01 CD2 6861.80 CD2 0.00 1075.9 0.00 1177.01 CD2 6861.80 CD2 0.00 1075.5 0.00 1075.5 0.00 1075.5 0.00 1075.5 0.00 1075.5 0.00 102 0.00 102 0.00 107 1070.5 1155.7.83 M13 0.00 102 0.00 102 0.00 102 0.00 102 0.00 102 0.00 103 0.00 103 0.00 103 0.00 103 0.00<td></td><td></td><td></td><td>CONDENSATE VITH NACH</td><td>(Hdd)</td><td>0.0</td><td>0.0</td><td>0.0</td></td>	CO2 CO2 0.0 1177.01 CD2 6861.80 CD2 0.00 1075.9 0.00 1177.01 CD2 6861.80 CD2 0.00 1075.5 0.00 1075.5 0.00 1075.5 0.00 1075.5 0.00 1075.5 0.00 102 0.00 102 0.00 107 1070.5 1155.7.83 M13 0.00 102 0.00 102 0.00 102 0.00 102 0.00 102 0.00 103 0.00 103 0.00 103 0.00 103 0.00 <td></td> <td></td> <td></td> <td>CONDENSATE VITH NACH</td> <td>(Hdd)</td> <td>0.0</td> <td>0.0</td> <td>0.0</td>				CONDENSATE VITH NACH	(Hdd)	0.0	0.0	0.0
H25 0.0 10 1	H25 0.0 <td></td> <td></td> <td></td> <td>C02</td> <td></td> <td>0.0</td> <td>0.0</td> <td>0.0</td>				C02		0.0	0.0	0.0
RENGTH 0.30714 IDNIC RALANCE CATTONS (M0L.ER.).0.18240477 IER (FPN) DIVIC BALANCE CATTONS (M0L.ER.).0.182404771 IER (FPN) DIFFERENCE (X1)22944771 IFFERENCE (X2)2940 -45.59 177.01 CO2 6861.80 CO2 0.00 197.99 H2 0.00 H2 0.00 197.97 H2 0.00 H2 0.00 197.98 H3 0.00 H2 0.00 197.98 H3 0.00 H2 0.00 1957.83 H13 0.00 H3 0.00 1957.83 H13 0.00 H3 0.00	RENGTH 0.30714 IONIC BALANCE CATTONS (HOL.ER.J.0.18260477) IFR ANTONS CHATONS CHATONS CHATONS -45.59 IFR (PPN) DIFFERENCE LED.J0.20044771 -45.59 IFR (PPN) DIFFERENCE LTO.20044771 177.01 CD2 6861.80 CD2 0.00 177.01 CD2 6861.80 CD2 0.00 177.01 CD2 6861.80 CD2 0.00 1757.00 HZS 0.00 HZS 0.00 2.40 CH4 0.00 HZS 0.00 2.500 MI 0.00 HZS 0.00 1557.02 MI 0.00 HZS 0.00 1557.02 MI 0.00 HZS 0.00 0.000 HZS 0.00 HZS 0.00 0.000 0.000 HZS 0.00 0.00				N2S		0.0	0.0	0*0
TEKNGTH 0.30714 IOMIC BALANCE: CATTONIK (MIL, ER, 10, 182.60477) TEK (PPN) DIFFEKENCE (X) - 45.59 TEX (PPN) DIFFEKENCE (X) - 45.59 177,01 CD2 6861.80 CO2 0.00 197.50 HZS 0.00 HZ 0.00 197.57.00 HZS 0.00 HZ 0.00 197.57.00 HZS 0.00 HZ 0.00 197.57.00 HZS 0.00 HZ 0.00 2.40 CZ 0.00 HZ 0.00 1975.63 MH3 0.00 HZ 0.00 1957.63 MH3 0.00 H3 0.00 1957.63 MH3 0.00 H3 0.00 1950.02 0.00 H3 0.00 H3	TERIGTH 0.30714 IOMIC BALANCE CATTONS (MIL., ER. 10.182.60477 FER (PPN) BIFFER (MC. (T) -45.59 FER (PPN) DEFF STEAM (FPN) -45.59 177.01 CD2 6861.80 CD2 0.000 197.00 HZS 0.00 HZ 0.00 199.79 HZ 0.00 HZ 0.00 199.79 HZ 0.00 HZ 0.00 199.79 HZ 0.00 HZ 0.00 10 2.40 CH 0.00 HZ 0.00 10								
IER (FPM) DEEP STEAM (FPM) 177.01 C02 6861.80 C02 0.00 4157.00 H25 0.00 H25 0.00 107.91 C02 6861.80 C02 0.00 107.99 H2 0.00 H2 0.00 107.99 H2 0.00 H2 0.00 22.00 H2 0.00 H3 0.00 1957.83 H13 0.00 H3 0.00 0.00 H3 0.00 H3 0.00 1957.83 H13 0.00 H3 0.00 0.000 H3 0.00 H3 0.00	IEX (PPN) DEEP STEAM (PPN) 177.01 CD2 6861.80 CD2 0.00 4157.00 KZS 0.00 HZS 0.00 199.57 HZ 0.00 HZ 0.00 2.40 CZ 0.00 HZ 0.00 2.40 CH 0.00 HZ 0.00 2.2.00 HZ 0.00 HZ 0.00 22.00 HZ 0.00 HZ 0.00 22.00 HZ 0.00 HZ 0.00 1997.63 MHS 0.00 HZ 0.00 0.000 0.00 HZ 0.00 HZ 0.000 0.000 HZ 0.00 HZ 0.00	ILC STRENG	ITH = 0.3071	*		ATIONS (MOL.EO. NIONS (MOL.EO. IFFERENCE ()	.)0.18260479 .)0.29044771 C) -45.59		245
177.01 C02 6861.80 C02 0.00 C02 4157.00 H/25 0.00 H/25 0.00 H/25 109.57 H/2 0.00 H/25 0.00 H/25 2.40 C12 0.00 H/25 0.00 H/25 2.40 C14 0.00 C1 0.00 H/2 0.200 C14 0.00 C14 0.00 H/2 1957.63 NH3 0.00 H/3 0.00 H/3 1950.02 0.00 H/3 0.00 H/3 0.00 H/3 1950.02 0.00 H/3 0.00 H/3 0.00 H/3 0.000 0.00 H/3 0.00 H/3 0.00 H/3 0.000 0.00 H/3 0.00 H/3 0.00 H/3	177.01 C02 6861.80 C02 0.00 C02 4157.00 H25 0.00 H25 0.00 H25 109.99 H2 0.00 H25 0.00 H25 2.40 02 0.00 H2 0.00 H25 2.40 02 0.00 H2 0.00 H2 2.40 02 0.00 12 0.00 H2 2.540 02 0.00 12 0.00 H3 0.00 1957.83 MH3 0.00 H3 0.00 H3 0.00 H3 0.000 1150.02 0.00 H3 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0	CP WATER	(Ndd)			DEEP STEAN	(Hdd)	GAS PRES	SURES (BARS ASS.)
4157.00 K/25 0.00 H/25 0.00 H/25 2.40 K/25 2.40 K/25 2.40 K/2 0.00 H/2 0.00 H/2 2.40 0.00 H/2 1.00 H/2 0.00 H/2 0.00 H/2 0.00 H/2 0.00 H/2 0.00 H/2 0.00 H/2 1.57.63 NH3 0.00 H/3 0.00 H/3 1.50.00 H/3 0.00 H/3 0.00 H/3 1.00 H/3 0.00 H/3 0.	4157.00 H/25 0.00 H/25 0.00 H/25 109.57 H/2 0.00 H/2 0.00 H/2 2.40 CH 0.00 C/2 0.00 H/2 0.560 CH 0.00 C/2 0.00 C/2 2.2.00 H/2 0.00 C/4 0.00 C/4 22.00 H/2 0.00 C/4 0.00 H/2 1957.63 M/3 0.00 H/3 0.00 H/3 0.00 150.02 0.00 H/3 0.00 H/3 0.00 H/3 0.00 0.000 0.000 H/3 0.00 H/3 0.00 H/3 0.00 0.000 0.000 H/3 0.00 H/3 0.00 0.00	22	177.01	8		C02	0.00	C02	0.254E-02
109.39 H2 0.00 H2 102 0.00 H2 102 0.00 102 102 102 102 102 102 102 102 102 102 102 102 102 103 103 0.00 H2 101AL 101AL 10.00	109.99 H2 0.00 H2 10 12 12 12 12 12 13 10 H2 10 H2 H3 0.00 H2 H3 0.00 H3 H3 10 H3 10 H3 10 H3 10 H3 10 H3 H3 10 H3 10 H3 10 H3 H3 10 10 10 H3 10 H3 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10		1157.00	Ŧ		H2S	0.00	HZS	0.000E+00
2.40 02 0.00 02 0.00 02 0.560 CH4 0.00 02 0.00 01 22.00 H2 0.00 CH4 0.00 CH4 22.00 H2 0.00 CH4 0.00 CH4 1959.283 MH3 0.00 H3 0.00 H3 159.62 0.00 0.00 H43 0.00 H3 0.00 0.00 H43 0.00 H3 H3 0.00 0.00 H43 0.00 H3 H3 0.000 0.00 H43 0.00 H3 H3	2.40 02 0.00 02 0.00 02 0.960 CH4 0.00 CH4 0.00 CH4 22.00 N2 0.00 CH4 0.00 CH4 1957.83 NH3 0.00 NH3 0.00 NH3 1957.83 NH3 0.00 NH3 0.00 NH3 0.00 0.00 HA3 0.00 NH3 0.01 0.00 0.00 HA3 0.00 NH3 0.00 0.000 0.00 HA3 0.00 NH3 0.00		109.99	2		CH	0.00	H	0.000F400
0.960 CH4 0.00 CH4 0.00 CH4 22.00 K2 0.00 K2 0.00 K2 1957.63 NH3 0.00 H43 0.00 K2 1950.02 150.02 0.00 H43 0.00 H43 0.00 K20 101/L	0.560 CH 0.00 CH 0.00 CH 22.00 K2 0.00 CH 1557.53 NH3 0.00 K2 0.00 K2 1557.53 1557.53 NH3 0.00 K2 157.00 CH 0.000 CH 0.000 CH 0.000 CH 1570 CH		2.40	18		18	0.00	Ģ	0.0005400
22.00 H2 0.00 H2 0.00 H2 1957.63 HK3 0.00 H3 0.00 H3 150.02 0.00 H43 0.00 H3 0.000 0.00 1013 1014L	22.00 H2 0.00 H2 0.00 H2 1957.83 HH3 0.00 H3 0.00 H3 159.02 H43 0.00 H3 0.00 H3 159.02 H3 0.000 H3 0.00 H3 101AL		0.960	1 2		CHA	0.00	CHA	0.0001400
1957.63 NH3 0.00 NH3 0.00 NH3 150.02 R20 0.00 0.00 0.00 0.00 0.00 0.00 0	1957.63 MIG 0.00 MIG 0.00 MIG 0.00 MIG 1250.02 1350.02 MIG 0.000 HIG 0.000 HIG 0.000 HIG 0.000 HIG 10.000 0.000 HIG 10 0.000		22.00	CR.		N2	0.00	24	0.0005400
159.02 159.02 10.00 10.0	150.02 150.02 101.00 0.00 0.00 H20 (1) 0.00 0.00 0.00 H20 (1) 0.00 0.00 H20 (1) 0.00 0.00 H20 (1) 0.00 0.00 H20 (1) 0.00 0.00 0.00 H20 (1) 0.00 0.00 0.00 H20 (1) 0.00 0.00 0.00 H20 (1) 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.		18.729	NN		THM	0.00	THM	0.0001400
0.00 0.00 0.0000	0.00 0.0000 H2D (T) 0.00 0.0000 H2D (T) 0.00		150.02	E		~		UCH I	0.7485100
0,000.0	0,0000 HZD (T) 0.00	2.0	0.00					TOTAL	V. TSIELAN
	H20 (I)		0.0000					The second	ANT TYPENA
	171 074					VAL DUD			

0.537 0.537 0.537	F-	789-0		. :	000 0	AL+++	0.000
0.599	L	0.632			VOU V	411 111	A 200
0.599				‡ :			0,070
0.599	5	0.616	FEOH	ŧ		A CH++	0.237
0.599	NAT	0.647	E I	FE(UH)3-		AL.(0H)24	0.682
C 7 7 7	Kt	0.616	FE	FE(IDH)4		AL (0H)4-	0.660
11010	1444	CC7.0	111			AL.5041	0.660
0.208	++99		FE		0.682	AL (SUA)2-	0.660
0.632	CAHC034	34 0.694	FE	-E(GH)4-	0.682	ALF++	0.237
0.224	HGHC03+		FFS	FF504+		ALF2+	0.682
0.660	CADH+		FEC			M F4-	0.440
0.192	HIGHH		FFC			AL FS	0.208
0.682	NH4+		FEC			ALF6	0.030
PONENTS 1	IN DEEP WATES	COMPONENTS IN DEEP WATER (PPN AND LOG NULE)	(11)				
0.00	102.9-	MG44	0.10	-5.789	2 (MI)/11	0.00	0.000
14.11	VCU'E-	NAC!		1.746	-FURNT-	0.00	0.000
12.71	-1.404	LIN I		127-5-	FE11 +	0.00	0.000
120.39	-2.898	NASD4-		4.684	FEC12	00.00	0.000
7.78	-4.082	K504-		-5.860	FECLH	0.00	0,000
142.30	-2.919	CAS04		-8.173	FECL24	0.00	0.000
0.00	0.000	MGSD4		-7.499	FEG.3	0.00	0.000
0.00	0.000	CACO3		-4.269	FECL4-	0.00	0.000
	-4.448	E0.03		-4.479	FES04	0.00	0,000
	-1.059	CAHC03+	0.78	-5.562	FES044	0.00	0.000
	-1.164	MGHCB34		IE/"5-	AL H H	0.00	0.000
	0.000	CARH+		-7.705	ALDNH	0.00	0.000
0.00	0.000	HIGHH		-6.513	AL.(0H)2+	0,00	0.000
0.00	0.000	WH40H	0.00	0.000	AL (OH) 3	0.00	0.000
	-23.100	NH4+	0.00	0.000	AL (0H) 4-	0.00	0.000
	11.139	FE++	00.00	0,000	ALS04+	00.00	0.000
	-3.684	FEFFF	00*0	0.000	AL(S04)2-	00.0	0.000
	-8.246	FEOH	0.00	0.000	ALFH	0.00	0.000
	-2.103	FE(UH)2	0.00	0.000	ALF24	0.00	0.000
	-1.261	FE(0H)3-	0.00	0.000	ALES	0.00	0.000
118.95	-0.747	FE(UH)4	0.00	0.000	ALE 4-	00.0	0.000
	-2.552	FE(DR)++	0.00	0.000	ALFS	0.00	0.600
	-5.485	FE(UH)24	0.00	0.000	ALF6	0.00	0.000
TH = 0.3		NIC BALANCE :	CALTONS (HOL. ER. 10.	18198945		
			ANTONS (MOL.EQ. 30.	28982148		
THERMONET	ERS DEGREES	C	1000/1 26	GREES KELV	VIN = 2,89		
0 07							
1.10							
87.7							
TENTIAL (VOLTS) :	EH H2S= 99.999		14= 99.999	EH H2= 99.9		EH NH3= 99.999
TY PRODUC	IS OF MINERA	LS IN DEEP WATER					
TEOR.	CALC.			CALC.		TEOK.	CALC.
-18.434	666.66	ALBITE LOW	-17.592	666.99	ANALCIME	-14.030	666*66 (
-5.238		CALCITE	-9.008	-7.924	CHALCEDONY	-3.074	-3.406
-81.396		FLUORITE	-10.611	-10.682	BOETHITE	-5.457	
-28.668		MICROCI, INE	-20.020	69.999	MAGNETITE	-31.789	
0EE.E?-		K-HONTHOR.	-45.850	666.999	MG-HOWINDR	94.326	
-42.759		۳	-23.042	66.999	PREHNITE	-37.930	
-113.530			-167.553	464.99	ZINAUD	-3-37	-3.406
	120.139 7.778 0.000 2.221 142.221 0.0000 0.0000 0.0000 0.0000 0.0000 0.000000	HISTON - 120.39 -2.898 HISTON - 77.39 -2.898 HISTON - 77.98 -4.002 HISTON 0.00 0.000 HISTON 0.00 0.000 HISTON 0.00 0.000 HISTON 0.00 0.000 HISTON 0.00 0.000 HISTON 0.00 0.000 HISTON 0.00 -73.100 HISTON 0.00 -73.100 HISTON 0.00 -73.100 HISTON 0.00 -73.100 HISTON 0.000 -73.100 HISTON	HISTON- 120, 39 -2.898 MISON- MISTON- 120, 39 -2.898 MISON- MISTON 147, 20 -2.919 KISON MISCON 0.000 0.000 KISON KISON 0.000 0.000 KISON KISON 0.000 C.000 KISON KISON 1413, 83 -1.164 MISON KISON 0.000 KISON KISON 0.000 KISON KISON 0.000 KISON KINA KISON 0.000 KISON KISON KINA KISON 0.000 KINA KINA KISON 0.000 KINA KINA KISON 0.000 KINA KINA KISON 0.000 KINA KINA KISON 0.000 KINA KINA KISON 0.000 KINA KISON 0.000 KISON KINA KISON 0.000 KISON KISON KINA KISON 0.000 KISON	MASIA- MASIA- KISPA- CASIA MAS	12039 -2.698 M6504 0.19 -5.640 7.7.8 -4.047 K504 0.19 -5.640 7.7.8 -4.047 K504 0.19 -5.640 0.00 0.000 K504 0.00 -7.497 0.00 0.000 K504 0.00 -7.479 0.00 0.000 K504 0.00 -7.479 0.201 -0.000 K504 0.00 -7.479 0.201 -0.000 K504 0.00 -7.479 0.201 -0.000 K5044 0.00 -7.479 0.201 -0.000 K5044 0.00 -0.00 0.00 0.000 K5044 0.00 0.00 0.00 -0.000 KHH 0.00 0.00 0.00 -0.00 KHH 0.00 0.00 0.111.119 FE1114 0.00 0.00 0.00 1111.119 FE1114 0.00 0.00 0.00 11111.119 <	2.44 -4.64 -4.64 -4.64 -4.64 -4.64 -0.10 -2.489 5.38 -4.479 5.580 0.00 -7.499 5.580 0.00 -6.113 2.580 0.00 -6.113 2.580 0.00 0.00 0.00 0.00 0.00 0.00 0.00	2.4.4.4.4.8.4 FECU.2 0 2.1.40 -4.6.8.4 FECU.2 0 0.000 -7.499 FECU.2 0 0.15 -5.5.32 RLIMH 0 0.16 -5.5.13 RLIMH 0 0.16 -5.5.13 RLIMH 0 0.16 0.000 P.5.5.2 RLIMH 0 0.16 0.000 ALGM2 0 0 0.00 0.000 ALGM2 0 0 0.00 0.000 ALGM2 0 0 0.000 0.000 ALGM4 0 0 0.000 0.000 ALGM4 0 0 0.000 0.000 ALGM4 0 0 0.000 0.000 ALGM4

-36.797 99.999 ZOISITE WOLLASTONITE 11.734 9.569 MARCASTIE -142.282 99.999 -25,570 99,999 WAJRAKITE

PROGRAM WATCH2. WATER SAWPLE (FPRI) MATER SAWPLE (FPRI) PHUTGEG.C 14 S102 14 K & & & K & & & K & & & & & & & & & & &	LAN.84		LAKES	ETHIOPIA			ACTIVITY C	DEFFICIENTS	ACTIVITY COEFFICIENTS IN DEEP WATER						
PROBRAM VATCH NATCH SAMPLE FHUREG.C S102 S102 S102 CA NA K K K CA NG CO2							Ŧ	0.822	KS04-	0.794	FEH		0.414 FEC	FECLE	187.0
HATER SAUPLE PHVR61,C S102 NA NA NA NG CO2							-18	0.775	4	0.775	HEH			AL+++	0.178
PH/M6.C S102 NA KK KG CA CO2	(Ndd	STEAN SAMPLE					H25104	0.403	- ±	18/.0	FECOH		0*790 ML	AL (0H)2H	0.794
SI02 KK KK CCA CC2 CC2	0 10/ 0	CAE (THIN TA		DECEMENTE TOWN	PCODCLO P	11111 0 0	H2R03-	0.764	1	0*770	FEC	;			0.786
K K K K K K K K K K K K K K K K K K K	141.00	LUD		NELENEMUS IENT.	DEUNCES 1		-502	18/*0	1100	515-0	FEUNITY		TH CAPID	ALSU41	0.704
K K	858.00	SCH		CANPI THE PRESCIES	RARS ARS.		-SH	0.775	CAHENTA	0.799	EFC				104.07
NS IS	45.00	CH CH		DISCHARGE ENTHALPY	K JOH /KG		l la	0.395	HGHLD3+	0.781	FES04+				0.794
NS CO2	3.00	02		DISCHARGE	KG/SEC.	0.0	-HS04-	0.786	CAON+	0.799	FECLH			ALF4-	0.786
602	0.240	CHA					NOS	0.376	HGOHH	0.804	FECL24				0.386
	1200.33	K2		NEASURED TEMPERATU	RE DEIGREES C	61.0	-+DSAN	0.794	NH4+	0.764	FEOL4-				0.118
204	15.00			RESISTIVITY/TEMP. OHMM/DEG.C	OHMM/DE6.(Contraction of States of Contraction								
H2S	0.20			EH/TEMP.	NU/DEG.C	0.000/ 0.0	CHENICAL CI	DMPONENTS I	CHEMICAL COMPONENTS IN DEEP WATER (PPM AND LOG MOLE)	PPH AND LOG M		100000			
ರ	339,00						HH (ACT.)		-7.929	H6++		-5.258	FE(IIII)3		0.000
F	38.00	LITERS GAS PER KG		And a second sec			놂		-3.646	NACL	2	-4.037	FE(0H)4-	0.00	0.000
B155,500,105	0.00	CUNDENSAIL/INE6.C		MEASURE U DOWNHULE IEMY.		FLUID INFLON	H4SI04	182.80	-2.721	NCL		-5.958	FECL+		0.000
ł a	1.4000			הנסתנגם וגותב		CENTION NILD	HOSTON		187	KCD4-	01.10	-5. 450	LEULA	00.0	0000
, H	0,0000	CONDENSATE (PPN)		0.0	0.0	0.0	MANTSTRA		-1.997	LaSn4		-4.415	FELI 24		0.000
EHW	0.000	PH/DEG.C		0.0	0.0	0.0	HJBDJ		-3.943	MGS/14		-6.444	FEOL3		000
		C02		0.0	0.0	0.0	H2R03-	0.94	-4.811	CACOU		-4.667	FECL4-	0.00	0.000
		SCH		0.0	0.0	0.0	H2CD3		-2.966	MGC03		-5.824	FES04		0.000
		MA		0.0	0.0	0.0	HC03-		-1.587	CAHC034		-4.425	FES044		0.000
				0.0	0.0	0.0	C03		-3.652	MGNC03+		-5.679	41++		0.000
				0.0	0.0	0.0	H2S		-6.651	CAON+		-7.024	ALOH++		0.000
				0*0	0.0	0*0	HS-		-5.248	HUDSH		-4.408	AL (0H)2+		0.000
		CONDEMSATE VITH NAGH (PPM)	(MAG) HEH	0.0	0"0	0.0	S		-12.681	NH4DH		0000	AL (0H)3		0.000
		C02		0.0	0.0	0.0	PLC2N		10/1/1-	1444 WH44		000.00	AL (UH) 4-		00000
		ST		0.0	0.0	0*0	-Lucu		-00-10-	1011		000*0	HLSUAT		000*0
TOUT STRENGTH = 0.01971	10010.0 =	TONTE BAI ANEE 1	CATTONS (MD	CATTONS (MOL CO. D. LAND RATTO				10.01	108-0-	1111		00010	AL (504) 2-		0000
	ne soara	THE PARTY OF THE P	ANIDNS (NO	(HOL.FD.)0.03896673			2 4		-2-699	FE(DH)2	0.00	0.000	ALE24	00.00	0.000
				(2) -0.92			-10		-2.024	FE(DH)3-		0.000	ALF3		0.000
							HA4		-1.430	FE(ON)4		0.000	ALF4-		0.000
DEEP WATER (PPN)	0		DEEP S	STEAM (PPH)	GAS PRESS	GAS PRESSURES (BARS A8S.)	ta		-2.940	FE(0H)++		0.000	ALFS		0.000
							C4++	0.62	-4.814	FE(UH)2+	0.00	0*000	ALF6	0.60	0.000
R		12	C02	0.00	C02	0.1446400									
NA 85			H2S	0.00	H2S	0.9786-05	IONIC STREET	CONIC STRENGTH = 0.03890		IGNIC RALANCE	CATIONS (CALIDNS (MUL.EU.)0.03834180	834180		
	45.00 H2	H2 0.00	EF CE	0.00	닾	0*0006400					ANIUNS (ANIUNS (MIL.EU.)0.03869065	540705		
			70	00.0	70	0,000EF00					DIFFENENCE		14.0		
			5	00.0	5 5	0.000ET00	CHENTCAL G	THERMORE IS	CHEMICAL GEOTHERMOMETERS DEGREFS C		1000/T DE	1000/T REGREES KFLUTH = 2.39	91.5		
			EHN	0.00	E E E	0.000E+00									
					H20	0.415E+01	DUARTZ	144.9							
DISS.S.	0.00				TOTAL.	0.429E40I	CHALCEDONY	115.8							
	000		T1 0CH		0.00		NAK	138.6							
	000		BUILDE	BOIL ING PORTION 0.	0.00		OXTRATION 9	TATTATTON POTENTIAL (URLTS) :		EH H75= -0.50Å		FH CH4= 99.999	EH H2= 99.999	54 NH3= 00'000	665.00
							LOG SOLVBIL	TTY PRODUCT	LOG SOLUBILITY PRODUCTS OF MINERALS IN DEEP WATER TEAD FAIL	IN DEEP WATER	TEDD	LALC		TCDD	LALC
							ADIII APTA	-15,787		ALBITE LOW	-15.179	99,999	ANAL CINE	-12.247	99.999
							ANHYDRITE		-9.480	CALCITE	-10.294	-9.263	CHAL CEDONY	-2.523	-2.721
							HG-CHLORITE			FLUIRITE	-10.552	-10.816	SOE THITE	-2,886	666.66
							CAUNDNI J TE	FFC*CZ-	99.999	ALCROCLINE V_MONTHINE	-10.882	99,999	MAISNE I J TE. MG-MONTHOD	-26.196	99.999
							NA-HONTHOR.		1.03	MUSCOUTTE	-19.143	660.00	PREHNITE	-35.864	666.99
÷							PYRRHOTI IE				-114.996	66.999	DUARTZ	-2.721	-2.721
							WAIRAKITE	-23.942		WOLL ASTONITE	9,591	7.940	ZOISITE	-35.394	566.99
							EPIDOTE	-40.129	66*66	MARCASITE	-94.045	665'66			

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