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# GEOCHEMICAL SAMPLING, LABORATORY ANALYSIS, AND MINERAL EQUILIBRIA CALCULATIONS FOR FLUIDS FROM SELECTED AREAS IN ICELAND

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# ABSTRACT

The work carried out during the project period of the geothermal training programme is described. Field work involved collection of samples of aqueous solutions from well SN-2 in the Seltjarnarnes geothermal area, well H-1 in the Reykjanes Isafjardardjup geothermal area, and from hot springs in the Borgarfjordur and Reykjanes Isafjardardjup geothermal areas. Steam and gas samples were collected from fumaroles G-27 and G-19, and the new well KG-24 in the Krafla geothermal area.

Laboratory work involved analysis of selected samples for pH, $CO_2$, $H_2S$, Cl, $SiO_2$, Al, Fe, and Mn by the methods used at the National Energy Authority of Iceland.

Mineral Equilibria calculations were carried out for selected low and high temperature geothermal fluids using the WATCH1 and WATCH3 computer programs, to obtain the temperatures at which the geothermal fluids were in equilibrium with the various expected alteration minerals. Out of 17 geothermal fluids for which the calculations were performed, 9 gave equilibrium temperatures within 10°C of the "expected" reservoir temperature, and 15 were within 20°C. The two for which the calculated temperatures differed from the expected reservoir temperatures by more than 20°C were high salinity fluids in open reservoirs.

There are however some differences between the results obtained using the WATCH program and those given by Reed and Spycher (1984) using the SOLVEQ program.

It is expected that this approach will give more accurate predictions when better thermodynamic data become available, particularly for aluminium aqueous species, and for clay minerals.

Cold waters which have never been in equilibrium with the surrounding rocks are easily recognised by the complete lack of equilibrium among the minerals.

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## 1. INTRODUCTION

Geochemistry has uses in both the exploration and exploitation stages of geothermal energy development. During the exploration stages, analysis of the chemical composition of hot springs and fumaroles can be used to infer the subsurface temperatures of the geothermal system, and hence the feasibility of exploitation of the system. The chemistry of the fluids also gives an indication of possible scaling and/or corrosion problems that may arise during exploitation. After exploitation is under way, monitoring of the chemistry of the well discharge fluids with time gives early indications of possible inflow of colder waters into the aquifer which may lead to the cooling of the system.

In order for predictions based on the chemistry of the fluids to be reliable, great diligence has to be excercised during collection and analysis of the geothermal samples. Subsequent interpretation is made easier by the use of computer programs, which allow for the evaluation of the distribution of aqueous species in solution at the high temperatures and pressures existing at depth, taking into account the sampling conditions and the various processes that may take place during the ascent of the fluids from the reservoir to the surface.

During the geothermal training program, the author had experience of applying the methods in use at the National Energy Authority of Iceland for collecting geothermal samples from springs, fumaroles and wells from both high and low temperature geothermal areas in Iceland. Analysis of selected chemical constituents was also carried out for various geothermal fluids. The WATCH computer program of Arnorsson et al (1982) was used to test the applicability of a proposed new approach to geothermometry which takes into account the attainment of overall chemical equilibrium between the geothermal fluid and all the possible mineral phases (Reed and Spycher, 1984).

# 2. COLLECTION OF GEOTHERMAL FLUID SAMPLES FOR CHEMICAL ANALYSIS

## 2.1 Introduction

Geothermal fluid samples for chemical analysis consist of aqueous solutions (water samples), steam (NaOH-collected condensate with gas), and gas samples (non-condensable gases, mainly $CO_2$ and $H_2S$). In low temperature geothermal areas, samples predominantly consist of aqueous solutions, although gases may also be sampled from hotsprings and geothermal wells; while in high temperature geothermal areas, aqueous solutions, steam, and gases are important in wells and hotsprings: in fumaroles, there may only be steam and gases that are available for collection.

Proper practice in the collection and preservation of samples is necessary to allow for appropriate interpretation of the resulting analytical data.

## 2.2 Field Work

During the Geothermal Training Programme practice in the collection of geothermal fluids was undertaken in three low temperature geothermal fields, and one high temperature geothermal field. Well samples in low temperature areas were collected from Seltjarnarnes well 2 and from Reykjanes, Isafjardardjup well 1. Low temperature hotspring samples were collected from England in the Borgarfjordur area, and from Reykjanes Isafjardardjup area. High temperature fluids were collected from both mixed water-steam wells and fumaroles in the Krafla geothermal field. The locations of these areas are shown in figure 1. The procedures used are those employed at the Icelandic National Energy Authority as described by Armannsson, (1985). Four samples were collected from each low temperature site as follows:

1. A raw untreated (Ru) sample portion in a 250ml glass tube for pH and $CO_2$ determination

2. A filtered untreated (Fu) sample portion in a 500ml plastic bottle for the determination of anions.
3. A filtered acidified (Fa) sample portion in a 100-500ml plastic bottle for the determination of cations.
4. A filtered diluted (Fd) sample portion in a 100ml plastic bottle for the determination of dissolved silica.
In some instances, a 100ml sample was collected, to which was added 1 or 2 pellets of solid NaOH for the determination of silica, $CO_2$ and $H_2S$ for comparison with the results of the methods above. In most cases, each type of sample was collected in duplicate.

In the high temperature field in Krafla, two fumaroles, G-27 and G-19, as well as the new well KG-24 were sampled. Four sample portions were collected from each of the fumaroles as follows:
1. A steam sample portion (Rb) obtained by bubbling the fumarole discharge into an air-free flask containing 40% NaOH solution.
2. A condensate sample portion (Ruv), collected into a gas tube.
3. A noncondensable gases fraction (Run), collected into a gas tube.
4. A steam condensate sample portion collected into a McCartney bottle for the determination of the isotopic composition of the condensate (Rui).

Both steam and water fractions were sampled from the well. The samples collected from the steam fraction were Rb, Ruv, and Run. From the water fraction were collected the Fu, Fa, Fd,and Fp portions. The latter was a filtered sample, to which was added zinc acetate to precipitate out reduced sulfur species from solution to stop their oxidation to sulfate. The sample was used for the determination of sulfate in solution.

## 3. CHEMICAL ANALYSIS OF GEOTHERMAL WATER SAMPLES

### 3.1 Introduction

Complete analyses of sampled geothermal fluids is necessary for the calculation of geothermometer temperatures, and to assess how close the samples are to attaining equilibrium with minerals which may cause scaling problems during the exploitation of the geothermal field. An assessment of potential corrosion problems and an indication of the hydrological conditions of the field can also be obtained through careful interpretation of the analytical data. Methods that are both highly accurate and precise are therefore required for the ensuing interpretation to be valid.

### 3.2 Laboratory Work

During the Geothermal Training Programme, analyses of selected aqueous solutions for selected species - pH, and concentrations of $CO_2$, $H_2S$, Cl, $SiO_2$, Al, Fe, and Mn - were carried out using the methods employed at the National Energy Authority. The methods of analysis of pH, $CO_2$, $H_2S$, Cl, and $SiO_2$ are described by Armannsson (1985). Analysis of Al was done by determination of the fluorescence of the lumogallion complex (Hydes and Liss,1976). Iron was determined spectrophotometrically after complexation with 2,4,6 tripyridyl - 1,3,5 triazine (TPTZ) (Grasshoff et al, 1983). Manganese was also determined spectrophotometrically after complexation with formaldoxime (Grasshoff et al, 1983).

The determination of pH, $CO_2$, and $H_2S$ in the fumarole and well samples was carried out in the Krafla Power Station field laboratory. Analyses were carried out as soon as possible after sampling, not later than the next day.

## 3.3 Results of Chemical Analysis

The results of the laboratory analyses are summarised in Table 1. The complete results of analyses carried out by the laboratory staff of the National Energy Authority on the same samples are given in Table 2. The methods are summarised in Table 3.

## 4. MINERAL EQUILIBRIA CALCULATIONS FOR THE ASSESSMENT OF RESERVOIR TEMPERATURES AND/OR MIXINGPROCESSES IN SELECTED HIGH AND LOW TEMPERATURE GEOTHERMAL WATERS IN ICELAND

### 4.1 Introduction

Among the main applications of the study of the chemistry of geothermal waters is the prediction of subsurface temperatures during exploration (i.e. before drilling starts), and the prediction of possible problems associated with scaling and corrosion during the exploitation of the geothermal field. As the reservoir is exploited, an influx of colder waters from the surroundings may lead to a decrease in the temperature of the geothermal system, which can be foretold by comparing changes in the reservoir temperatures indicated by the various chemical geothermometers.

Chemical geothermometers have been developed for use in the prediction of reservoir temperatures under different conditions (Fournier and Rowe, 1966; Fournier and Truesdell, 1973; Fournier, 1979; Fournier and Potter, 1982; Arnorsson, 1975; Arnorsson et al, 1983b). However, the use of these geothermometers has often required prior knowledge of the conditions of the geothermal field, such as subsurface geology. When applied simultaneously, the various geothermometers frequently yield appreciably different values for reservoir temperatures in the same field. It is clearly desirable to have a geothermometer which can give reliable indications of subsurface temperatures during the exploration and exploitation stages of geothermal investigations.

It has been proposed (Reed and Spycher, 1984) that by determining all the mineral phases that can be in equilibrium with a given geothermal fluid at a given temperature, the most probable reservoir temperature can be determined. This is the temperature at which the maximum number of mineral phases are in equilibrium with each other and with the geothermal fluid constituents. By definition, at equilibrium,

$Q_k = K_k$, where $Q_k$ is the activity quotient for the aqueous species arising from the dissolution of the mineral,k, and $K_k$ is the equilibrium constant for the dissolution reaction; ie.

$$K_k = \overset{i}{\Pi} a_i{}^{\nu i,k}/a_k.$$

in which $a_i$ is the activity and $m_{ik}$ is the stoichiometric coefficient of species i in the equilibrium mass action expression for mineral k, written for the mineral dissolving (ie. mineral on the left hand side and aqueous components on the right hand side), and $a_k$ is the activity of mineral k. Similarly,

$$Q_k = \overset{i}{\Pi} a_{i,k}{}^{\nu i,k}.$$

Since at equilibrium $Q_k = K_k$, $\log(Q/K) = 0$ at the equilibrium temperature.

In a plot of log(Q/K) versus temperature, all minerals in equilibrium with the solution will converge to a value of zero at the same temperature. Geothermal fluids in which there is mixing of solutions of different composition will show either (a) a shift in the positions at which the minerals are apparently in equilibrium to lower log(Q/K) values if the solutions that mix with the geothermal fluid are very dilute or (b) a complete lack of any identifiable equilibrium temperature if the solution mixing with the geothermal fluid is not dilute, or if the unmixed geothermal fluid is boiling.

Results of chemical analyses of selected geothermal waters from high and low temperature fields in Iceland have been used to calculate possible equilibrium temperatures and/or mixing indications of the fluids using the WATCH mineral equilibria programme of Arnorsson et al, (1982). The results of some of these computations have been compared to the published results of computations for the same samples obtained using the SOLVEQ programme (Reed and Spycher, 1984).

The aim of this work was to investigate the applicability of this concept of "complete mineral equilibria" in the determination of reservoir temperatures using chemical analytical data from both high and low temperature geothermal fields in Iceland.

## 4.2 Theory of Complete Mineral Equilibria Geothermometry

Reed and Spycher (1984) have proposed that by determining all the mineral phases that are in equilibrium with a given geothermal fluid at a given temperature, the most probable reservoir temperature can be determined. This is the temperature at which the maximum number of mineral phases are in equilibrium with the geothermal fluid, and with each other. As can be shown from considerations of the phase rule, the maximum number of mineral phases which can coexist in equilibrium is about 10 - 12 (see for example Arnorsson et al, 1982). In practice there are usually 5 - 6 minerals that coexist, say in a hand specimen. Since it is not known a priori which phases actually exist in a given geothermal system, the calculations are performed for as many "realistic" minerals as possible: the existing assemblages will be in equilibrium, while others will not be.

In a plot of log(Q/K) versus temperature, geothermal fluids in which there is mixing of solutions of different compositions will show either (a) a shift in the positions at which the minerals are apparently in equilibrium to negative values of log(Q/K) if the solutions that mix with the geothermal fluid are very dilute, or (b) a complete lack of any identifiable equilibrium temperature if the solution that is mixing with the geothermal fluid is not dilute.

Further, if the geothermal fluid is boiling prior to sampling, there is an unsystematic dispersion of the log(Q/K) plots, since the loss of gases (including $H_2O$ vapour) will lead to (a) a simple concentration of elements in the residual aqueous solution (b) a change in the gas content of the aqueous solution, which may lead to precipitation or dissolution of some mineral phases but not others (c) a change in the pH of the aqueous solution, which may also lead to dissolution or precipitation of some mineral phases but not others. These factors lead to complex changes in the apparent temperatures at which the various minerals are in equilibrium with the geothermal fluid.

Examples of expected plots of log (Q/K) versus temperature at equilibrium, after mixing, and after boiling are shown in Figures 2, 3, and 4.

### 4.3 Water Chemistry Data

Most of the data used in these computations was taken from Arnorsson et al (1983a). Additional data were obtained from the samples collected during the training programme, or supplied by Dr. Halldor Armannsson, from analyses carried out in the laboratory of the INEA, Orkustofnun. All the data used are presented in Tables 1 to 3. The sample locations are shown in Figure 1.

The wet-steam well data was interpreted using the WATCH1 programme, while the hot springs and hot water wells data was interpreted using the WATCH3 program of Arnorsson et al (1982).

### 4.4 Results of WATCH1 and WATCH3 Computations

Examples of outputs from the WATCH1 and WATCH3 programs are given in Tables 5 and 6. The programs are used to calculate the equilibrium constants at a desired temperature, mostly using data from Helgeson (1969) and Helgeson et al (1978) (Arnorsson et al, 1982). Where thermodynamic data are available only at 25°C, equilibria at elevated temperatures have been predicted by the methods of Helgeson (1967).

Examples of mineral equilibria diagrams (log (Q/K) versus temperature) obtained for the above data are presented in Figures 5 and 6. According to the WATCH program computations,the minerals attain equilibrium over a range of temperatures, rather than at one specific temperature, or a narrow temperature interval as indicated in the figures in Reed and Spycher (1984). The range of equilibrium temperatures, arbitrarily defined as the temperature interval over which at least two minerals attain equilibrium within 4 C° of each other, are presented in table 7. Table 7 also shows the temperature range over which most minerals appear to reach equilibrium (cluster equilibrium temperature), and the optimum equilibrium temperature, defined as the temperature at which the highest number of expected minerals are in equilibrium with the aqueous solution, and with each other. The measured temperature, and the chalcedony and/or quartz equilibrium temperatures, as well as the NaK temperature, are also presented for comparison.

The calculated equilibrium temperature for Reykholt well 1 is in excellent agreement with the measured downhole temperature. For this sample, the calculated equilibrium temperature of 135°C is only 2 C° off the measured downhole temperature of 133°C. The differences between calculated equilibria temperatures and measured downhole temperatures then vary from 7 to 8 C° in Urridavatn well 8 and Krafla well 9 to 46 C° for Reykjanes well 8. The calculated temperatures can be too low, as at the Svartsengi well 4, Reykjanes well 8, Hveragerdi well 4, or Urridavatn well 8 areas, but they are more typically higher than the measured temperatures. Two of the samples used by Reed and Spycher (1984) to support their proposed approach to geothermometry - Reykjanes well 8 and Hveragerdi well 4 - give calculated equilibrium temperatures with the WATCH program, that are 46 and 15°C too low, respectively, compared to the measured downhole temperatures.

The third, Namafjall well 8 gives a calculated temperature that is in very good agreement with the estimated reservoir temperature at the time of sampling. Figures 7, 8,and 9 show comparisons between the plots given in Reed and Spycher (1984) from calculations with the SOLVEQ program, and those obtained in this study using the WATCH1 program.

### 4.5 Discussion

Measured temperatures do not necessarily show the reservoir temperatures within 1 or 2 degrees. There may be several feeding aquifers at different temperatures within a well. Also, temperature logging in wells is usually carried out shortly after drilling, when the effects of disturbances due to drilling might not have worn off, and may still be having an effect on the temperature distribution in the well. Temperature logs made long after drilling also indicate hybrid quasi-steady state temperatures, in cases where there are several aquifers feeding the well. The question therefore arises as to what should constitute an acceptable estimate of the temperature of the reservoir, since in the case of a multiple feed aquifers of different temperatures, such a temperature does not exist: it would be asking too much to expect a geothermometer to give the temperatures of all the individual aquifers. In the exploration stages, the aim of estimating reservoir temperatures is to give an indication as to what uses a particular geothermal field should be put to, e.g. whether it can be used for the generation of electricity, or not. In such instances, and considering the uncertainties mentioned above, a temperature estimate that is within 10 to 20°C may be acceptable.

The calculated equilibrium temperatures for Svartsengi and Reykjanes are unreasonably low. Both of these areas have very open systems, and fluid flow is probably fast. They are saline (sea water), and it is conceivable that the fast inflow of sea water does not allow for attainment of chemical equilibrium, even though the waters get heated to high temperatures. The WATCH program may also not adequately account for the thermodynamics of aqueous species at these high temperatures and high salinities.

The measured temperature at Reykjabol (152°C) may be slightly lower than the true reservoir temperatures as it was measured soon after drilling (Benedikt Steingrimsson and Halldor

Armannsson, personal communication), and the calculated optimum equilibrium temperature of 161°C is very reasonable. It is conceivable that a trickle of cooler aquifer mixes with the warmer aquifer and cools it: this cooler flow may be responsible for the value of 126°C obtained.

The aquifer in well 9 at Krafla was originally at 300°C, but later cooled down. The temperature of 240°C was a compromise based on several measurements: it is conceivable that the hotter water did not lose all its imprints. The calculated value of 248°C therefore seems to be very good (Halldor Armannsson, personal communication).

The temperature data presented for well 7 at Krafla by Arnorsson et al (1983a) were measured soon after drilling. There is, for example, no longer any flow at 160°C, and the deepest aquifer has been completely blocked off (no effect on the flow). On the other hand, the equilibrium temperature at 1700m depths is approximately 325°C. It has been estimated that in 1979, when the sample was collected, the flow from the upper zone (206°C) contributed about 40% to the total flow, while the flow from the lower zone (325°C) contributed approximately 60% to the total flow (Halldor Armannsson, personal communication). Thus a temperature of approximately 277°C would be expected from the mixture, and the calculated temperature of 275°C is in excellent accord with this.

During the magmatic activities at Krafla in April and September of 1977, there was a southward flow of magma which affected the Namafjall field severely, where wells 4 and 8 are situated: well 4 actually erupted some magma. The area was extensively fractured, and a large amount of cold groundwater entered the geothermal system. It was difficult to obtain temperature data from these wells, but one profile obtained for well 4 in 1984 shows an inflow temperature of 180°C (Halldor Armannsson and Benedikt Steingrimsson, personal communication). The samples referred to in Arnorsson et al (1983a) were collected in 1979, but the temperature data listed were obtained before 1977 (Halldor Armannsson, personal communication). The calculated equilibrium temperature value of 185°C for well 4 is therefore very reasonable, and the temperature of 160°C for well 8 (which was always cooler than well 4 (Halldor Armannsson, personal communication)) is probably close to the reservoir temperature at the time the samples were collected.

The Seltjarnarnes well 2 draws from relatively shallow depths, and conventional geothermometers suggest temperatures higher than those measured, with the waters probably coming from a hotter, deeper aquifer. Well 4, which is adjacent to well 2, draws from a deeper aquifer at 120°C, which is the primary reservoir water. There are indications that the two wells are hydrologically connected (Tulinius et al, 1987). The calculated values of 134°C and 138°C are therefore within 20°C of the deep reservoir water; the calculated 94°C temperature probably reflects water that has mixed with cooler, shallow water.

The temperature of 82°C calculated for England, Borgarfjordur, is a little lower than the measured temperature of 91°C. This can, however be taken to be a strong indication that temperatures substantially higher than the measured surface temperatures are unlikely to exist in the reservoir. The same argument probably applies for the calculated equilibrium temperature of 90°C for the Reykjanes, Isafjardardjup spring: the highest temperatures obtained in borehole 2 adjacent to (15m away from) the spring that was sampled, was 94.5°C at a depth of 240m, after which it decreased to 92°C.

The calculated equilibrium temperature for Urridavatn well 8 is 84°C, compared to a measured temperature of 77°C. This is considered to be reasonable enough, considering the uncertainties mentioned earlier. The sample from well 4 was collected from an artesian flow at a temperature of 60.2°C. This probably contained a considerable amount of a cooler component from the lake (Benjaminsson and Gislason, 1986). When the well is pumped, the temperature of the flow increases to 64-65°C, which is probably close to the temperature of the main aquifer. The similarity between the range and cluster equilibrium temperatures for well 4 and 8 at Urridavatn suggests that the two wells probably draw fluids from the same aquifers, but in different proportions.

In the IRDP well, the main flow is 47°C, but a deeper one at 78°C has also been observed. The calculated value of 65°C is somewhat high, since the contribution from the lower aquifer is not likely to be large enough to cause such a large difference in temperature.

As expected, the cold spring at Borgarfjordur did not indicate any minerals to be in equilibrium with one another. If the 17 other samples are considered in light of the information discussed above, it is seen that there are 9 samples for which the optimum equilibrium temperature is within 10°C of the expected reservoir temperature, and 15 samples for which the optimum temperature is within 20°C of the expected reservoir temperature. Two samples out of 17 have calculated equilibrium temperatures differing from the expected reservoir temperatures by more than 20°C. These are the high temperature, highly saline waters in open reservoirs for which either equilibrium is not attained in the reservoir, or the WATCH program calculations do not adequately model.

The computations assume an equilibrium situation. Such equilibrium is only established where waters have been at the high reservoir temperatures for sufficiently long periods of time for water-rock reactions to have attained equilibrium at one temperature. This condition is violated in cases where waters come from different aquifers at different temperatures. This is the case with the discharges from Reykjanes well 8, in which aquifer temperatures range from 274° to 292°C. Equilibrium might also not be attained in flowing systems, when there is relatively rapid movement of waters through aquifers as probably happens during exploitation of geothermal systems. Further, during ascent of geothermal fluids, some minerals may be precipitated from solution (as is observed at Krafla, Svartsengi and Hveragerdi, where calcite scaling frequently causes blocking of wells), while other minerals may be dissolved from the wall rocks into solution.

There are considerable uncertainties in the available thermodynamic data, especially for aqueous species of aluminium. This means that calculated equilibrium constants may not be very accurate, particularly at temperatures above 200°C (Arnorsson et al, 1982). Thermodynamic data for some solid solution minerals are currently not available. According to Reed and Spycher (1984) this introduces only small errors if end-member data are used instead of the actual solid solutions. However, for minerals with a very low slope in log(Q/K) versus temperature curve, small shifts in the value of log(Q/K) can result in large shifts in the intersection temperatures.

The WATCH program recalculates the deep water composition by assuming adiabatic steam loss. This assumption is probably true for low temperature systems in which boiling starts near the surface, but it may be less valid in the case of high temperature systems where there may be a continuous steam loss as the solution rises to the surface.

The mineral phases that are taken into consideration in the WATCH program calculations are those that are commonly observed in drill holes in Icelandic geothermal systems. As mentioned above, solid solutions and interlayering of clay minerals has not been taken into consideration. For accurate simulation of the geothermal system, the real conditions at depth must be portrayed as closely as possible, and these minerals need to be taken into account.

The quality of the chemical analyses is assumed to be very high. However, inaccuracies in the analyses, particularly for the gases could cause a wide scatter in the calculated equilibrium temperatures.

## 5. SUMMARY AND CONCLUSIONS

During the geothermal training program period, experience in collecting samples from hotsprings, fumaroles, and wells from both high temperature and low temperature geothermal areas in Iceland following the methods used at the National Energy Authority of Iceland was gained. Analysis of pH, $CO_2$, $H_2S$, Cl, $SiO_2$, Al, Fe, and Mn was also carried out on selected geothermal samples.

Calculations were made to verify the new approach to geothermometry proposed by Reed and Spycher (1984), in which the total equilibrium of the water-rock system is examined, using computations with the WATCH programme of Arnorsson et al (1982). These computations showed that the approach can be used to give an indication of the reservoir temperature to within 20°C, particularly for relatively dilute waters. Calculated equilibrium temperatures for high temperature, high salinity fluids vary from the expected reservoir temperatures by more than 20°C. Thermodynamic data of better quality, and a better undersatanding of the processes which take place during the generation and subsequent ascent of the geothermal fluid are needed before this approach to geothermometry can be applied with confidence to all types of geothermal fluids. Waters in which equilibrium is not approached at all (as for example river waters) can be distinguished by a complete lack of equilibrium.

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Table 1. Results of chemical analyses of selected aqueous geothermal samples.

| Spl No. | Locality | T/°C | pH/T°C | CO2 ppm | H2S ppm | Cl ppm | SiO2 ppm | Al ppm | Fe ppm | Mn ppm |
|---|---|---|---|---|---|---|---|---|---|---|
| 880072 | Seltjarnarnes well 2, 80m | 31 | 8.85/18.5 | 23 | 0.02 | 1417 | 8 | 0.164 | 0.445 | <0.00002 |
| 880073 | " " ", 570m | 78 | 8.45/20.8 | 11 | 0.01 | 1527 | 48 | 0.137 | 0.066 | 0.00002 |
| 880074 | " " ", 725m | 77 | 8.18/21.2 | 9 | 0.01 | 1395 | 147 | 0.278 | 0.237 | <0.00002 |
| 880075 | Borgarfjordur, cold spring | 3.8 | 8.10/20.3 | 25 | 0.02 | 8 | 18 | 0.048 | 0.010 | 0.011 |
| 880076 | England, hot spring | 91.1 | 9.24/21.3 | 51 | 0.24 | 19 | 167 | 0.031 | 0.014 | 0.009 |
| 889015 | Thorlakshofn, groundwater mixed with 1/2 sea water | 27 | 8.09/22.0 | 16.1 | <0.03 | 10066 | 23.4 | 0.022 | 0.131 | 0.402 |
| 889034 | Reykjavik, cold groundwater | 16 | 8.05/23.3 | 177 | <0.03 | 387 | 21.4 | 0.095 | 0.069 | 0.122 |
| 889035 | Reykjavik, cold lake | 19 | 9.44/23.4 | 88.7 | <0.03 | 418 | 18.2 | 0.058 | 0.131 | 0.108 |
| 880079 | Urridavatn well 8 | 77 | 9.82/23.6 | 10.8 | 0.06 | 46.3 | 66.3 | 0.138 | 0.007 | 0.004 |
| 880080 | Urridavatn well 4 | 60 | 9.81/23.7 | 21.0 | 0.07 | 29.0 | 54.4 | 0.106 | 0.023 | 0.016 |
| 880081 | IRDP well, Areyjar | 43 | 9.64/23.8 | 5.6 | <0.03 | 70.5 | 59.3 | 0.036 | 0.002 | 0.005 |
| 881003 | G-27 fumarole, Krafla | | | | | | | | | |
| | steam fraction | 93 | nd | 40860 | 792 | nd | nd | nd | nd | nd |
| | condensate fraction | 93 | 4.70/19.2 | 936 | 15.4 | 1.6 | nd | nd | nd | nd |
| 881004 | G-19 fumarole, Krafla | | | | | | | | | |
| | steam fraction | 94.8 | nd | 8427 | 234 | nd | nd | nd | nd | nd |
| | condensate fraction | 94.8 | 4.50/21.6 | 630 | 44.6 | 0.4 | nd | nd | nd | nd |
| 881005 | KG-24 well, Krafla | | | | | | | | | |
| | steam fraction | 130 | nd | 1251 | 123 | nd | nd | nd | nd | nd |
| | condensate fraction | 130 | 4.65/22.2 | 415 | 88.9 | nd | nd | nd | nd | nd |
| | water fraction | 130 | 9.31/20.5 | 33.8 | 12.3 | nd | 298 | nd | nd | nd |

Note: "nd" denotes "not determined"

Table 2. Results of complete chemical analyses of some of the samples in Table 1. Results for sample 60 were taken from Arnorsson et al (1983a)

| Spl. No. | Temp. /°C | pH/T°C | Resist. Ωm/°C | SiO2 ppm | Na ppm | K ppm | Ca ppm | Mg ppm | CO2 ppm | SO4 ppm | H2S ppm | Cl ppm | F ppm | Al ppm | Fe ppm | Mn ppm | TDS ppm |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 880072 | nd | 8.85/19 | 3990/21.2 | 41.3 | 568.9 | 7.3 | 277 | 0.27 | 23 | 192.4 | <0.01 | 1216 | 0.473 | 0.164 | 0.445 | <0.00002 | 2327.4 |
| 880073 | nd | 8.45/21 | 4270/21.1 | 92.3 | 595.6 | 14.5 | 324.7 | 0.28 | 11 | 221.7 | <0.01 | 1321 | 0.549 | 0.137 | 0.066 | 0.00002 | 2582.3 |
| 880074 | nd | 8.18/21 | 3850/21.1 | 85.9 | 537.2 | 10.1 | 285.4 | 0.22 | 9 | 203.2 | <0.01 | 1167 | 0.527 | 0.278 | 0.237 | <0.00002 | 2298.7 |
| 880075 | 3.8 | 8.10/20 | 90.0/20.9 | 15.8 | 9.1 | 0.34 | 5.87 | 2.12 | 25 | 4.8 | <0.01 | 8.4 | 0.081 | 0.048 | 0.010 | 0.011 | 71.4 |
| 880076 | 91.1 | 9.27/20 | 344/20.8 | 164.6 | 73.8 | 2.5 | 2.30 | 0.04 | 51 | 55.6 | 0.24 | 18.0 | 1.113 | 0.031 | 0.014 | 0.009 | 368.9 |
| 880079 | 77.2 | 9.82/23.6 | 367/21.5 | 66.3 | 70.7 | 1.22 | 7.29 | 0 | 10.8 | 55.2 | 0.06 | 46.3 | 0.697 | 0.138 | 0.007 | 0.004 | 258.6 |
| 880080 | 60.2 | 9.81/23.7 | 268/21.3 | 54.4 | 53.6 | 0.78 | 4.15 | 0.009 | 21.0 | 28.9 | 0.07 | 29.0 | 0.467 | 0.106 | 0.023 | 0.016 | 163.1 |
| 880081 | 42.8 | 9.64/23.8 | 598/21.3 | 59.3 | 94.9 | 1.21 | 31.9 | 0 | 5.6 | 138.1 | <0.03 | 70.5 | 2.056 | 0.036 | 0.002 | 0.0005 | 403.6 |
| 60 | 84 | 9.07/11 | nd | 70.9 | 184.2 | 4.34 | 67.6 | 0.094 | 9.0 | 42.1 | <0.01 | 390.2 | 0.23 | 0.02 | 0.017 | nd | 965 |

Table 3. Summary of analytical methods

| | |
|---|---|
| pH | pH-meter |
| $\Sigma$CO2 | Titration with 0.1N HCl using pH-meter |
| $\Sigma$H2S | Titration with $Hg(CH3COO)_2$ using dithizone as indicator |
| Cl | Mohr titration |
| SiO2 | Spectrophotometric on yellow silicomolybdate complex |
| Al | Fluorimetric on pink lumogallion complex |
| Fe | Spectrophotometric on pink TPTZ complex |
| Mn | Spectrophotometric on red-brown formaldoxime complex |

Table 4. Chemical composition of water and steam from selected wet-steam wells in Iceland (from Arnorsson et al 1983a). Concentrations are in ppm. Sample numbers correspond to locality numbers shown in figure 1.

| | Svartsengi | Reykjanes | Reykholt | Reykjabol | Hveragerdi | Krafla | Krafla | Namafjall | Namafjall |
|---|---|---|---|---|---|---|---|---|---|
| | well 4 | well 8 | well 1 | well 1 | well 4 | well 9 | well 7 | well 4 | well 8 |
| Sample No. | 08 | 09 | 28 | 30 | 32 | 48 | 49 | 51 | 52 |
| Water sample (ppm) | | | | | | | | | |
| pH/°C | 7.53/20 | 6.38/20 | 9.30/20 | 9.28/20 | 8.82/20 | 9.02/22 | 8.52/20 | 9.33/22 | 8.20/22 |
| $SiO_2$ | 534.6 | 631.1 | 179.8 | 252.8 | 281.0 | 575.5 | 766.8 | 442.8 | 446.3 |
| B | 8.65 | 8.72 | 0.35 | 0.65 | 0.62 | 0.71 | 1.50 | 1.48 | 1.66 |
| Na | 8037 | 11150 | 109.7 | 102.2 | 153.3 | 193.9 | 193.0 | 158.6 | 154.8 |
| K | 1245 | 1720 | 5.54 | 6.21 | 13.4 | 29.0 | 36.0 | 25.5 | 24.0 |
| Ca | 1343 | 1705 | 2.68 | 1.28 | 1.73 | 2.54 | 1.90 | 2.81 | 4.52 |
| Mg | 1.68 | 1.44 | 0.055 | 0.048 | 0.002 | 0.064 | 0.067 | 0.046 | 0.085 |
| Fe | 0.196 | 0.329 | 0.010 | 0.007 | 0.008 | 0.020 | 8.78 | 0.007 | 0.019 |
| Al | 0.07 | 0.07 | 0.17 | 0.42 | 0.14 | 0.12 | 0.21 | 0.10 | 0.10 |
| $\Sigma CO_2$ | 32.6 | 63.1 | 30.4 | 54.3 | 74.2 | 100.0 | 186.6 | 70.7 | 88.2 |
| $SO_4$ | 40.5 | 28.4 | 72.6 | 70.7 | 43.7 | 194.5 | 143.0 | 42.2 | 48.7 |
| $\Sigma H_2S$ | 0.16 | 2.21 | 1.04 | 4.09 | 19.2 | 36.2 | 22.2 | 109.2 | 132.6 |
| Cl | 17010 | 22835 | 77.7 | 41.6 | 109.5 | 28.0 | 52.0 | 16.3 | 16.6 |
| F | 0.16 | 0.21 | 2.69 | 1.86 | 1.82 | 0.87 | 1.03 | 0.68 | 0.43 |
| TDS | 27470 | 39124 | 555 | 569 | 765 | 1237 | 1389 | 1003 | 902 |
| Condensate (ppm) | | | | | | | | | |
| $CO_2$ | 722 | 584 | 123 | 242 | 627 | 553 | 14680 | 190 | 172 |
| $H_2S$ | 18.8 | 65.6 | 7.80 | 10.3 | 84.5 | 108 | 381 | 258 | 277 |
| Gas w/condensate (vol%) | | | | | | | | | |
| $CO_2$ | 97.7 | 96.2 | 18.0 | 33.2 | 84.5 | 88.6 | - | 27.2 | 36.8 |
| $H_2S$ | 0.8 | 2.9 | 0.4 | 0.6 | 3.0 | 5.0 | - | 10.4 | 17.0 |
| $H_2$ | 0.1 | 0.2 | 0.4 | 0.4 | 2.8 | 3.4 | 2.5 | 48.6 | 37.4 |
| $CH_4$ | 0.1 | 0.1 | 0.3 | 0.3 | 0.4 | 0.1 | 0.1 | 2.3 | 2.9 |
| $N_2$ | 1.3 | 0.6 | 80.9 | 65.5 | 9.4 | 2.6 | 0.7 | 11.5 | 5.9 |
| l gas/kg condensate/°C | 0.67/20 | 2.63/20 | 1.92/20 | 3.85/20 | 1.06/20 | 2.08/20 | 8.50/20 | 0.86/20 | 6.25/20 |
| sampling pressure/bars | 3.8 | 20.0 | 2.0 | 4.0 | 6.8 | 7.9 | 5.5 | 8.6 | 9.8 |
| Disch. Enth. MJ/Kg | 1.028 | 1.151 | 0.559 | 0.628 | 0.782 | 0.962 | 1.602 | 1.117 | 1.092 |
| Mass flow kg/s. | 40 | 50 | 8 | 10 | 80 | 40 | 12 | 40 | 45 |

Table 5. Physical data on drillholes (modified from Arnorsson et al, 1983a, unless otherwise indicated).

| Sample No. | Location | Depth (meters) | Discharge (kg/sec) | Fluid inflow depth/temp. (meters) (°C) |
|---|---|---|---|---|
| 08 | Svartsengi,4 | 1703 | 40 | 1090/243, 1180,1255,1365,1565/242. |
| 09 | Reykjanes,8 | 1756 | 50 | 1010/274, 1155/279, 1235,1280/280 1510/284, 1650,1660/288, 1705,1740/292. |
| 28 | Reykholt,1 | 752 | 8 | 745/133. |
| 30 | Reykjabol,1 | 820 | 10 | 773/152. |
| 32 | Hveragerdi,4 | 692 | 80 | 630,660,670/181. |
| 48 | Krafla,9 | 1263 | 40 | 1226/240. |
| 49 | Krafla,7 | 2165 | 8 | 825,1163/206, 1700/325. |
| 51 | Namafjall,4 | 1136 | 40 | 640,1040/180. |
| 52 | Namafjall,8 | 1283 | 45 | 850,1000/160. |
| 72}<br>73}<br>74} | Seltjarnarnes,2 | 856 | 5 | 80/31,580/78, 760/77 [a]. |
| 79 | Urridavatn,8 | 1066 | | 700,870/77 [b]. |
| 80 | Urridavatn,4 | 1136 | | 200,450/64 [c]. |
| 81 | IRDP | 1919 | | 517-628/47(main), 1710/78 [d]. |

[a] Tomasson et al, 1977

[b] Benjaminsson, 1984

[c] Benjaminsson et al, 1982

[d] Benedikt Steimgrimsson, pers. comm.

Table 6. Example of a printout from the WATCH1 program

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UNU Geothermal Training Programme

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08                            Svartsengi Well 4

PROGRAM WATCH1.

WATER SAMPLE (PPM)            STEAM SAMPLE

PH/DEG.C           7.53/20.0  GAS (VOL.%)                    REFERENCE TEMP.       DEGREES C    242.0 (ARBITRARY)
SIO2             534.60       CO2               97.70
NA              8037.00       H2S                 .80        SAMPLING PRESSURE     BARS ABS.     4.8
K               1245.00       H2                  .10        DISCHARGE ENTHALPY     MJOUL/KG    1.046 (CALCULATED)
CA              1343.00       O2                  .01        DISCHARGE               KG/SEC.     40.0
MG                1.620       CH4                 .10
CO2               32.60       N2                 1.30        MEASURED TEMPERATURE DEGREES C     242.0
SO4               40.50                                      RESISTIVITY/TEMP.    OHMM/DEG.C      .0/  .0
H2S                 .16                                      EH/TEMP.               MV/DEG.C     .000/  .0
CL             17010.00
F                   .16       LITERS GAS PER KG
DISS.SOLIDS    27470.00       CONDENSATE/DEG.C    .67/20.0      MEASURED DOWNHOLE TEMP.     FLUID INFLOW
AL                .0700                                            DEGREES C/METERS        DEPTH (METERS)
B                8.6500
FE                .1960       CONDENSATE (PPM)                     1090.0      243.0          1090.0
NH3               .0000       PH/DEG.C            .00/  .0         1180.0      242.0          1180.0
                              CO2              722.00              1255.0      242.0          1255.0
                              H2S               18.80              1365.0      242.0          1365.0
                              NA                  .00              1565.0      242.0          1565.0
                                                                       .0         .0              .0
                                                                       .0         .0              .0
                                                                       .0         .0              .0
                              CONDENSATE WITH NAOH (PPM)               .0         .0              .0
                              CO2              722.00                  .0         .0              .0
                              H2S               18.80                  .0         .0              .0

IONIC STRENGTH =    .49691      IONIC BALANCE :   CATIONS (MOL.EQ.) .44664270
                                                  ANIONS  (MOL.EQ.) .47954240
                                                  DIFFERENCE    (%)     -7.10

DEEP WATER (PPM)                                       DEEP STEAM (PPM)            GAS PRESSURES (BARS ABS.)

SIO2         430.13         CO2         167.36         CO2                .00      CO2        .387E-02
NA          6465.97         H2S           3.80         H2S                .00      H2S        .384E-04
K           1001.58         H2             .01         H2                 .00      H2         .304E-04
CA          1080.48         O2             .02         O2                 .00      O2         .260E-05
MG            1.303         CH4            .09         CH4                .00      CH4        .445E-04
SO4           32.58         N2            1.98         N2                 .00      N2         .470E-03
CL         13683.81         NH3            .00         NH3                .00      NH3        .000E+00
F               .13                                                                H2O        .347E+02
DISS.S.    22100.30                                                                TOTAL      .347E+02
AL            .0563
B            6.9585                                    H2O (%)                 .00
FE            .1577                                    BOILING PORTION         .00
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## Table 6. (continued)

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SAMPLE : 08

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ACTIVITY COEFFICIENTS IN DEEP WATER
H+             .630      KSO4-          .538      FE++           .106      FECL+          .487
OH-            .466      F-             .466      FE+++          .020      AL+++          .020
H3SIO4-        .487      CL-            .444      FEOH+          .524      ALOH++         .092
H2SIO4--       .092      NA+            .487      FE(OH)3-       .524      AL(OH)2+       .538
H2BO3-         .419      K+             .444      FE(OH)4--      .083      AL(OH)4-       .507
HCO3-          .487      CA++           .106      FEOH++         .083      ALSO4+         .507
CO3--          .073      MG++           .151      FE(OH)2+       .538      AL(SO4)2-      .507
HS-            .466      CAHCO3+        .557      FE(OH)4-       .538      ALF++          .092
S--            .083      MGHCO3+        .487      FESO4+         .524      ALF2+          .538
HSO4-          .507      CAOH+          .557      FECL++         .083      ALF4-          .507
SO4--          .062      MGOH+          .571      FECL2+         .524      ALF5--         .073
NASO4-         .538      NH4+           .419      FECL4-         .487      ALF6---        .003

CHEMICAL COMPONENTS IN DEEP WATER (PPM AND LOG MOLE)
H+ (ACT.)      .00   -5.751        MG++         1.27   -4.282         FE(OH)3        .15   -5.860
OH-            .17   -4.990        NACL      1555.70   -1.575         FE(OH)4-       .18   -5.847
H4SIO4      686.50   -2.146        KCL        115.35   -2.810         FECL+          .00   -7.833
H3SIO4-        .74   -5.108        NASO4-       6.12   -4.289         FECL2          .00  -11.008
H2SIO4--       .00  -10.012        KSO4-        4.12   -4.516         FECL++         .00  -17.536
NAH3SIO4       .98   -5.083        CASO4       17.21   -3.898         FECL2+         .00  -18.260
H3BO3        39.76   -3.192        MGSO4         .09   -6.113         FECL3          .00  -19.421
H2BO3-         .04   -6.134        CACO3         .09   -6.056         FECL4-         .00  -20.521
H2CO3       203.56   -2.484        MGCO3         .00   -9.862         FESO4          .00  -11.345
HCO3-         6.31   -3.985        CAHCO3+     42.12   -3.380         FESO4+         .00  -20.085
CO3--          .00   -8.517        MGHCO3+       .01   -7.085         AL+++          .00  -19.951
H2S           3.60   -3.976        CAOH+         .41   -5.144         ALOH++         .00  -13.468
HS-            .20   -5.221        MGOH+         .02   -6.322         AL(OH)2+       .00   -8.014
S--            .00  -13.710        NH4OH         .00     .000         AL(OH)3        .16   -5.683
H2SO4          .00  -12.210        NH4+          .00     .000         AL(OH)4-       .00   -8.742
HSO4-          .37   -5.417        FE++          .00   -8.402         ALSO4+         .00  -21.370
SO4--        12.13   -3.899        FE+++         .00  -22.150         AL(SO4)2-      .00  -23.642
HF             .02   -6.004        FEOH+         .00   -8.650         ALF++          .00  -16.642
F-             .11   -5.238        FE(OH)2       .00   -9.666         ALF2+          .00  -15.255
CL-       12685.27    -.446        FE(OH)3-      .00  -10.958         ALF3           .00  -15.765
NA+        5852.59    -.594        FE(OH)4--     .00  -16.613         ALF4-          .00  -17.952
K+          939.90   -1.619        FE(OH)++      .00  -14.724         ALF5--         .00  -21.119
CA++       1058.39   -1.578        FE(OH)2+      .00   -8.890         ALF6---        .00  -25.426

IONIC STRENGTH =   .37167      IONIC BALANCE :   CATIONS (MOL.EQ.) .33195230
                                                 ANIONS  (MOL.EQ.) .35822360
                                                 DIFFERENCE    (%)     -7.61

CHEMICAL GEOTHERMOMETERS DEGREES C               1000/T DEGREES KELVIN =  1.94

QUARTZ       233.9
CHALCEDONY   999.9
NAK          244.1

OXIDATION POTENTIAL (VOLTS) :     EH H2S=  -.444    EH CH4=  -.510    EH H2=  -.459    EH NH3= 99.999

LOG SOLUBILITY PRODUCTS OF MINERALS IN DEEP WATER
                 TEOR.    CALC.                    TEOR.    CALC.                      TEOR.    CALC.
ADULARIA       -14.433  -14.386    ALBITE LOW    -13.978  -13.321    ANALCIME        -11.524  -11.174
ANHYDRITE       -7.959   -7.660    CALCITE       -12.565  -12.212    CHALCEDONY       -2.027   -2.146
MG-CHLORITE    -84.280  -86.475    FLUORITE      -10.915  -13.692    GOETHITE          1.834    -.795
LAUMONTITE     -24.532  -23.091    MICROCLINE    -15.126  -14.386    MAGNETITE       -17.696  -21.612
CA-MONTMOR.    -72.625  -69.571    K-MONTMOR.    -34.035  -35.480    MG-MONTMOR.     -74.122  -72.118
NA-MONTMOR.    -34.308  -34.415    MUSCOVITE     -17.853  -15.694    PREHNITE        -37.070  -34.143
PYRRHOTITE     -25.519  -47.686    PYRITE        -47.057  -60.469    QUARTZ           -2.140   -2.146
WAIRAKITE      -24.408  -23.091    WOLLASTONITE    7.619    6.800    ZOISITE         -37.611  -34.797
EPIDOTE        -37.233  -34.938    MARCASITE     -30.030  -60.469
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Table 6. (continued)

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UNU Geothermal Training Programme                DEEP WATER COOLED TO 250.0 DEGREES C.
SAMPLE = 08
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ACTIVITY COEFFICIENTS IN DEEP WATER
H+           .625        KSO4-        .530         FE++          .099         FECL+          .479
OH-          .458        F-           .458         FE+++         .018         AL+++          .018
H3SIO4-      .479        CL-          .435         FEOH+         .517         ALOH++         .086
H2SIO4--     .086        NA+          .479         FE(OH)3-      .517         AL(OH)2+       .530
H2BO3-       .410        K+           .435         FE(OH)4--     .078         AL(OH)4-       .499
HCO3-        .479        CA++         .099         FEOH++        .078         ALSO4+         .499
CO3--        .068        MG++         .144         FE(OH)2+      .530         AL(SO4)2-      .499
HS-          .458        CAHCO3+      .549         FE(OH)4-      .530         ALF++          .086
S--          .078        MGHCO3+      .479         FESO4+        .517         ALF2+          .530
HSO4-        .499        CAOH+        .549         FECL++        .078         ALF4-          .499
SO4--        .058        MGOH+        .564         FECL2+        .517         ALF5--         .068
NASO4-       .530        NH4+         .410         FECL4-        .479         ALF6---        .002

CHEMICAL COMPONENTS IN DEEP WATER (PPM AND LOG MOLE)
H+ (ACT.)      .00   -5.804        MG++          1.27   -4.283         FE(OH)3        .13   -5.911
OH-            .21   -4.908        NACL       1758.62   -1.522         FE(OH)4-       .20   -5.799
H4SIO4      686.48   -2.146        KCL         128.75   -2.763         FECL+          .00   -8.443
H3SIO4-        .76   -5.100        NASO4-        6.08   -4.292         FECL2          .00  -11.298
H2SIO4--       .00   -9.991        KSO4-         4.35   -4.493         FECL++         .00  -18.041
NAH3SIO4       .98   -5.081        CASO4        17.49   -3.891         FECL2+         .00  -18.788
H3BO3        39.75   -3.192        MGSO4          .09   -6.137         FECL3          .00  -19.939
H2BO3-         .05   -6.092        CACO3          .10   -6.010         FECL4-         .00  -21.009
H2CO3       203.68   -2.484        MGCO3          .00   -9.857         FESO4          .00  -11.996
HCO3-         5.89   -4.015        CAHCO3+      42.62   -3.375         FESO4+         .00  -20.630
CO3--          .00   -8.556        MGHCO3+        .01   -7.092         AL+++          .00  -20.557
H2S           3.61   -3.975        CAOH+          .53   -5.031         ALOH++         .00  -13.820
HS-            .19   -5.245        MGOH+          .03   -6.151         AL(OH)2+       .00   -8.137
S--            .00  -13.616        NH4OH          .00     .000         AL(OH)3        .16   -5.682
H2SO4          .00  -12.186        NH4+           .00     .000         AL(OH)4-       .00   -8.867
HSO4-          .40   -5.382        FE++           .00   -9.035         ALSO4+         .00  -21.956
SO4--        11.78   -3.911        FE+++          .00  -22.818         AL(SO4)2-      .00  -24.222
HF             .02   -5.981        FEOH+          .00   -9.162         ALF++          .00  -17.123
F-             .11   -5.242        FE(OH)2        .00  -10.016         ALF2+          .00  -15.643
CL-       12555.81    -.451        FE(OH)3-       .00  -11.106         ALF3           .00  -16.089
NA+        5772.77    -.600        FE(OH)4--      .00  -16.696         ALF4-          .00  -18.235
K+          932.80   -1.622        FE(OH)++       .00  -15.172         ALF5--         .00  -21.371
CA++       1058.02   -1.578        FE(OH)2+       .00   -9.109         ALF6---        .00  -25.671

IONIC STRENGTH =    .36800      IONIC BALANCE :   CATIONS (MOL.EQ.) .32828750
                                                  ANIONS  (MOL.EQ.) .35455960
                                                  DIFFERENCE    (%)     -7.69

OXIDATION POTENTIAL (VOLTS) :      EH H2S=  -.462    EH CH4=  -.528    EH H2=  -.470    EH NH3= 99.999

LOG SOLUBILITY PRODUCTS OF MINERALS IN DEEP WATER
                 TEOR.    CALC.                      TEOR.    CALC.                       TEOR.    CALC.
ADULARIA       -14.402  -14.405      ALBITE LOW    -13.956  -13.341      ANALCIME       -11.528  -11.195
ANHYDRITE       -8.106   -7.732      CALCITE       -12.771  -12.308      CHALCEDONY      -1.995   -2.146
MG-CHLORITE    -84.886  -86.008      FLUORITE      -10.957  -13.743      GOETHITE         2.273    -.827
LAUMONTITE     -24.572  -23.131      MICROCLINE    -15.073  -14.405      MAGNETITE      -16.930  -22.185
CA-MONTMOR.    -72.599  -70.585      K-MONTMOR.    -33.974  -35.986      MG-MONTMOR.    -74.100  -73.129
NA-MONTMOR.    -34.252  -34.922      MUSCOVITE     -17.843  -15.875      PREHNITE       -37.322  -34.060
PYRRHOTITE     -21.030  -47.731      PYRITE        -41.351  -60.895      QUARTZ          -2.105   -2.146
WAIRAKITE      -24.549  -23.131      WOLLASTONITE    7.484    6.880      ZOISITE        -37.954  -34.795
EPIDOTE        -37.493  -34.887      MARCASITE     -24.586  -60.895
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## Table 6. (continued)

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UNU Geothermal Training Programme                 DEEP WATER COOLED TO 200.0 DEGREES C.
SAMPLE = 08
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ACTIVITY COEFFICIENTS IN DEEP WATER
H+            .658      KSO4-         .573        FE++          .137       FECL+          .527
OH-           .507      F-            .507        FE+++         .032       AL+++          .032
H3SIO4-       .527      CL-           .486        FEOH+         .561       ALOH++         .122
H2SIO4--      .122      NA+           .527        FE(OH)3-      .561       AL(OH)2+       .573
H2BO3-        .463      K+            .486        FE(OH)4--     .112       AL(OH)4-       .545
HCO3-         .527      CA++          .137        FEOH++        .112       ALSO4+         .545
CO3--         .099      MG++          .187        FE(OH)2+      .573       AL(SO4)2-      .545
HS-           .507      CAHCO3+       .591        FE(OH)4-      .573       ALF++          .122
S--           .112      MGHCO3+       .527        FESO4+        .561       ALF2+          .573
HSO4-         .545      CAOH+         .591        FECL++        .112       ALF4-          .545
SO4--         .087      MGOH+         .604        FECL2+        .561       ALF5--         .099
NASO4-        .573      NH4+          .463        FECL4-        .527       ALF6---        .006

CHEMICAL COMPONENTS IN DEEP WATER (PPM AND LOG MOLE)
H+ (ACT.)      .00   -5.521      MG++          1.28   -4.279        FE(OH)3         .03   -6.613
OH-            .06   -5.439      NACL       1031.32   -1.753        FE(OH)4-        .01   -7.106
H4SIO4      686.69   -2.146      KCL          66.77   -3.048        FECL+           .16   -5.767
H3SIO4-        .64   -5.173      NASO4-        6.00   -4.297        FECL2           .00  -10.817
H2SIO4--       .00  -10.127      KSO4-         3.32   -4.610        FECL++          .00  -16.022
NAH3SIO4       .87   -5.132      CASO4        14.87   -3.962        FECL2+          .00  -16.664
H3BO3        39.77   -3.192      MGSO4          .11   -6.048        FECL3           .00  -17.896
H2BO3-         .03   -6.314      CACO3          .05   -6.269        FECL4-          .00  -19.178
H2CO3       203.11   -2.485      MGCO3          .00   -9.867        FESO4           .00   -9.022
HCO3-         9.46   -3.810      CAHCO3+      37.69   -3.429        FESO4+          .00  -18.366
CO3--          .00   -8.265      MGHCO3+        .01   -7.039        AL+++           .00  -16.873
H2S           3.54   -3.984      CAOH+          .10   -5.763        ALOH++          .00  -11.688
HS-            .26   -5.110      MGOH+          .00   -7.180        AL(OH)2+        .00   -7.404
S--            .00  -14.175      NH4OH          .00     .000        AL(OH)3         .16   -5.690
H2SO4          .00  -12.465      NH4+           .00     .000        AL(OH)4-        .00   -8.147
HSO4-          .21   -5.655      FE++           .04   -6.154        ALSO4+          .00  -18.424
SO4--        14.59   -3.818      FE+++          .00  -19.784        AL(SO4)2-       .00  -20.724
HF             .01   -6.172      FEOH+          .01   -7.059        ALF++           .00  -14.184
F-             .12   -5.215      FE(OH)2        .00   -8.924        ALF2+           .00  -13.261
CL-       13026.40    -.435      FE(OH)3-       .00  -11.274        ALF3            .00  -14.078
NA+        6058.92    -.579      FE(OH)4--      .00  -17.278        ALF4-           .00  -16.460
K+          965.61   -1.607      FE(OH)++       .00  -13.460        ALF5--          .00  -19.759
CA++       1061.07   -1.577      FE(OH)2+       .00   -8.793        ALF6---         .00  -24.067

IONIC STRENGTH =   .38149      IONIC BALANCE :   CATIONS (MOL.EQ.) .34167250
                                                 ANIONS  (MOL.EQ.) .36794220
                                                 DIFFERENCE    (%)      -7.40

OXIDATION POTENTIAL (VOLTS) :      EH H2S=  -.362   EH CH4=  -.421   EH H2=  -.409   EH NH3= 99.999

LOG SOLUBILITY PRODUCTS OF MINERALS IN DEEP WATER
                  TEOR.    CALC.                     TEOR.    CALC.                      TEOR.    CALC.
ADULARIA        -14.776  -14.303    ALBITE LOW     -14.271  -13.240    ANALCIME        -11.648  -11.094
ANHYDRITE        -7.207   -7.320    CALCITE        -11.526  -11.709    CHALCEDONY       -2.217   -2.146
MG-CHLORITE     -81.685  -89.234    FLUORITE       -10.718  -13.459    GOETHITE          -.350   -1.614
LAUMONTITE      -24.602  -22.913    MICROCLINE     -15.613  -14.303    MAGNETITE       -21.553  -21.712
CA-MONTMOR.     -73.343  -64.068    K-MONTMOR.     -34.669  -32.734    MG-MONTMOR.     -74.794  -66.635
NA-MONTMOR.     -34.902  -31.671    MUSCOVITE      -18.071  -14.724    PREHNITE        -36.095  -34.675
PYRRHOTITE      -48.482  -55.348    PYRITE         -76.641  -66.074    QUARTZ           -2.340   -2.146
WAIRAKITE       -23.902  -22.913    WOLLASTONITE     8.387    6.455    ZOISITE         -36.177  -34.885
EPIDOTE         -37.293  -36.289    MARCASITE      -58.102  -66.074
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Table 6. (continued)

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UNU Geothermal Training Programme                 DEEP WATER COOLED TO 150.0 DEGREES C.
SAMPLE = 08
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ACTIVITY COEFFICIENTS IN DEEP WATER
H+          .687     KSO4-        .609     FE++         .173     FECL+        .566
OH-         .547     F-           .547     FE+++        .047     AL+++        .047
H3SIO4-     .566     CL-          .528     FEOH+        .598     ALOH++       .156
H2SIO4--    .156     NA+          .566     FE(OH)3-     .598     AL(OH)2+     .609
H2BO3-      .506     K+           .528     FE(OH)4--    .144     AL(OH)4-     .582
HCO3-       .566     CA++         .173     FEOH++       .144     ALSO4+       .582
CO3--       .130     MG++         .227     FE(OH)2+     .609     AL(SO4)2-    .582
HS-         .547     CAHCO3+      .625     FE(OH)4-     .609     ALF++        .156
S--         .144     MGHCO3+      .566     FESO4+       .598     ALF2+        .609
HSO4-       .582     CAOH+        .625     FECL++       .144     ALF4-        .582
SO4--       .116     MGOH+        .637     FECL2+       .598     ALF5--       .130
NASO4-      .609     NH4+         .506     FECL4-       .566     ALF6---      .011

CHEMICAL COMPONENTS IN DEEP WATER (PPM AND LOG MOLE)
H+ (ACT.)      .00   -5.339      MG++        1.28   -4.278      FE(OH)3        .00   -9.817
OH-            .02   -6.035      NACL      794.59   -1.867      FE(OH)4-       .00  -10.885
H4SIO4      687.09   -2.146      KCL        35.86   -3.318      FECL+          .14   -5.828
H3SIO4-        .44   -5.333      NASO4-      5.32   -4.350      FECL2          .00  -13.611
H2SIO4--       .00  -10.374      KSO4-       2.65   -4.708      FECL++         .00  -16.764
NAH3SIO4       .62   -5.278      CASO4      11.19   -4.085      FECL2+         .00  -17.349
H3BO3        39.78   -3.192      MGSO4        .10   -6.094      FECL3          .00  -18.702
H2BO3-         .02   -6.472      CACO3        .03   -6.499      FECL4-         .00  -20.233
H2CO3       202.75   -2.486      MGCO3        .00   -9.857      FESO4          .00   -8.693
HCO3-        15.60   -3.592      CAHCO3+    28.13   -3.556      FESO4+         .00  -18.875
CO3--          .00   -7.945      MGHCO3+      .01   -6.977      AL+++          .00  -13.463
H2S           3.49   -3.989      CAOH+        .02   -6.567      ALOH++         .00   -9.728
HS-            .30   -5.043      MGOH+        .00   -8.126      AL(OH)2+       .01   -6.762
S--            .00  -14.737      NH4OH        .00     .000      AL(OH)3        .15   -5.724
H2SO4          .00  -13.039      NH4+         .00     .000      AL(OH)4-       .00   -7.611
HSO4-          .09   -6.042      FE++         .07   -5.882      ALSO4+         .00  -15.193
SO4--        18.35   -3.719      FE+++        .00  -19.541      AL(SO4)2-      .00  -17.531
HF             .01   -6.459      FEOH+        .00   -7.618      ALF++          .00  -11.406
F-             .12   -5.192      FE(OH)2      .00  -10.509      ALF2+          .00  -10.964
CL-       13184.71    -.430      FE(OH)3-     .00  -14.141      ALF3           .00  -12.089
NA+        6152.23    -.573      FE(OH)4--    .00  -20.612      ALF4-          .00  -14.662
K+          982.01   -1.600      FE(OH)++     .00  -14.404      ALF5--         .00  -18.074
CA++       1066.01   -1.575      FE(OH)2+     .00  -11.047      ALF6---        .00  -22.337

IONIC STRENGTH =   .38628      IONIC BALANCE :   CATIONS (MOL.EQ.) .34630230
                                                 ANIONS  (MOL.EQ.) .37258310
                                                 DIFFERENCE    (%)     -7.31

OXIDATION POTENTIAL (VOLTS) :     EH H2S=  -.275    EH CH4=  -.328    EH H2=  -.358    EH NH3= 99.999

LOG SOLUBILITY PRODUCTS OF MINERALS IN DEEP WATER
               TEOR.    CALC.                    TEOR.    CALC.                    TEOR.    CALC.
ADULARIA     -15.664  -14.231    ALBITE LOW    -15.067  -13.173    ANALCIME      -12.168  -11.027
ANHYDRITE     -6.366   -6.993    CALCITE       -10.399  -11.169    CHALCEDONY     -2.492   -2.146
MG-CHLORITE  -80.047  -93.252    FLUORITE      -10.561  -13.245    GOETHITE       -2.669   -4.804
LAUMONTITE   -25.402  -22.752    MICROCLINE    -16.731  -14.231    MAGNETITE     -25.789  -28.845
CA-MONTMOR.  -76.836  -56.804    K-MONTMOR.    -36.807  -29.111    MG-MONTMOR.   -78.177  -59.389
NA-MONTMOR.  -36.953  -28.053    MUSCOVITE     -18.991  -13.468    PREHNITE      -35.828  -35.536
PYRRHOTITE   -74.605  -82.269    PYRITE       -111.470  -90.329    QUARTZ         -2.683   -2.146
WAIRAKITE    -23.901  -22.752    WOLLASTONITE    9.469    6.195    ZOISITE       -35.407  -35.155
EPIDOTE      -39.779  -40.340    MARCASITE     -90.765  -90.329
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### Table 6. (continued)

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UNU Geothermal Training Programme                DEEP WATER COOLED TO 100.0 DEGREES C.
SAMPLE = 08
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ACTIVITY COEFFICIENTS IN DEEP WATER
H+            .716      KSO4-         .645      FE++          .213      FECL+         .605
OH-           .588      F-            .588      FE+++         .068      AL+++         .068
H3SIO4-       .605      CL-           .569      FEOH+         .634      ALOH++        .195
H2SIO4--      .195      NA+           .605      FE(OH)3-      .634      AL(OH)2+      .645
H2BO3-        .549      K+            .569      FE(OH)4--     .183      AL(OH)4-      .620
HCO3-         .605      CA++          .213      FEOH++        .183      ALSO4+        .620
CO3--         .167      MG++          .270      FE(OH)2+      .645      AL(SO4)2-     .620
HS-           .588      CAHCO3+       .659      FE(OH)4-      .645      ALF++         .195
S--           .183      MGHCO3+       .605      FESO4+        .634      ALF2+         .645
HSO4-         .620      CAOH+         .659      FECL++        .183      ALF4-         .620
SO4--         .151      MGOH+         .670      FECL2+        .634      ALF5--        .167
NASO4-        .645      NH4+          .549      FECL4-        .605      ALF6---       .019

CHEMICAL COMPONENTS IN DEEP WATER (PPM AND LOG MOLE)
H+ (ACT.)      .01   -5.251        MG++          1.29   -4.276        FE(OH)3         .00  -13.028
OH-            .00   -6.778        NACL        456.81   -2.107        FE(OH)4-        .00  -14.694
H4SIO4      687.55   -2.146        KCL          20.07   -3.570        FECL+           .07   -6.089
H3SIO4-        .22   -5.646        NASO4-        4.45   -4.427        FECL2           .00  -17.307
H2SIO4--       .00  -10.895        KSO4-         2.05   -4.819        FECL++          .00  -17.671
NAH3SIO4       .34   -5.546        CASO4         8.37   -4.211        FECL2+          .00  -18.190
H3BO3        39.79   -3.191        MGSO4          .07   -6.252        FECL3           .00  -19.684
H2BO3-         .01   -6.621        CACO3          .02   -6.776        FECL4-          .00  -21.496
H2CO3       202.33   -2.487        MGCO3          .00   -9.902        FESO4           .00   -8.446
HCO3-        23.12   -3.422        CAHCO3+      16.36   -3.791        FESO4+          .00  -19.536
CO3--          .00   -7.744        MGHCO3+        .01   -6.939        AL+++           .00  -10.298
H2S           3.53   -3.985        CAOH+          .00   -7.492        ALOH++          .00   -7.939
HS-            .27   -5.092        MGOH+          .00   -9.089        AL(OH)2+        .04   -6.234
S--            .00  -15.413        NH4OH          .00     .000        AL(OH)3         .11   -5.839
H2SO4          .00  -13.905        NH4+           .00     .000        AL(OH)4-        .00   -7.388
HSO4-          .03   -6.525        FE++           .11   -5.699        ALSO4+          .00  -12.181
SO4--        21.54   -3.649        FE+++          .00  -19.517        AL(SO4)2-       .00  -14.547
HF             .00   -6.823        FEOH+          .00   -8.347        ALF++           .00   -8.717
F-             .13   -5.179        FE(OH)2        .00  -12.340        ALF2+           .00   -8.637
CL-       13397.14    -.423        FE(OH)3-       .00  -17.365        ALF3            .00   -9.982
NA+        6285.34    -.563        FE(OH)4--      .00  -24.460        ALF4-           .00  -12.700
K+          990.46   -1.596        FE(OH)++       .00  -15.451        ALF5--          .00  -16.196
CA++       1071.52   -1.573        FE(OH)2+       .00  -13.336        ALF6---         .00  -20.404

IONIC STRENGTH =   .39263     IONIC BALANCE :   CATIONS (MOL.EQ.) .35246830
                                                ANIONS  (MOL.EQ.) .37876140
                                                DIFFERENCE    (%)     -7.19

OXIDATION POTENTIAL (VOLTS) :     EH H2S=  -.198    EH CH4=  -.245    EH H2=  -.313    EH NH3= 99.999

LOG SOLUBILITY PRODUCTS OF MINERALS IN DEEP WATER
                 TEOR.    CALC.                        TEOR.    CALC.                       TEOR.    CALC.
ADULARIA       -17.222  -14.165       ALBITE LOW     -16.485  -13.106       ANALCIME       -13.199  -10.961
ANHYDRITE       -5.607   -6.714       CALCITE         -9.438  -10.765       CHALCEDONY      -2.841   -2.146
MG-CHLORITE    -80.302  -98.500       FLUORITE       -10.538  -13.063       GOETHITE        -4.674   -7.877
LAUMONTITE     -27.182  -22.602       MICROCLINE     -18.598  -14.165       MAGNETITE      -29.703  -36.139
CA-MONTMOR.    -85.559  -47.778       K-MONTMOR.     -41.648  -24.608       MG-MONTMOR.    -86.708  -50.378
NA-MONTMOR.    -41.660  -23.549       MUSCOVITE      -21.151  -11.925       PREHNITE       -36.778  -36.717
PYRRHOTITE     -99.806 -108.424       PYRITE        -147.012 -113.241       QUARTZ          -3.098   -2.146
WAIRAKITE      -24.710  -22.602       WOLLASTONITE    10.824    6.112       ZOISITE        -35.893  -35.597
EPIDOTE        -43.603  -44.593       MARCASITE     -123.575 -113.241
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Table 6. (continued)

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UNU Geothermal Training Programme         .        DEEP WATER COOLED TO  50.0 DEGREES C.
SAMPLE = 08
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ACTIVITY COEFFICIENTS IN DEEP WATER
H+             .738      KSO4-         .672      FE++          .248      FECL+          .635
OH-            .619      F-            .619      FE+++         .088      AL+++          .088
H3SIO4-        .635      CL-           .602      FEOH+         .662      ALOH++         .229
H2SIO4--       .229      NA+           .635      FE(OH)3-      .662      AL(OH)2+       .672
H2BO3-         .583      K+            .602      FE(OH)4--     .216      AL(OH)4-       .649
HCO3-          .635      CA++          .248      FEOH++        .216      ALSO4+         .649
CO3--          .199      MG++          .307      FE(OH)2+      .672      AL(SO4)2-      .649
HS-            .619      CAHCO3+       .686      FE(OH)4-      .672      ALF++          .229
S--            .216      MGHCO3+       .635      FESO4+        .662      ALF2+          .672
HSO4-          .649      CAOH+         .686      FECL++        .216      ALF4-          .649
SO4--          .182      MGOH+         .696      FECL2+        .662      ALF5--         .199
NASO4-         .672      NH4+          .583      FECL4-        .635      ALF6---        .028

CHEMICAL COMPONENTS IN DEEP WATER (PPM AND LOG MOLE)
H+ (ACT.)      .01   -5.295       MG++         1.29   -4.274        FE(OH)3        .00  -16.361
OH-            .00   -7.763       NACL       131.92   -2.646        FE(OH)4-       .00  -18.705
H4SIO4      687.87   -2.145       KCL         10.99   -3.831        FECL+          .02   -6.604
H3SIO4-        .07   -6.144       NASO4-       3.38   -4.547        FECL2          .00  -22.291
H2SIO4--       .00  -11.775       KSO4-        1.43   -4.977        FECL++         .00  -18.712
NAH3SIO4       .12   -5.976       CASO4        6.14   -4.346        FECL2+         .00  -19.178
H3BO3        39.79   -3.191       MGSO4         .03   -6.562        FECL3          .00  -20.858
H2BO3-         .01   -6.768       CACO3         .01   -7.183        FECL4-         .00  -23.011
H2CO3       201.94   -2.487       MGCO3         .00  -10.077        FESO4          .00   -8.283
HCO3-        29.43   -3.317       CAHCO3+      6.55   -4.189        FESO4+         .00  -20.314
CO3--          .00   -7.706       MGHCO3+       .01   -6.956        AL+++          .00   -7.573
H2S           3.62   -3.973       CAOH+         .00   -8.654        ALOH++         .01   -6.591
HS-            .18   -5.276       MGOH+         .00  -10.260        AL(OH)2+       .04   -6.163
S--            .00  -16.213       NH4OH         .00     .000        AL(OH)3        .03   -6.433
H2SO4          .00  -15.179       NH4+          .00     .000        AL(OH)4-       .00   -7.954
HSO4-          .01   -7.129       FE++          .14   -5.590        ALSO4+         .00   -9.607
SO4--        24.48   -3.594       FE+++         .00  -19.643        AL(SO4)2-      .00  -11.995
HF             .00   -7.341       FEOH+         .00   -9.310        ALF++          .02   -6.349
F-             .11   -5.222       FE(OH)2       .00  -14.585        ALF2+          .02   -6.552
CL-       13598.55    -.416       FE(OH)3-      .00  -21.224        ALF3           .00   -8.073
NA+        6413.40    -.554       FE(OH)4--     .00  -29.182        ALF4-          .00  -10.922
K+          995.40   -1.594       FE(OH)++      .00  -16.580        ALF5--         .00  -14.504
CA++       1076.07   -1.571       FE(OH)2+      .00  -15.710        ALF6---        .00  -18.668

IONIC STRENGTH =   .39861     IONIC BALANCE :   CATIONS (MOL.EQ.) .35829780
                                                ANIONS  (MOL.EQ.) .38460230
                                                DIFFERENCE    (%)     -7.08

OXIDATION POTENTIAL (VOLTS) :      EH H2S=  -.130    EH CH4=  -.172    EH H2=  -.274    EH NH3= 99.999

LOG SOLUBILITY PRODUCTS OF MINERALS IN DEEP WATER
                 TEOR.    CALC.                          TEOR.    CALC.                         TEOR.    CALC.
ADULARIA       -19.664  -14.119       ALBITE LOW       -18.715  -13.056       ANALCIME        -14.883  -10.911
ANHYDRITE       -4.966   -6.510       CALCITE           -8.720  -10.583       CHALCEDONY       -3.297   -2.145
MG-CHLORITE    -82.885 -105.881       FLUORITE         -10.737  -13.038       GOETHITE         -6.429  -10.906
LAUMONTITE     -30.213  -22.494       MICROCLINE       -21.446  -14.119       MAGNETITE       -33.553  -43.951
CA-MONTMOR.   -101.366  -35.869       K-MONTMOR.       -50.171  -18.661       MG-MONTMOR.    -102.214  -38.480
NA-MONTMOR.    -49.974  -17.598       MUSCOVITE        -25.002   -9.912       PREHNITE        -39.270  -38.468
PYRRHOTITE    -125.035 -134.618       PYRITE          -185.595 -135.240       QUARTZ           -3.641   -2.145
WAIRAKITE      -26.535  -22.494       WOLLASTONITE      12.603    6.268       ZOISITE         -37.927  -36.365
EPIDOTE        -47.739  -49.374       MARCASITE       -158.572 -135.240
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# Table 6. (continued)

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UNU Geothermal Training Programme                    DEEP WATER COOLED TO    .0 DEGREES C.
SAMPLE : 08
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ACTIVITY COEFFICIENTS IN DEEP WATER
H+            .746       KSO4-        .682       FE++         .259       FECL+         .646
OH-           .630       F-           .630       FE+++        .095       AL+++         .095
H3SIO4-       .646       CL-          .614       FEOH+        .672       ALOH++        .240
H2SIO4--      .240       NA+          .646       FE(OH)3-     .672       AL(OH)2+      .682
H2BO3-        .595       K+           .614       FE(OH)4--    .227       AL(OH)4-      .660
HCO3-         .646       CA++         .259       FEOH++       .227       ALSO4+        .660
CO3--         .210       MG++         .318       FE(OH)2+     .682       AL(SO4)2-     .660
HS-           .630       CAHCO3+      .695       FE(OH)4-     .682       ALF++         .240
S--           .227       MGHCO3+      .646       FESO4+       .672       ALF2+         .682
HSO4-         .660       CAOH+        .695       FECL++       .227       ALF4-         .660
SO4--         .193       MGOH+        .705       FECL2+       .672       ALF5--        .210
NASO4-        .682       NH4+         .595       FECL4-       .646       ALF6---       .031

CHEMICAL COMPONENTS IN DEEP WATER (PPM AND LOG MOLE)
H+ (ACT.)      .00   -5.585       MG++        1.30   -4.272        FE(OH)3        .00  -20.320
OH-            .00   -9.141       NACL       59.01   -2.996        FE(OH)4-       .00  -23.498
H4SIO4      688.01   -2.145       KCL         5.72   -4.115        FECL+          .00   -7.475
H3SIO4-        .01   -6.847       NASO4-      2.13   -4.748        FECL2          .00  -29.230
H2SIO4--       .00  -13.082       KSO4-        .80   -5.229        FECL++         .00  -20.208
NAH3SIO4       .03   -6.591       CASO4       4.40   -4.491        FECL2+         .00  -20.657
H3BO3        39.79   -3.191       MGSO4        .01   -7.076        FECL3          .00  -22.608
H2BO3-         .01   -6.895       CACO3        .00   -7.765        FECL4-         .00  -25.200
H2CO3       201.68   -2.488       MGCO3        .00  -10.413        FESO4          .00   -8.228
HCO3-        32.64   -3.272       CAHCO3+     1.66   -4.784        FESO4+         .00  -21.523
CO3--          .00   -7.836       MGHCO3+      .01   -7.041        AL+++          .00   -6.897
H2S           3.72   -3.962       CAOH+        .00  -10.222        ALOH++         .00   -7.391
HS-            .08   -5.590       MGOH+        .00  -11.944        AL(OH)2+       .00   -8.359
S--            .00  -17.082       NH4OH        .00     .000        AL(OH)3        .00   -9.381
H2SO4          .00  -17.156       NH4+         .00     .000        AL(OH)4-       .00  -11.309
HSO4-          .00   -7.953       FE++         .16   -5.555        ALSO4+         .00   -9.119
SO4--        27.19   -3.548       FE+++        .00  -20.182        AL(SO4)2-      .00  -11.530
HF             .00   -8.104       FEOH+        .00  -10.616        ALF++          .06   -5.871
F-             .09   -5.314       FE(OH)2      .00  -17.501        ALF2+          .04   -6.256
CL-       13645.29    -.415       FE(OH)3-     .00  -26.146        ALF3           .00   -7.876
NA+        6442.34    -.552       FE(OH)4--    .00  -35.344        ALF4-          .00  -10.818
K+          998.35   -1.593       FE(OH)++     .00  -18.112        ALF5--         .00  -14.456
CA++       1078.52   -1.570       FE(OH)2+     .00  -18.587        ALF6---        .00  -18.544

IONIC STRENGTH =   .40012      IONIC BALANCE :   CATIONS (MOL.EQ.) .35970790
                                                 ANIONS  (MOL.EQ.) .38602530
                                                 DIFFERENCE   (%)     -7.06

OXIDATION POTENTIAL (VOLTS) :     EH H2S=  -.074   EH CH4=  -.112   EH H2=  -.244   EH NH3= 99.999

LOG SOLUBILITY PRODUCTS OF MINERALS IN DEEP WATER
               TEOR.    CALC.                    TEOR.    CALC.                      TEOR.    CALC.
ADULARIA     -23.276  -14.102    ALBITE LOW    -22.008  -13.039    ANALCIME        -17.390  -10.894
ANHYDRITE     -4.511   -6.419    CALCITE        -8.378  -10.670    CHALCEDONY       -3.921   -2.145
MG-CHLORITE  -88.387 -116.737    FLUORITE      -11.323  -13.185    GOETHITE         -8.225  -14.323
LAUMONTITE   -34.804  -22.459    MICROCLINE    -25.573  -14.102    MAGNETITE       -38.146  -53.470
CA-MONTMOR. -121.263  -19.312    K-MONTMOR.    -61.001  -10.383    MG-MONTMOR.    -121.654  -21.926
NA-MONTMOR.  -60.441   -9.321    MUSCOVITE     -30.074   -7.142    PREHNITE        -43.653  -41.153
PYRRHOTITE -152.446 -164.666    PYRITE       -231.987 -159.601    QUARTZ           -4.382   -2.145
WAIRAKITE    -29.576  -22.459    WOLLASTONITE   15.039    6.868    ZOISITE         -41.763  -37.673
EPIDOTE      -54.230  -55.476    MARCASITE    -200.020 -159.601
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Table 7. Example of a printout from the WATCH3 program

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UNU Geothermal Training Programme

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073                           seltjarnarnes well sn-2 570m depth

PROGRAM WATCH2.

WATER SAMPLE (PPM)            STEAM SAMPLE

PH/DEG.C         8.45/21.0    GAS (VOL.%)                    REFERENCE TEMP.     DEGREES C         .0 (CHA)
SIO2                 92.30    CO2
NA                  595.60    H2S                            SAMPLING PRESSURE   BARS ABS.
K                    14.50    H2                             DISCHARGE ENTHALPY   MJOUL/KG
CA                  324.70    O2                             DISCHARGE              KG/SEC.        .0
MG                    .280    CH4
CO2                  11.00    N2                             MEASURED TEMPERATURE DEGREES C        .0
SO4                 221.70                                   RESISTIVITY/TEMP.   OHMM/DEG.C   4270.0/21.1
H2S                    .10                                   BH/TEMP.              MV/DEG.C    .000/  .0
CL                 1321.00
F                      .55    LITERS GAS PER KG
DISS.SOLIDS        2582.00    CONDENSATE/DEG.C                  MEASURED DOWNHOLE TEMP.   FLUID INFLOW
AL                   .1370                                         DEGREES C/METERS       DEPTH (METERS)
B                    .0000
FE                   .0660    CONDENSATE (PPM)                       .0         .0               .0
NH3                  .0000    PH/DEG.C                               .0         .0               .0
Mn                    0.00    CO2                                    .0         .0               .0
                              H2S                                    .0         .0               .0
                              NA                                     .0         .0               .0
                                                                     .0         .0               .0
                                                                     .0         .0               .0
                                                                     .0         .0               .0
                              CONDENSATE WITH NAOH (PPM)             .0         .0               .0
                              CO2                                    .0         .0               .0
                              H2S                                    .0         .0               .0

IONIC STRENGTH =   .05133     IONIC BALANCE :   CATIONS (MOL.EQ.) .04176022
                                                ANIONS  (MOL.EQ.) .04146050
                                                DIFFERENCE    (%)        .72

DEEP WATER (PPM)                                     DEEP STEAM (PPM)         GAS PRESSURES (BARS ABS.)

SIO2        92.31        CO2            11.00        CO2              .00     CO2        .138E-04
NA         595.60        H2S              .10        H2S              .00     H2S        .103E-06
K           14.50        H2               .00        H2               .00     H2         .000E+00
CA         324.70        O2               .00        O2               .00     O2         .000E+00
MG           .280        CH4              .00        CH4              .00     CH4        .000E+00
SO4        221.70        N2               .00        N2               .00     N2         .000E+00
CL        1320.89        NH3              .00        NH3              .00     NH3        .000E+00
F             .55                                                             H2O        .105E+01
DISS.S.   2582.00                                                             TOTAL      .105E+01
AL          .1370
B           .0000                                    H2O (%)                .00
FE          .0660                                    BOILING PORTION        .00
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## Table 7. (continued)

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SAMPLE : 073

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ACTIVITY COEFFICIENTS IN DEEP WATER
H+          .829       KSO4-       .800       FE++         .427       FECL+        .785
OH-         .780       F-          .780       FE+++        .192       AL+++        .192
H3SIO4-     .785       CL-         .774       FEOH+        .796       ALOH++       .415
H2SIO4--    .415       NA+         .785       FE(OH)3-     .796       AL(OH)2+     .800
H2BO3-      .768       K+          .774       FE(OH)4--    .407       AL(OH)4-     .791
HCO3-       .785       CA++        .427       FEOH++       .407       ALSO4+       .791
CO3--       .397       MG++        .463       FE(OH)2+     .800       AL(SO4)2-    .791
HS-         .780       CAHCO3+     .805       FE(OH)4-     .800       ALF++        .415
S--         .407       MGHCO3+     .785       FESO4+       .796       ALF2+        .800
HSO4-       .791       CAOH+       .805       FECL++       .407       ALF4-        .791
SO4--       .387       MGOH+       .810       FECL2+       .796       ALF5--       .397
NASO4-      .800       NH4+        .768       FECL4-       .785       ALF6---      .126

CHEMICAL COMPONENTS IN DEEP WATER (PPM AND LOG MOLE)
H+ (ACT.)       .00   -7.423     MG++            .21   -5.067      FE(OH)3        .00   -8.845
OH-             .33   -4.711     NACL           7.62   -3.885      FE(OH)4-       .00   -8.420
H4SIO4       141.41   -2.832     KCL             .05   -6.145      FECL+          .01   -7.230
H3SIO4-        5.15   -4.266     NASO4-         8.11   -4.167      FECL2          .00  -19.126
H2SIO4--        .00   -7.553     KSO4-           .60   -5.352      FECL++         .00  -21.275
NAH3SIO4       1.28   -4.966     CASO4         86.30   -3.198      FECL2+         .00  -22.418
H3BO3           .00     .000     MGSO4           .35   -5.538      FECL3          .00  -24.683
H2BO3-          .00     .000     CACO3           .88   -5.057      FECL4-         .00  -27.477
H2CO3           .85   -4.864     MGCO3           .00   -8.489      FESO4          .01   -7.346
HCO3-         11.00   -3.744     CAHCO3+        4.71   -4.332      FESO4+         .00  -20.756
CO3--           .04   -6.159     MGHCO3+         .00   -7.815      AL+++          .00  -17.418
H2S             .01   -6.523     CAOH+           .13   -5.640      ALOH++         .00  -12.737
HS-             .09   -5.579     MGOH+           .00   -7.534      AL(OH)2+       .00   -8.598
S--             .00  -13.942     NH4OH           .00     .000      AL(OH)3        .03   -5.924
H2SO4           .00  -16.963     NH4+            .00     .000      AL(OH)4-       .37   -5.411
HSO4-           .00   -7.527     FE++            .04   -6.166      ALSO4+         .00  -17.687
SO4--        153.54   -2.796     FE+++           .00  -22.369      AL(SO4)2-      .00  -18.788
HF              .00   -8.223     FEOH+           .03   -6.418      ALF++          .00  -14.944
F-              .55   -4.539     FE(OH)2         .00   -8.116      ALF2+          .00  -13.858
CL-         1316.24   -1.430     FE(OH)3-        .00  -11.037      ALF3           .00  -14.342
NA+          590.79   -1.590     FE(OH)4--       .00  -16.196      ALF4-          .00  -16.400
K+            14.30   -3.437     FE(OH)++        .00  -16.007      ALF5--         .00  -13.404
CA++         296.98   -2.130     FE(OH)2+        .00  -11.438      ALF6---        .00  -23.304

IONIC STRENGTH =   .04980      IONIC BALANCE :   CATIONS (MOL.EQ.) .04095064
                                                 ANIONS  (MOL.EQ.) .04061699
                                                 DIFFERENCE   (%)        .82

CHEMICAL GEOTHERMOMETERS DEGREES C               1000/T DEGREES KELVIN =  2.67

QUARTZ       124.7
CHALCEDONY   101.0
NAK           82.7

OXIDATION POTENTIAL (VOLTS) :     EH H2S=  -.366    EH CH4= 99.999    EH H2= 99.999    EH NH3= 99.999

LOG SOLUBILITY PRODUCTS OF MINERALS IN DEEP WATER
               TEOR.    CALC.                         TEOR.    CALC.                       TEOR.    CALC.
ADULARIA      -17.181  -17.441     ALBITE LOW        -16.448  -15.588      ANALCIME       -13.171  -12.756
ANHYDRITE      -5.621   -5.709     CALCITE            -9.456   -9.059      CHALCEDONY      -2.832   -2.832
MG-CHLORITE   -80.275  -84.852     FLUORITE          -10.536  -11.794      GOETHITE        -4.636   -3.638
LAUMONTITE   -27.133  -24.622      MICROCLINE        -18.550  -17.441      MAGNETITE      -29.623  -25.576
CA-MONTMOR.  -85.307  -82.527      K-MONTMOR.        -41.511  -43.562      MG-MONTMOR.    -86.461  -85.429
NA-MONTMOR.  -41.526  -41.709      MUSCOVITE         -21.090  -18.595      PREHNITE       -36.744  -33.328
PYRRHOTITE   -99.285  -94.726      PYRITE           -146.252 -121.007      QUARTZ          -3.088   -2.832
WAIRAKITE    -24.684  -24.622      WOLLASTONITE       10.792    9.515      ZOISITE        -35.868  -34.505
EPIDOTE      -43.519  -37.626      MARCASITE        -122.879 -121.007
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## Table 7. (continued)

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UNU Geothermal Training Programme                  DEEP WATER COOLED TO 200.0 DEGREES C.
SAMPLE = 073
=====================================================================================================================

ACTIVITY COEFFICIENTS IN DEEP WATER
H+          .782        KSO4-        .745        FE++         .324        FECL+        .726
OH-         .719        F-           .719        FE+++        .114        AL+++        .114
H3SIO4-     .726        CL-          .711        FEOH+        .740        ALOH++       .312
H2SIO4--    .312        NA+          .726        FE(OH)3-     .740        AL(OH)2+     .745
H2BO3-      .703        K+           .711        FE(OH)4--    .304        AL(OH)4-     .733
HCO3-       .726        CA++         .324        FEOH++       .304        ALSO4+       .733
CO3--       .293        MG++         .362        FE(OH)2+     .745        AL(SO4)2-    .733
HS-         .719        CAHCO3+      .752        FE(OH)4-     .745        ALF++        .312
S--         .304        MGHCO3+      .726        FESO4+       .740        ALF2+        .745
HSO4-       .733        CAOH+        .752        FECL++       .304        ALF4-        .733
SO4--       .283        MGOH+        .757        FECL2+       .740        ALF5--       .293
NASO4-      .745        NH4+         .703        FECL4-       .726        ALF6---      .064

CHEMICAL COMPONENTS IN DEEP WATER (PPM AND LOG MOLE)
H+ (ACT.)      .00   -7.067       MG++          .16   -5.173       FE(OH)3        .01   -6.915
OH-           1.53   -4.045       NACL        20.18   -3.462       FE(OH)4-       .13   -5.975
H4SIO4      143.52   -2.826       KCL           .21   -5.552       FECL+          .00  -10.159
H3SIO4-       3.40   -4.446       NASO4-      12.08   -3.994       FECL2          .00  -15.902
H2SIO4--       .00   -8.123       KSO4-        1.07   -5.102       FECL++         .00  -22.229
NAH3SIO4       .85   -5.141       CASO4      174.01   -2.893       FECL2+         .00  -23.389
H3BO3          .00     .000       MGSO4         .52   -5.363       FECL3          .00  -25.334
H2BO3-         .00     .000       CACO3         .72   -5.143       FECL4-         .00  -27.588
H2CO3         3.69   -4.226       MGCO3         .00   -9.123       FESO4          .00  -11.149
HCO3-         4.38   -4.144       CAHCO3+     11.27   -3.953       FESO4+         .00  -22.133
CO3--          .00   -7.385       MGHCO3+       .00   -7.980       AL+++          .00  -21.707
H2S            .04   -5.988       CAOH+        1.62   -4.546       ALOH++         .00  -14.831
HS-            .06   -5.720       MGOH+         .02   -6.340       AL(OH)2+       .00   -8.706
S--            .00  -13.522       NH4OH         .00     .000       AL(OH)3        .36   -5.332
H2SO4          .00  -14.264       NH4+          .00     .000       AL(OH)4-       .04   -6.372
HSO4-          .09   -6.037       FE++          .00   -9.947       ALSO4+         .00  -21.540
SO4--        87.90   -3.039       FE+++         .00  -25.278       AL(SO4)2-      .00  -22.548
HF             .00   -6.893       FEOH+         .00   -9.053       ALF++          .00  -18.048
F-             .55   -4.541       FE(OH)2       .00   -9.252       ALF2+          .00  -16.004
CL-        1308.55   -1.433       FE(OH)3-      .00  -10.175       ALF3           .00  -15.884
NA+         585.16   -1.594       FE(OH)4--     .00  -14.948       ALF4-          .00  -17.570
K+           14.08   -3.444       FE(OH)++      .00  -17.288       ALF5--         .00  -20.386
CA++        267.57   -2.175       FE(OH)2+      .00  -10.754       ALF6---        .00  -24.440

IONIC STRENGTH =  .04674      IONIC BALANCE :   CATIONS (MOL.EQ.) .03931884
                                                ANIONS  (MOL.EQ.) .03897264
                                                DIFFERENCE   (%)        .88

OXIDATION POTENTIAL (VOLTS) :     EH H2S=  -.505    EH CH4= 99.999    EH H2= 99.999    EH NH3= 99.999

LOG SOLUBILITY PRODUCTS OF MINERALS IN DEEP WATER
              TEOR.    CALC.                      TEOR.    CALC.                        TEOR.    CALC.
ADULARIA     -14.776  -17.498    ALBITE LOW     -14.271  -15.640     ANALCIME       -11.646  -12.814
ANHYDRITE     -7.207   -6.252    CALCITE        -11.526  -10.582     CHALCEDONY      -2.217   -2.826
MG-CHLORITE  -81.685  -80.911    FLUORITE       -10.718  -12.033     GOETHITE         -.350   -1.916
LAUMONTITE   -24.602  -24.827    MICROCLINE     -15.613  -17.498     MAGNETITE      -21.553  -22.643
CA-MONTMOR.  -73.343  -90.588    K-MONTMOR.     -34.669  -47.553     MG-MONTMOR.    -74.794  -93.537
NA-MONTMOR.  -34.902  -45.695    MUSCOVITE      -18.071  -19.981     PREHNITE       -36.095  -33.041
PYRRHOTITE   -48.482  -74.001    PYRITE         -76.641 -100.350     QUARTZ          -2.340   -2.826
WAIRAKITE    -23.902  -24.827    WOLLASTONITE     8.387    8.643     ZOISITE        -36.177  -34.282
EPIDOTE      -37.293  -34.957    MARCASITE      -58.102 -100.350
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## Table 7. (continued)

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UNU Geothermal Training Programme               DEEP WATER COOLED TO 150.0 DEGREES C.
SAMPLE = 073
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ACTIVITY COEFFICIENTS IN DEEP WATER
H+            .810      KSO4-        .778       FE++          .385       FECL+        .763
OH-           .757      F-           .757       FE+++         .157       AL+++        .157
H3SIO4-       .763      CL-          .751       FEOH+         .774       ALOH++       .373
H2SIO4--      .373      NA+          .763       FE(OH)3-      .774       AL(OH)2+     .778
H2BO3-        .744      K+           .751       FE(OH)4--     .365       AL(OH)4-     .769
HCO3-         .763      CA++         .385       FEOH++        .365       ALSO4+       .769
CO3--         .355      MG++         .421       FE(OH)2+      .778       AL(SO4)2-    .769
HS-           .757      CAHCO3+      .785       FE(OH)4-      .778       ALF++        .373
S--           .365      MGHCO3+      .763       FESO4+        .774       ALF2+        .778
HSO4-         .769      CAOH+        .785       FECL++        .365       ALF4-        .769
SO4--         .344      MGOH+        .789       FECL2+        .774       ALF5--       .355
NASO4-        .778      NH4+         .744       FECL4-        .763       ALF6---      .098

CHEMICAL COMPONENTS IN DEEP WATER (PPM AND LOG MOLE)
H+ (ACT.)     .00   -7.172       MG++          .18   -5.135       FE(OH)3       .01   -6.869
OH-           .77   -4.343       NACL        14.50   -3.605       FE(OH)4-      .08   -6.211
H4SIO4     142.08   -2.830       KCL           .10   -5.853       FECL+         .00   -7.513
H3SIO4-      4.61   -4.315       NASO4-      10.51   -4.054       FECL2         .00  -16.014
H2SIO4--      .00   -7.771       KSO4-         .83   -5.209       FECL++        .00  -20.567
NAH3SIO4     1.13   -5.019       CASO4      129.36   -3.022       FECL2+        .00  -21.710
H3BO3         .00     .000       MGSO4         .49   -5.390       FECL3         .00  -23.800
H2BO3-        .00     .000       CACO3         .83   -5.079       FECL4-        .00  -26.310
H2CO3        1.95   -4.502       MGCO3         .00   -8.796       FESO4         .00   -8.107
HCO3-        7.58   -3.906       CAHCO3+      8.67   -4.067       FESO4+        .00  -20.247
CO3--         .01   -6.731       MGHCO3+       .00   -7.880       AL+++         .00  -19.273
H2S           .02   -6.261       CAOH+         .49   -5.062       ALOH++        .00  -13.566
HS-           .08   -5.622       MGOH+         .00   -6.975       AL(OH)2+      .00   -8.495
S--           .00  -13.746       NH4OH         .00     .000       AL(OH)3       .24   -5.517
H2SO4         .00  -15.413       NH4+          .00     .000       AL(OH)4-      .19   -5.632
HSO4-         .02   -6.704       FE++          .01   -6.936       ALSO4+        .00  -19.313
SO4--      120.94   -2.900       FE+++         .00  -22.611       AL(SO4)2-     .00  -20.360
HF            .00   -7.499       FEOH+         .02   -6.604       ALF++         .00  -16.283
F-            .55   -4.540       FE(OH)2       .00   -7.549       ALF2+         .00  -14.776
CL-       1312.04   -1.432       FE(OH)3-      .00   -9.460       ALF3          .00  -15.001
NA+        587.65   -1.592       FE(OH)4--     .00  -14.389       ALF4-         .00  -16.902
K+          14.20   -3.440       FE(OH)++      .00  -15.525       ALF5--        .00  -19.836
CA++       282.50   -2.152       FE(OH)2+      .00  -10.040       ALF6---       .00  -23.830

IONIC STRENGTH =   .04827      IONIC BALANCE :   CATIONS (MOL.EQ.) .04013072
                                                 ANIONS  (MOL.EQ.) .03978148
                                                 DIFFERENCE    (%)       .87

OXIDATION POTENTIAL (VOLTS) :      EH H2S=  -.430    EH CH4= 99.999    EH H2= 99.999    EH NH3= 99.999

LOG SOLUBILITY PRODUCTS OF MINERALS IN DEEP WATER
                 TEOR.    CALC.                        TEOR.    CALC.                       TEOR.    CALC.
ADULARIA       -15.664  -17.464     ALBITE LOW       -15.067  -15.609     ANALCIME        -12.168  -12.779
ANHYDRITE       -6.366   -5.930     CALCITE          -10.399   -9.748     CHALCEDONY       -2.432   -2.830
MG-CHLORITE    -80.047  -82.572     FLUORITE         -10.561  -11.888     GOETHITE         -2.669   -1.857
LAUMONTITE     -25.402  -24.705     MICROCLINE       -16.731  -17.464     MAGNETITE       -25.789  -19.991
CA-MONTMOR.    -76.836  -86.991     K-MONTMOR.       -36.807  -45.776     MG-MONTMOR.     -78.177  -89.935
NA-MONTMOR.    -36.953  -43.922     MUSCOVITE        -18.991  -19.354     PREHNITE        -35.828  -33.369
PYRRHOTITE     -74.605  -76.763     PYRITE          -111.470 -103.199     QUARTZ           -2.683   -2.830
WAIRAKITE      -23.901  -24.705     WOLLASTONITE       9.469    8.947     ZOISITE         -35.407  -34.314
EPIDOTE        -39.779  -35.225     MARCASITE        -90.765 -103.199
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## Table 7. (continued)

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UNU Geothermal Training Programme                  DEEP WATER COOLED TO 100.0 DEGREES C.
SAMPLE = 073
=============================================================================================================


ACTIVITY COEFFICIENTS IN DEEP WATER
H+            .831       KSO4-          .802        FE++          .432       FECL+         .788
OH-           .783       F-             .783        FE+++         .196       AL+++         .196
H3SIO4-       .788       CL-            .777        FEOH+         .798       ALOH++        .421
H2SIO4--      .421       NA+            .788        FE(OH)3-      .798       AL(OH)2+      .802
H2BO3-        .771       K+             .777        FE(OH)4--     .413       AL(OH)4-      .794
HCO3-         .788       CA++           .432        FEOH++        .413       ALSO4+        .794
CO3--         .403       MG++           .467        FE(OH)2+      .802       AL(SO4)2-     .794
HS-           .783       CAHCO3+        .808        FE(OH)4-      .802       ALF++         .421
S--           .413       MGHCO3+        .788        FESO4+        .798       ALF2+         .802
HSO4-         .794       CAOH+          .808        FECL++        .413       ALF4-         .794
SO4--         .392       MGOH+          .812        FECL2+        .798       ALF5--        .403
NASO4-        .802       NH4+           .771        FECL4-        .788       ALF6---       .130

CHEMICAL COMPONENTS IN DEEP WATER (PPM AND LOG MOLE)
H+ (ACT.)      .00   -7.432       MG++          .21   -5.067        FE(OH)3          .00   -8.892
OH-            .32   -4.721       NACL         7.51   -3.891        FE(OH)4-         .00   -8.473
H4SIO4      141.41   -2.832       KCL           .05   -6.148        FECL+            .01   -7.234
H3SIO4-       5.15   -4.267       NASO4-       8.11   -4.167        FECL2            .00  -13.209
H2SIO4--       .00   -7.553       KSO4-         .60   -5.352        FECL++           .00  -21.305
NAH3SIO4      1.29   -4.963       CASO4       86.75   -3.196        FECL2+           .00  -22.442
H3BO3          .00     .000       MGSO4         .35   -5.538        FECL3            .00  -24.709
H2BO3-         .00     .000       CACO3         .89   -5.052        FECL4-           .00  -27.509
H2CO3          .83   -4.873       MGCO3         .00   -8.480        FESO4            .01   -7.336
HCO3-        11.04   -3.743       CAHCO3+      4.66   -4.336        FESO4+           .00  -20.777
CO3--          .04   -6.151       MGHCO3+       .00   -7.813        AL+++            .00  -17.392
H2S            .01   -6.528       CAOH+         .13   -5.650        ALOH++           .00  -12.723
HS-            .09   -5.579       MGOH+         .00   -7.544        AL(OH)2+         .00   -8.604
S--            .00  -13.948       NH4OH         .00     .000        AL(OH)3          .09   -5.933
H2SO4          .00  -17.001       NH4+          .00     .000        AL(OH)4-         .37   -5.408
HSO4-          .00   -7.547       FE++          .04   -6.162        ALSO4+           .00  -17.658
SO4--       153.23   -2.797       FE+++         .00  -22.382        AL(SO4)2-        .00  -18.758
HF             .00   -8.239       FEOH+         .03   -6.423        ALF++            .00  -14.923
F-             .55   -4.539       FE(OH)2       .00   -8.136        ALF2+            .00  -13.840
CL-        1316.31   -1.430       FE(OH)3-      .00  -11.080        ALF3             .00  -14.326
NA+         590.83   -1.590       FE(OH)4--     .00  -16.247        ALF4-            .00  -16.386
K+           14.30   -3.437       FE(OH)++      .00  -16.031        ALF5--           .00  -13.333
CA++        296.87   -2.130       FE(OH)2+      .00  -11.476        ALF6---          .00  -23.236

IONIC STRENGTH =   .04979     IONIC BALANCE :   CATIONS (MOL.EQ.) .04094628
                                                ANIONS  (MOL.EQ.) .04061263
                                                DIFFERENCE   (%)        .82

OXIDATION POTENTIAL (VOLTS) :     EH H2S=  -.365    EH CH4= 99.999    EH H2= 99.999    EH NH3= 99.999

LOG SOLUBILITY PRODUCTS OF MINERALS IN DEEP WATER
                TEOR.    CALC.                       TEOR.    CALC.                          TEOR.    CALC.
ADULARIA      -17.222  -17.438    ALBITE LOW      -16.485  -15.585      ANALCINE          -13.199  -12.753
ANHYDRITE      -5.607   -5.699    CALCITE          -9.438   -9.041      CHALCEDONY         -2.841   -2.832
MG-CHLORITE   -80.302  -84.892    FLUORITE        -10.538  -11.786      GOETHITE           -4.674   -3.741
LAUMONTITE    -27.182  -24.614    MICROCLINE      -18.598  -17.438      MAGNETITE         -29.763  -23.664
CA-MONTMOR.   -85.559  -82.406    K-MONTMOR.      -41.648  -43.502      MG-MONTMOR.       -86.708  -85.306
NA-MONTMOR.   -41.660  -41.649    MUSCOVITE       -21.151  -18.573      PREHNITE          -36.778  -33.331
PYRRHOTITE    -99.806  -95.133    PYRITE         -147.012 -121.401      QUARTZ             -3.098   -2.832
WAIRAKITE     -24.710  -24.614    WOLLASTONITE     10.824    9.536      ZOISITE           -35.833  -34.433
EPIDOTE       -43.603  -37.672    MARCASITE      -123.575 -121.401
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## Table 7. (continued)

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UNU Geothermal Training Programme                    DEEP WATER COOLED TO  50.0 DEGREES C.
SAMPLE = 073
==========================================================================================

ACTIVITY COEFFICIENTS IN DEEP WATER
H+             .846      KSO4-          .820       FE++          .469       FECL+          .807
OH-            .802      F-             .802       FE+++         .230       AL+++          .230
H3SIO4-        .807      CL-            .797       FEOH+         .816       ALOH++         .458
H2SIO4--       .458      NA+            .807       FE(OH)3-      .816       AL(OH)2+       .820
H2BO3-         .791      K+             .797       FE(OH)4--     .450       AL(OH)4-       .812
HCO3-          .807      CA++           .469       FEOH++        .450       ALSO4+         .812
CO3--          .441      MG++           .503       FE(OH)2+      .820       AL(SO4)2-      .812
HS-            .802      CAHCO3+        .825       FE(OH)4-      .820       ALF++          .458
S--            .450      MGHCO3+        .807       FESO4+        .816       ALF2+          .820
HSO4-          .812      CAOH+          .825       FECL++        .450       ALF4-          .812
SO4--          .430      MGOH+          .829       FECL2+        .816       ALF5--         .441
NASO4-         .820      NH4+           .791       FECL4-        .807       ALF6---        .159

CHEMICAL COMPONENTS IN DEEP WATER (PPM AND LOG MOLE)
H+ (ACT.)      .00   -7.964        MG++         .24   -4.998         FE(OH)3       .00  -11.323
OH-            .11   -5.207        NACL        1.99   -4.467         FE(OH)4-      .00  -11.090
H4SIO4      141.31   -2.833        KCL          .03   -6.441         FECL+         .00   -7.746
H3SIO4-       5.14   -4.267        NASO4-      5.56   -4.331         FECL2         .00  -24.220
H2SIO4--       .00   -7.425        KSO4-        .38   -5.549         FECL++        .00  -22.897
NAH3SIO4      1.41   -4.924        CASO4      56.59   -3.381         FECL2+        .00  -24.025
H3BO3          .00     .000        MGSO4        .17   -5.839         FECL3         .00  -26.506
H2BO3-         .00     .000        CACO3        .95   -5.024         FECL4-        .00  -29.654
H2CO3          .25   -5.398        MGCO3        .00   -8.159         FESO4         .01   -7.198
HCO3-        13.27   -3.663        CAHCO3+     1.68   -4.778         FESO4+        .00  -22.147
CO3--          .14   -5.624        MGHCO3+      .00   -7.812         AL+++         .00  -15.944
H2S            .01   -6.810        CAOH+        .03   -6.333         ALOH++        .00  -12.179
HS-            .09   -5.556        MGOH+        .00   -8.176         AL(OH)2+      .00   -8.867
S--            .00  -14.031        NH4OH        .00     .000         AL(OH)3       .03   -6.382
H2SO4          .00  -19.284        NH4+         .00     .000         AL(OH)4-      .44   -5.331
HSO4-          .00   -8.663        FE++         .05   -6.014         ALSO4+        .00  -16.428
SO4--       176.86   -2.735        FE+++        .00  -23.033         AL(SO4)2-     .00  -17.584
HF             .00   -9.215        FEOH+        .01   -6.879         ALF++         .00  -13.810
F-             .55   -4.539        FE(OH)2      .00   -9.394         ALF2+         .00  -13.003
CL-        1319.67   -1.429        FE(OH)3-     .00  -13.455         ALF3          .00  -13.641
NA+         593.47   -1.588        FE(OH)4--    .00  -18.972         ALF4-         .00  -15.792
K+           14.37   -3.435        FE(OH)++     .00  -17.205         ALF5--        .00  -18.826
CA++        306.98   -2.116        FE(OH)2+     .00  -13.433         ALF6---       .00  -22.607

IONIC STRENGTH =   .05089     IONIC BALANCE :   CATIONS (MOL.EQ.) .04153923
                                                ANIONS  (MOL.EQ.) .04122734
                                                DIFFERENCE   (%)        .75

OXIDATION POTENTIAL (VOLTS) :     EH H2S=  -.311    EH CH4= 99.999    EH H2= 99.999    EH NH3= 99.999

LOG SOLUBILITY PRODUCTS OF MINERALS IN DEEP WATER
                 TEOR.    CALC.                      TEOR.    CALC.                     TEOR.    CALC.
ADULARIA       -19.664  -17.416     ALBITE LOW     -18.715  -15.564     ANALCIME      -14.863  -12.731
ANHYDRITE       -4.966   -5.545     CALCITE         -8.720   -8.424     CHALCEDONY     -3.297   -2.833
MG-CHLORITE    -82.885  -88.171     FLUORITE       -10.737  -11.714     GOETHITE       -6.429   -5.874
LAUMONTITE     -30.213  -24.545     MICROCLINE     -21.446  -17.416     MAGNETITE     -33.553  -28.636
CA-MONTMOR.   -101.366  -76.521     K-MONTMOR.     -50.171  -40.571     MG-MONTMOR.  -102.214  -79.373
NA-MONTMOR.    -49.974  -38.719     MUSCOVITE      -25.002  -17.581     PREHNITE      -39.270  -34.762
PYRRHOTITE    -125.035 -115.786     PYRITE        -185.595 -141.638     QUARTZ         -3.641   -2.833
WAIRAKITE      -26.535  -24.545     WOLLASTONITE    12.603   10.650     ZOISITE       -37.927  -34.844
EPIDOTE        -47.739  -40.636     MARCASITE     -158.572 -141.638
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# Table 7. (continued)

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UNU Geothermal Training Programme                    DEEP WATER COOLED TO    .0 DEGREES C.
SAMPLE = 073
=========================================================================================================

ACTIVITY COEFFICIENTS IN DEEP WATER
H+             .850          KSO4-           .825          FE++           .481          FECL+          .813
OH-            .808          F-              .808          FE+++          .241          AL+++          .241
H3SIO4-        .813          CL-             .803          FEOH+          .822          ALOH++         .470
H2SIO4--       .470          NA+             .813          FE(OH)3-       .822          AL(OH)2+       .825
H2BO3-         .798          K+              .803          FE(OH)4--      .463          AL(OH)4-       .818
HCO3-          .813          CA++            .481          FEOH++         .463          ALSO4+         .818
CO3--          .453          MG++            .514          FE(OH)2+       .825          AL(SO4)2-      .818
HS-            .808          CAHCO3+         .830          FE(OH)4-       .825          ALF++          .470
S--            .463          MGHCO3+         .813          FESO4+         .822          ALF2+          .825
HSO4-          .818          CAOH+           .830          FECL++         .463          ALF4-          .818
SO4--          .443          MGOH+           .834          FECL2+         .822          ALF5--         .453
NASO4-         .825          NH4+            .798          FECL4-         .813          ALF6---        .169

CHEMICAL COMPONENTS IN DEEP WATER (PPM AND LOG MOLE)
H+ (ACT.)      .00   -8.906          MG++             .27   -4.957         FE(OH)3         .00  -14.103
OH-            .02   -5.927          NACL             .87   -4.828         FE(OH)4-        .00  -14.042
H4SIO4      141.73   -2.831          KCL              .01   -6.735         FECL+           .00   -8.615
H3SIO4-       4.64   -4.312          NASO4-          3.31   -4.556         FECL2           .00  -31.167
H2SIO4--       .00   -7.417          KSO4-            .20   -5.825         FECL++          .00  -25.163
NAH3SIO4      1.52   -4.890          CASO4          38.34   -3.550         FECL2+          .00  -26.287
H3BO3          .00     .000          MGSO4            .05   -6.342         FECL3           .00  -29.047
H2BO3-         .00     .000          CACO3           1.04   -4.984         FECL4-          .00  -32.637
H2CO3          .05   -6.081          MGCO3            .00   -7.839         FESO4           .01   -7.161
HCO3-        13.86   -3.644          CAHCO3+          .40   -5.402         FESO4+          .00  -24.148
CO3--          .46   -5.120          MGHCO3+          .00   -7.889         AL+++           .00  -14.500
H2S            .00   -7.129          CAOH+            .00   -7.247         ALOH++          .00  -11.561
HS-            .09   -5.544          MGOH+            .00   -9.171         AL(OH)2+        .00   -8.998
S--            .00  -13.915          NH4OH            .00     .000         AL(OH)3         .02   -6.615
H2SO4          .00  -22.589          NH4+             .00     .000         AL(OH)4-        .46   -5.316
HSO4-          .00  -10.158          FE++             .06   -5.966         ALSO4+          .00  -15.202
SO4--       191.77   -2.700          FE+++            .00  -24.334         AL(SO4)2-       .00  -16.403
HF             .00  -10.542          FEOH+            .00   -7.524         ALF++           .00  -12.473
F-             .55   -4.539          FE(OH)2          .00  -11.000         ALF2+           .00  -11.772
CL-        1320.35   -1.429          FE(OH)3-         .00  -16.412         ALF3            .00  -12.426
NA+         594.32   -1.588          FE(OH)4--        .00  -22.509         ALF4-           .00  -14.579
K+           14.43   -3.433          FE(OH)++         .00  -18.848         ALF5--          .00  -17.574
CA++        312.83   -2.108          FE(OH)2+         .00  -15.774         ALF6---         .00  -21.180

IONIC STRENGTH =   .05153      IONIC BALANCE :   CATIONS (MOL.EQ.) .04185931
                                                 ANIONS  (MOL.EQ.) .04156729
                                                 DIFFERENCE    (%)       .70

OXIDATION POTENTIAL (VOLTS) :      EH H2S=  -.269    EH CH4= 99.999    EH H2= 99.999    EH NH3= 99.999

LOG SOLUBILITY PRODUCTS OF MINERALS IN DEEP WATER
                TEOR.    CALC.                          TEOR.    CALC.                        TEOR.    CALC.
ADULARIA      -23.276  -17.404     ALBITE LOW         -22.008  -15.553     ANALCIME         -17.390  -12.722
ANHYDRITE      -4.511   -5.478     CALCITE             -8.378   -7.889     CHALCEDONY        -3.321   -2.831
MG-CHLORITE   -88.387  -93.644     FLUORITE           -11.323  -11.688     GOETHITE          -8.225   -8.106
LAUMONTITE    -34.804  -24.514     MICROCLINE         -25.573  -17.404     MAGNETITE        -38.146  -34.535
CA-MONTMOR.  -121.263  -67.824     K-MONTMOR.         -61.001  -36.227     MG-MONTMOR.     -121.654  -70.645
NA-MONTMOR.   -60.441  -34.377     MUSCOVITE          -30.074  -16.128     PREHNITE         -43.653  -36.147
PYRRHOTITE   -152.446 -137.996     PYRITE            -231.987 -162.799     QUARTZ            -4.382   -2.831
WAIRAKITE     -29.576  -24.514     WOLLASTONITE        15.039   12.556     ZOISITE          -41.763  -35.510
EPIDOTE       -54.230  -44.253     MARCASITE         -200.020 -162.799
```

Table 8. Summary of results of mineral equilibria calculations using the WATCH1 and WATCH3 computer programs

| Sample No. | Locality | Measured temp. °C | Chalced temp. °C | Quartz temp. °C | NaK temp. °C | Range equil. temp. °C | Cluster equil. temp. °C | Best equil. temp °C |
|---|---|---|---|---|---|---|---|---|
| 08 | Svartsengi,4 | 242 | na | 234 | 244 | 214 - >250 | 214 - 250 | 214 |
| 09 | Reykjanes,8 | 274 - 292 | na | 247 | 259 | 194 - 281 | 201 - 272 | 246 |
| 28 | Reykholt,1 | 133 | 134 | 156 | 135 | 85 - >150 | 131 - >150 | 135 |
| 30 | Reykjabol,1 | 152 | 157 | 178 | 151 | 106 - >200 | 123 -188 | 126/161 |
| 32 | Hveragerdi,4 | 181 | 169 | 190 | 187 | 104 - 234 | 121 - 166 | 166 |
| 48 | Krafla,9 | 240 | na | 246 | 234 | 142 - >250 | 219 -250 | 248 |
| 49 | Krafla,7 | 206 - 325 | na | 265 | 251 | 134 - >350 | 217 - 301 | 275 |
| 51 | Namafjall,4 | 180 | na | 214 | 251 | 113 - 288 | 138 - 215 | 185 |
| 52 | Namafjall,8 | 160(est.) | na | 220 | 247 | 87 - 300 | 141 - 226 | 160 |
| 60 | Isafjardard,sp. | 84? | 85 | 110 | 82 | 10 - >150 | 57 - 92 | 90 |
| 72 | Seltj.,2, 80m | 31 | 59 | 85 | 52 | 62 - 119 | 62 - 97 | 94 |
| 73 | Seltj.,2, 570m | 78 | 101 | 125 | 83 | 92 - 166 | 92 - 134 | 134 |
| 74 | Seltj.,2, 725m | 77 | 98 | 122 | 69 | 77 - >200 | 98 - 138 | 138 |
| 75 | Borgarfjord.,cold | 3.8 | 25 | 51 | 112 | 10 - >40 | 10 - 29 | none |
| 76 | England, hot | 91 | 128 | 150 | 104 | 59 -167 | 81 - 117 | 82 |
| 79 | Urridavatn,8 | 77 | 60 | 86 | 66 | 39 - >200 | 49 - 87 | 84 |
| 80 | Urridavatn,4 | 64 | 50 | 76 | 58 | 38 - >200 | 43 - 88 | 42 |
| 81 | IRDP | 47/78 | 62 | 87 | 52 | 2 - >100 | 44 - 67 | 65 |

Note: ? denotes temperatures measured at the surface

na denotes "not applicable"

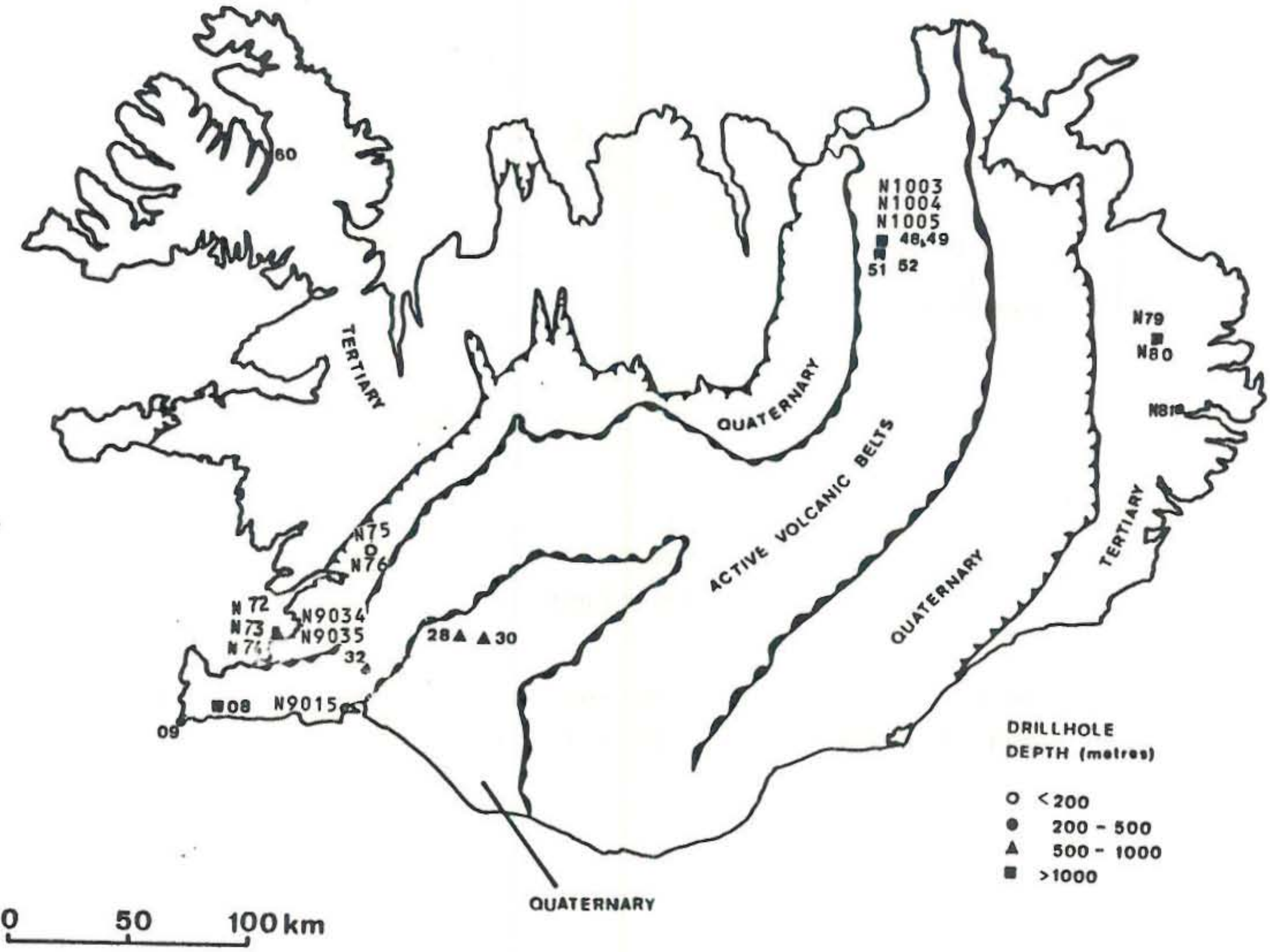

Figure 1. Map of Iceland showing localities from which samples were collected, analysed or interpreted.Samples designated with N (e.g. N73) were collected by the National Energy Authority in 1988. Other samples are from Arnorsson et al (1983a).

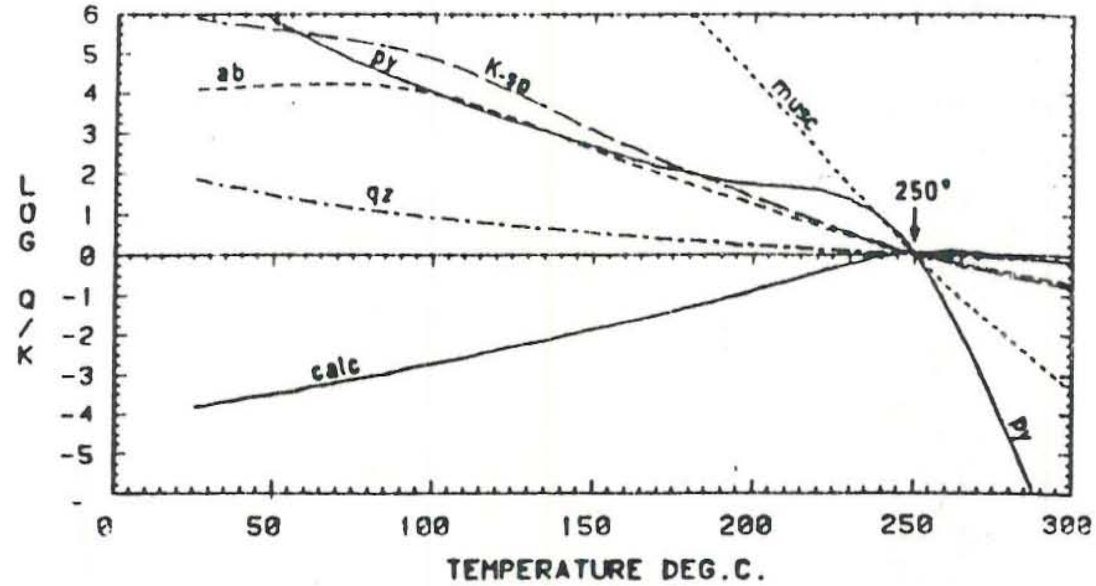

Figure 2. Plot of Log(Q/K) versus temperature for a geothermal fluid at equilibrium at 250°C (Reed and Spycher, 1984).

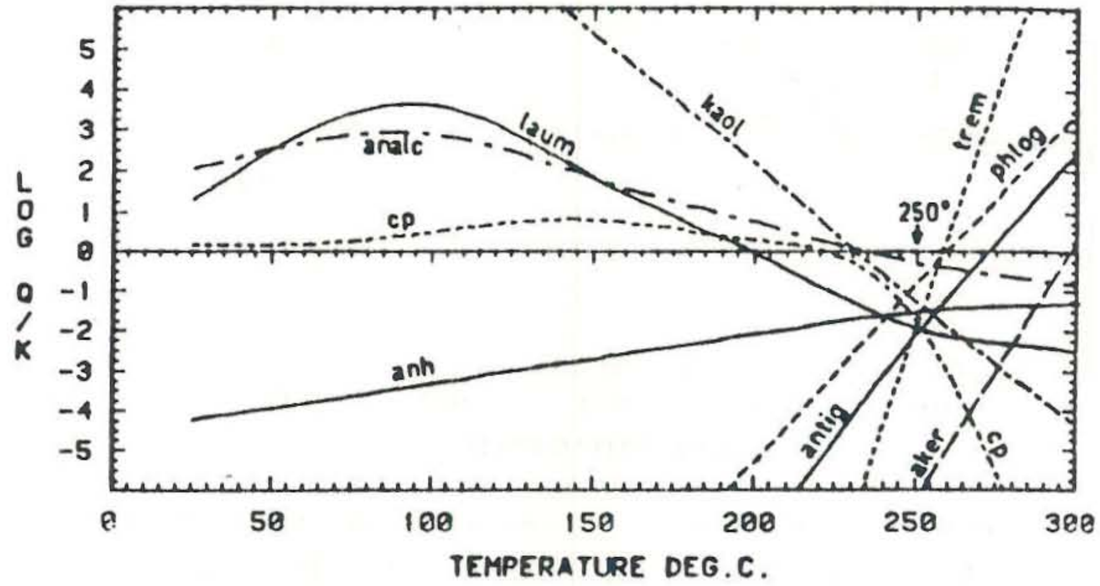

Figure 3. Plot of Log(Q/K) versus temperature for a geothermal fluid mixed with highly dilute water (Reed and Spycher, 1984).

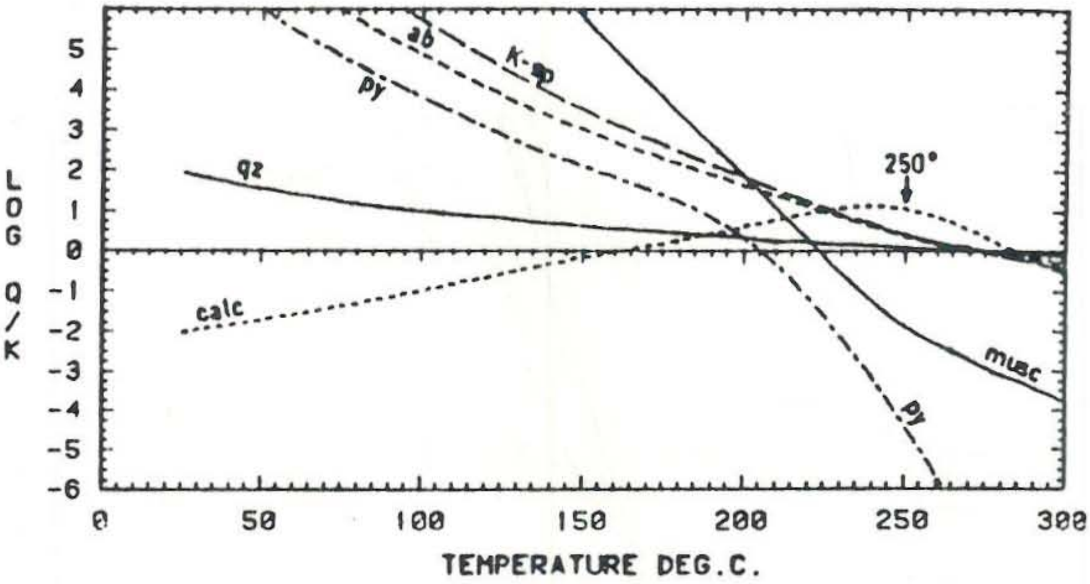

Figure 4. Plot of Log(Q/K) versus temperature for a geothermal fluid that has boiled (Reed and Spycher, 1984).

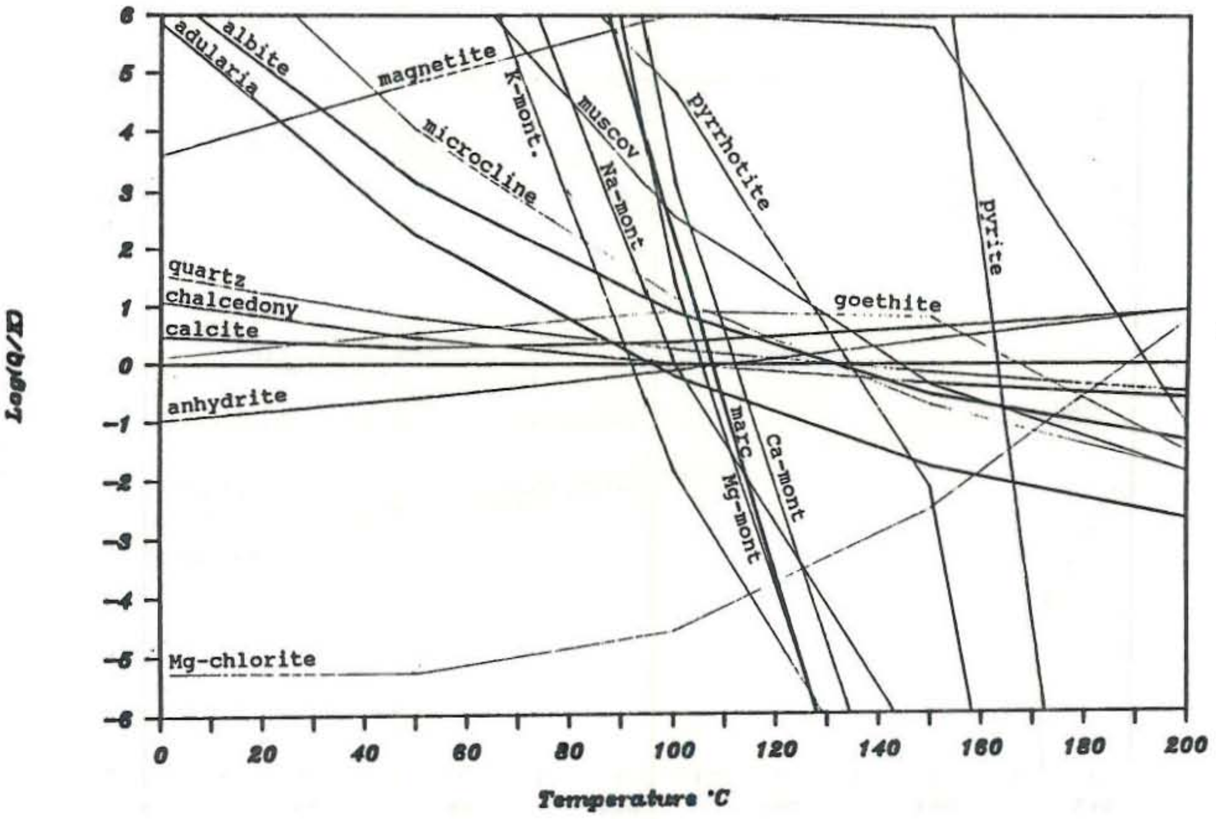

Figure 5. Mineral equilibrium diagram for sample from Seljarnarnes well 2 at 570m depth. All likely primary and secondary minerals have been included. Calculated on WATCH3.

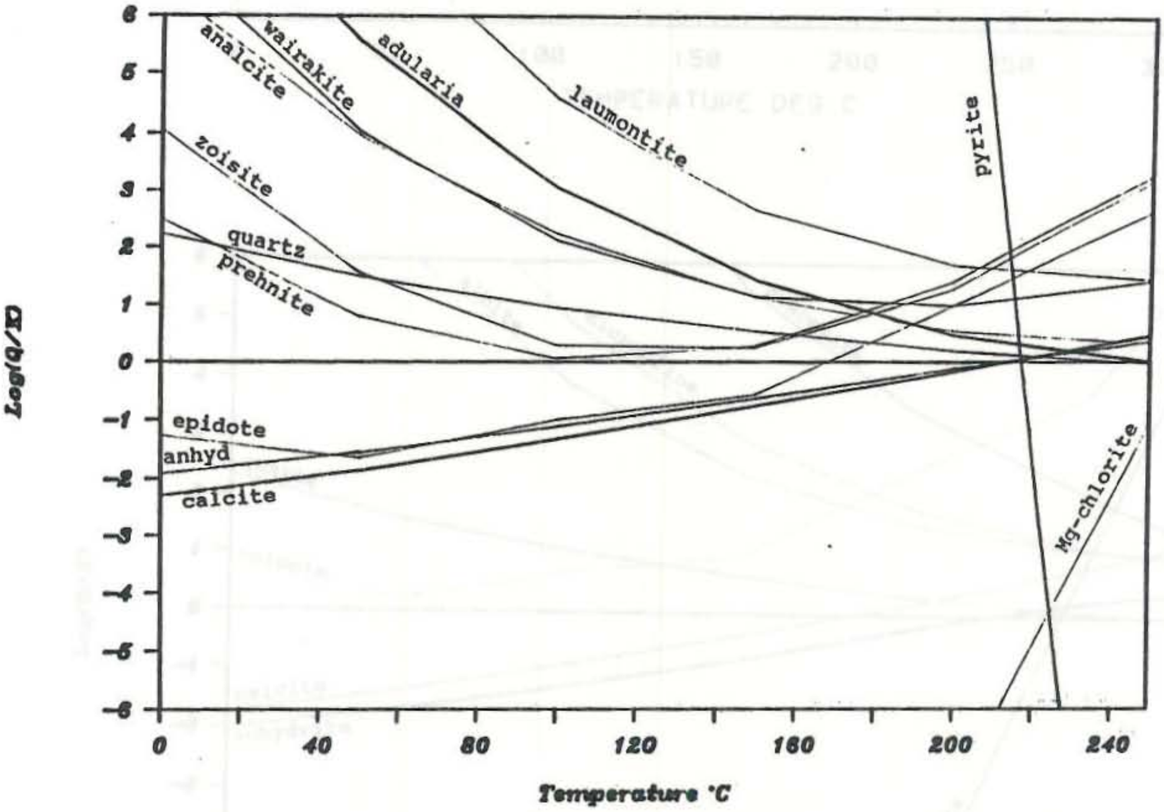

Figure 6. Mineral equilibrium diagram for Svartsengi Well 4. All likely primary and secondary minerals have been included. Calculated on WATCH1.

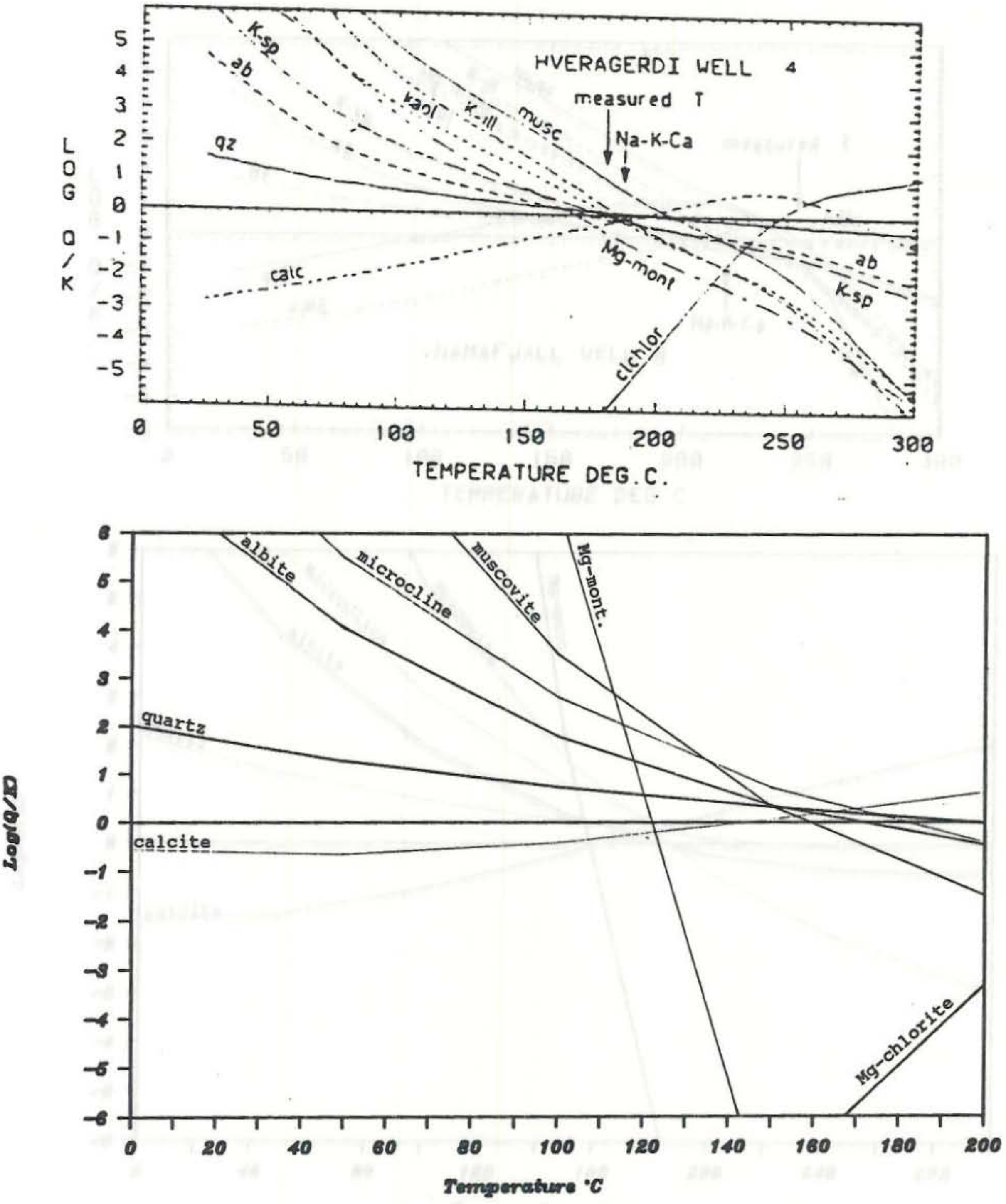

Figure 8. Comparison between mineral equilibria diagrams from the SOLVEQ (upper figure) and WATCH (lower figure) programs for Hveragerdi well 4.