# METEORIC WATER - BASALT INTERACTION IN NORTHEASTERN ICELAND: METHODS AND CHEMICAL ANALYSES

By Sigurdur R. Gislason and Shirley L. Rettig

---

U.S. GEOLOGICAL SURVEY

Open-File Report 87-49

U.S. DEPARTMENT OF THE INTERIOR
March 3, 1849

Reston, Virginia

1986

UNITED STATES DEPARTMENT OF THE INTERIOR

DONALD PAUL HODEL, Secretary

GEOLOGICAL SURVEY

Dallas L. Peck, Director

---

For additional information write to:

Shirley L. Rettig
Water Resources Division
U.S. Geological Survey
National Center, MS 432
Reston, VA 22092

Copies of this report can
be purchased from:

Open-File Services Section
Western Distribution Branch
U.S. Geological Survey
Box 25425, Federal Center
Denver, Colorado 80225
Telephone: (303) 236-7476

# CONTENTS

# ILLUSTRATIONS

## FIGURES

## TABLES

# CONVERSION FACTORS

| Multiply metric unit | By | To obtain inch-pound unit |
|---|---|---|
| millimeter (mm) | 0.0394 | inch (in.) |
| centimeter (cm) | 0.394 | inch (in.) |
| meter (m) | 3.281 | foot (ft) |
| kilogram per second (kg/s) | 137.66<br>2.205 | cubic feet per second<br>pound per second |
| milligrams per liter (mg/L) | 1.000 | parts per million (ppm) |
| liter per second (L/s) | 15.85 | gallon per minute (gal/min) |
| kilopascal (kPa) | 0.01 | bar |
| megajoule per kilogram (MJ/kg) | .0004301 | BTU (British thermal units) per pound |

Temperatures in degrees Celsius (°C) can be converted to degrees Fahrenheit (°F) as follows:

$$^{\circ}C = (^{\circ}F - 32)/1.8$$

# METEORIC WATER - BASALT INTERACTION IN NORTHEASTERN ICELAND: METHODS AND ANALYTICAL RESULTS

---

By Sigurdur R. Gislason and Shirley L. Rettig

---

## ABSTRACT

Results of the chemical analysis of atmospheric precipitation, spring waters, and geothermal water and steam in the rift zone of northeastern Iceland are presented. Methods of sample collection and analysis are described. Analyses performed in two laboratories generally agreed within 10 percent.

# INTRODUCTION

The rift zone of northeastern Iceland provides a unique opportunity for the study of solute acquisition by meteoric waters in a basaltic, unvegetated environment where the fluids finally concentrate in the geothermal fields associated with the Krafla volcano. Lithologies are uniform, and the solutes are derived from atmospheric precipitation and from congruent and incongruent dissolution of basalts.

The purpose of this paper is to report the results of chemical analysis of atmospheric precipitation, spring waters, and geothermal waters and steam (tables 1-4) collected in the course of this investigation.

## SAMPLING AND ANALYTICAL METHODS

Rain was sampled during the summer months (May, June, July, August, and September) in 1982 and 1983 at five meteorological stations in northeastern Iceland. Their locations are shown in figure 1.

The rain collectors (designed by Mr. Hreinn Hjartarson of the Meteorological Office in Reykjavik, Iceland) are mounted on a 127-mm (millimeter) by 127-mm timber base about 1.5 m (meters) above the ground. The collector consists of an outer funnel 15 cm in diameter (fig. 2) which is permanently sealed to a bottle cap. The cap is screwed on a sampling bottle which fits tightly in a holder made of galvanized iron. An inner funnel with a 3-cm-wide neck is placed in the neck of the outer funnel to minimize evaporation. All equipment that comes in contact with the sample is made of polyethylene. Sampling bottles are wrapped in aluminum foil to reflect solar energy and reduce heating and evaporation. Relative humidity in the area ranges from 75 to 90 percent (Icelandic Meteorological Office, 1939-79). At the end of each month, the sampling bottle is disconnected and sealed, and the funnel is mounted on a new sampling bottle, wrapped in aluminum foil, and placed in the holder for the next month. At the end of the summer, samples were filtered through a 0.45-µm (micrometer) Millipore[1] filter and then analyzed for major elements.

Snow from the Vatnajokull Glacier was sampled on April 1, 1982, by Helgi Bjornsson (Science Institute, University of Iceland, Reykjavik) 1,621 m above sea level

---

[1] Use of brand names in this report is for identification purposes only and does not constitute endorsement by the U.S. Geological Survey.

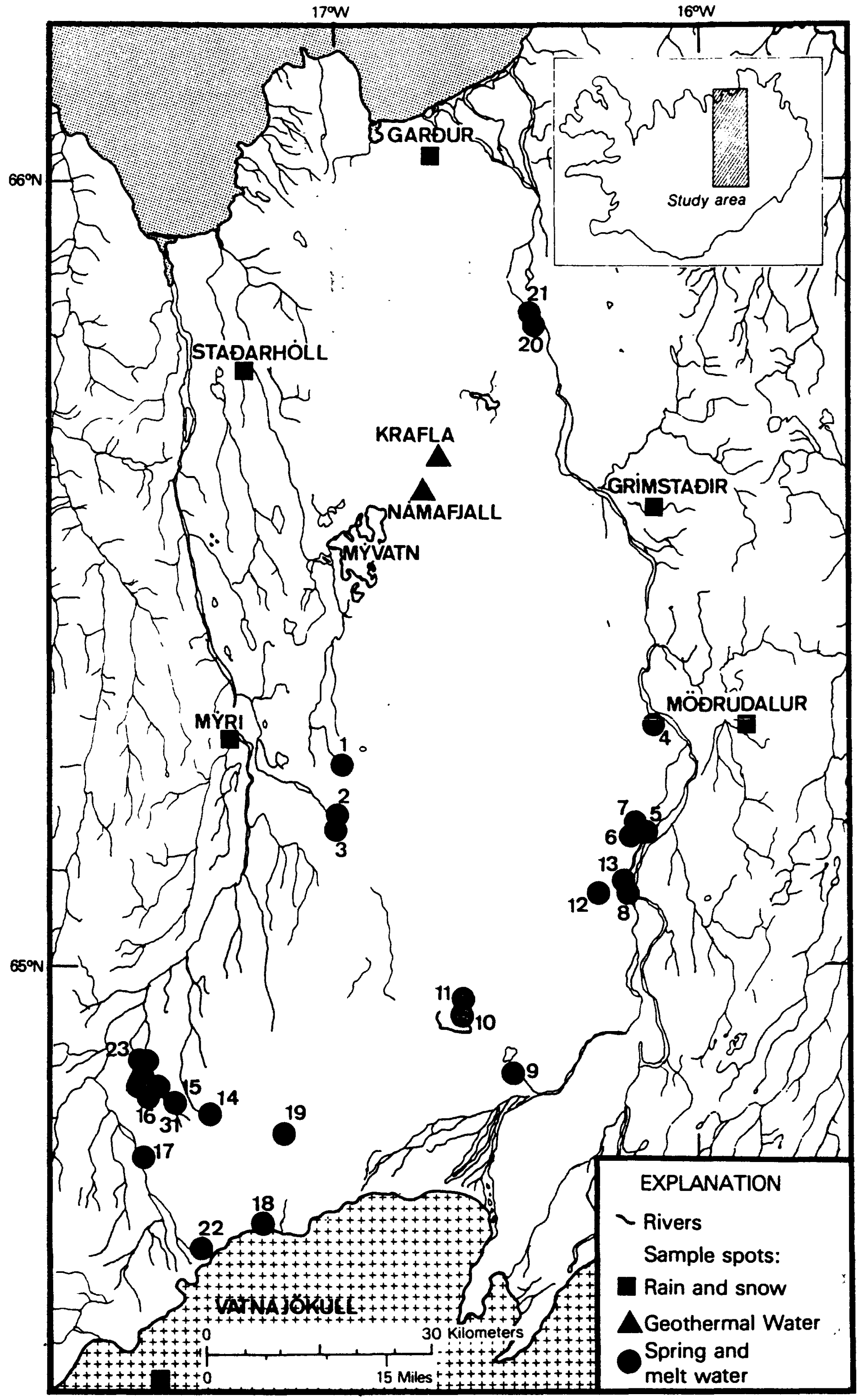

Figure 1.--Sampling localities and surface drainage inside and outside the rift zone in northern Iceland.

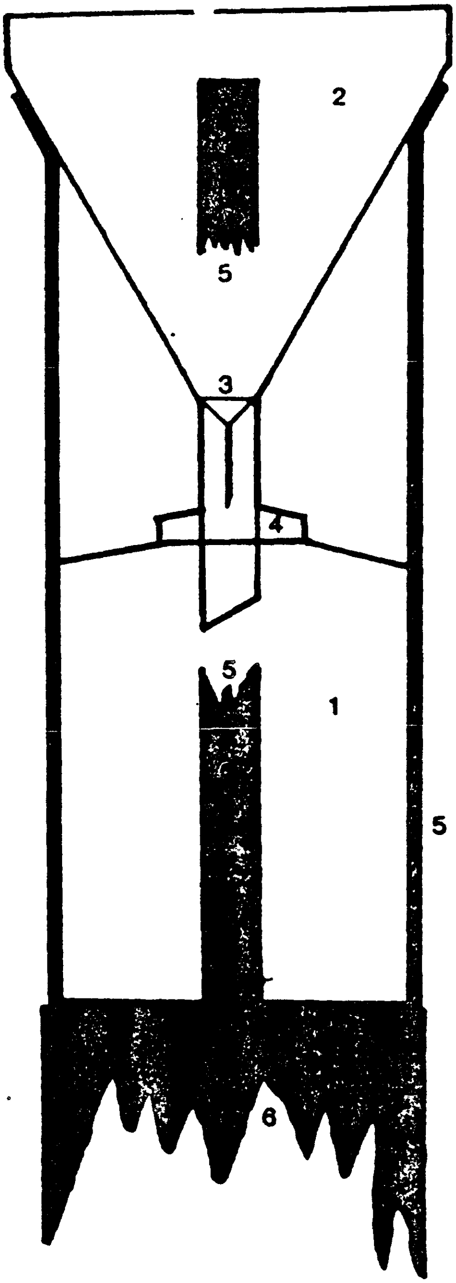

Figure 2.--Rain collector used for sampling rain during the summer months.

1. Sampling bottle (1 liter)
2. Outer funnel (15 cm in diameter)
3. Inner funnel (neck 3 cm in diameter)
4. Cap, permanently sealed to the outer funnel's neck
5. Bottle holder, made of galvanized iron
6. 127-mm by 127-mm timber base, about 1.5 m above the ground

(fig. 1). The samples represent the winter precipitation from September 1981 to April 1982, which is about 80 percent of the total annual precipitation (Bjornsson, 1979). The snow column was 419 cm deep, and it was separated into 25 sections which were placed in wide-mouth plastic bottles. The melted samples were later filtered through 0.45-μm Millipore filters, and alternative sections were analyzed for major elements.

The cold springs were sampled at the base of the lava fronts. In several cases, water flowed from the springs with a considerable head. Flow rates were estimated, and rocks in or near the spring were inspected for alteration products. The temperature of the water was measured by electronic thermometer (Fisher Scientific Co.), and the pH was measured with a Cole-Parmer portable pH meter and epoxy-body combination electrodes. The pH meter was calibrated with three buffers (phosphate, borax, and phthalate) which were placed in the spring and allowed to equilibrate with the temperature of the spring water. Samples were also titrated for total carbonate at the same temperature (±2 °C), as described by Gunnlaugsson and Arnorsson (1980) using a Gilmont microburette. One liter of untreated water was taken as a sample, and two 100-mL (milliliter) samples were filtered through 0.45-μm Millipore filters and acidified to a pH of 1.0, one sample with HCL (hydrochloric acid) and the other with $HNO_3$ (nitric acid). Samples were titrated immediately for $H_2S$ (hydrogen sulfide) as described by Archer (1955). The melted snow samples were treated similarly.

Waters from springs of intermediate temperature (30-60 °C) were cooled to ambient temperature in a stainless steel cooling spiral and then analyzed for pH, total carbonate, and $H_2S$.

High-temperature geothermal fluids (250 to 350°C) also were sampled. A Werbe separator was used to collect water and steam samples at the drill head. Both phases were sampled at the same pressure, and enthalpy measurements were made according to James (1962). Information on downhole temperatures were kindly provided by Mr. B. Steingrimsson at the National Energy Authority, Reykjavik, Iceland. Gas, condensate, and water were collected in tightly sealed glass tubes. Water samples for silica determination were immediately diluted with distilled water, and samples for sulfate determination were treated with zinc acetate in order to precipitate all reduced sulfurs as zinc sulfide. One liter of untreated sample was reserved for major element analysis, and two 100-mL samples were filtered through 0.45-μm Millipore filters and acidified, one with HCL and one with $HNO_3$. The separated steam fraction was collected in a 40-percent sodium hydroxide solution in an evacuated flask. The pH of the water was measured in the laboratory at room temperature immediately after sampling. Total carbonate was analyzed by titration with 0.01N (normal) HCL from pH 8.2 to pH 3.8 according to the method of Gunnlaugsson and Arnorsson (1980). Total $H_2S$ was determined by titration with 0.01N mercuric acetate with dithizone as an indicator, as described by Archer (1955). Methane, hydrogen, nitrogen, oxygen, and argon were analyzed by gas chromatography as described by Hauksson (1980) using helium and nitrogen as carrier gases. Oxygen was separated from argon by "washing" the sample in an alkaline pyrogallol solution. Any oxygen which was detected was subtracted from the total analysis together with a sufficient quantity of nitrogen to constitute the "atmospheric" ratio of four parts oxygen to one part nitrogen. Total sulfate in geothermal waters was measured by titration with barium chloride using thorium as an indicator as described by Fritz and Yanamura (1955). The precision of the methods described above is discussed by Arnorsson and others (1983).

Sodium, potassium, calcium, magnesium, strontium, and lithium were determined by atomic absorption as described in Skougstad and others (1979). Chloride was determined by ultrasensitive electrode (Gama Rad Inc.). Sulfate was measured turbidimetrically as described by Tabatabai (1974), and silica was measured colorimetrically using the silicomolybdate yellow method of Gunnlaugsson and Arnorsson. Iron, aluminum, and orthophosphate were analyzed colorimetrically following Skougstad and others (1979). Fluoride was determined by the use of a fluoride electrode, except for a few samples which were determined colormetrically using the SPADNS (4,5 dihydroxy-3-(parasulfophenylazo)-2,7-naphthalene-disulfonic acid trisodium salt) method as described in Standard Methods for the Examination of Water and Wastewater, 14th Edition (American Public Health Association, 1976).

Analysis of the samples was done both at the Department of Earth and Planetary Sciences of the Johns Hopkins University and in the laboratories of the Water Resources Division of the U.S. Geological Survey in Reston, Virginia. About half of the samples were analyzed in both laboratories; and the results of the duplicated analyses, although not shown in this report, are generally in good agreement, with a difference of less than 10 percent. The exceptions are the fluoride values in table 3, for which the colorimetric values are about 50 percent higher than those obtained with the fluoride electrode.

# CONCLUSIONS

Data are presented that show the concentrations in milligrams per liter, of major constituents of rain, snow, spring waters, and geothermal waters and steam in the vicinity of the Krafla volcano in the rift zone in northeastern Iceland. Analyses performed in the two laboratories are generally in good agreement with differences of less than 10 percent. The exceptions are a few fluoride analyses that were done by different methods; these differ by 50 percent.

Table 1.--The composition of rain waters in northeastern Iceland, expressed in milligrams per liter

| Sample No. | Station | Date | pH at 23°C [1] | $SiO_2$ | Na | Ca | K | Mg | $SO_4$ | Cl | F | $CO_2$ [2] | Sr |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| RA 001 | MYRI | 6/82 | 5.3 | 1.0 | 0.83 | 0.42 | 0.14 | 0.09 | 1.4 | 0.92 | 0.07 | 0.9 | 0.0 |
| RA 006 | " | 7/82 | 5.4 | .9 | .71 | .23 | .14 | .07 | 1.2 | .31 | .06 | .8 | .0 |
| RA 011 | " | 8/82 | 5.9 | .6 | .82 | .14 | .13 | .08 | 1.0 | .94 | .02 | 1.1 | <.05 |
| RA 015 | " | 9/82 | 5.3 | .6 | 1.10 | .12 | .10 | .11 | .3 | 1.60 | .02 | 1.1 | .0 |
| RA 021 | " | 4+5/83 | - | - | 1.33 | .28 | .36 | .12 | - | 2.0 | <.01 | - | - |
| RA 022 | " | 6/83 | - | .1 | .44 | .15 | .26 | .03 | 1.4 | .5 | <.01 | - | - |
| RA 023 | " | 7/83 | - | .1 | .44 | .11 | .15 | .05 | .9 | .5 | <.01 | - | - |
| RA 024 | " | 8/83 | - | .1 | .26 | .15 | .26 | .05 | 1.0 | .5 | <.01 | - | - |
| RA 003 | STADARHOLL | 6/82 | 6.9 | 2.2 | 2.11 | .76 | 1.82 | .26 | 5.7 | 2.88 | .05 | 3.07 | - |
| RA 008 | " | 7/82 | 4.9 | 3.9 | 1.34 | .60 | 3.84 | .28 | 6.5 | 2.04 | .04 | .77 | .0 |
| RA 013 | " | 8/82 | 4.8 | .6 | 1.41 | .14 | .12 | .15 | .6 | 2.18 | .02 | .92 | .0 |
| RA 017 | " | 9/82 | 5.3 | .6 | 2.42 | .16 | .14 | .27 | .6 | 4.46 | .02 | 1.14 | .0 |
| RA 025 | " | 4+5/83 | - | 1.0 | 2.76 | .74 | 1.16 | .25 | 6.9 | 5.2 | <.01 | - | - |
| RA 026 | " | 6/83 | - | .6 | .43 | .25 | .58 | .19 | 1.2 | .8 | <.01 | - | - |
| RA 027 | " | 7/83 | - | 1.0 | 1.77 | .64 | .91 | .34 | 3.1 | .5 | <.01 | - | - |
| RA 028 | " | 8/83 | - | .1 | 1.11 | .16 | .40 | .19 | 2.8 | .6 | <.01 | - | - |
| RA 02 | GARDUR | 6/82 | 6.4 | 1.4 | 1.71 | .59 | .90 | .22 | 4.88 | 2.10 | .05 | 1.58 | - |
| RA 07 | " | 7/82 | 6.0 | .9 | .96 | 1.04 | .13 | .13 | 1.3 | .92 | .02 | 1.00 | .0 |
| RA 12 | " | 8/82 | 5.5 | .6 | 2.05 | .30 | .15 | .23 | .6 | 3.37 | .02 | .98 | <.05 |
| RA 16 | " | 9/82 | 4.8 | .3 | 5.39 | .30 | .23 | .67 | 1.5 | 10.32 | .02 | 1.10 | .0 |
| RA 29 | " | 4+5/83 | - | .5 | 3.98 | .44 | 1.38 | .54 | 6.8 | 6.8 | <.01 | - | - |
| RA 30 | " | 6/83 | - | .0 | 1.77 | .13 | .16 | .22 | 1.6 | .5 | <.01 | - | - |
| RA 31 | " | 7/83 | - | .0 | 2.10 | .14 | .18 | .27 | 1.3 | .5 | <.01 | - | - |
| RA 32 | " | 8/83 | - | .0 | 2.45 | .13 | .15 | .28 | .6 | .7 | <.01 | - | - |
| RA 04 | GRIMSTADIR | 6/82 | 6.5 | 2.6 | 1.66 | 1.39 | .93 | .39 | 3.75 | 2.68 | .07 | 1.76 | - |
| RA 09 | " | 7/82 | 5.6 | .7 | 1.01 | .38 | .36 | .92 | .7 | 1.05 | .03 | .85 | .0 |
| RA 14 | " | 8/82 | 5.7 | 1.9 | .82 | .14 | .20 | .13 | .5 | .95 | .02 | 1.04 | .0 |
| RA 18 | " | 9/82 | 4.7 | 2.8 | .88 | .40 | .17 | .14 | .8 | 1.7 | <.01 | - | - |
| RA 33 | " | 4+5/83 | - | - | 2.19 | .45 | 1.55 | .17 | - | - | <.01 | - | - |
| RA 34 | " | 6/83 | - | .0 | .30 | .08 | .07 | .04 | .4 | .4 | <.01 | - | - |
| RA 35 | " | 7/83 | - | .2 | .69 | .17 | .35 | .06 | 2.3 | .6 | <.01 | - | - |
| RA 36 | " | 8/83 | - | .3 | .64 | .19 | .48 | .07 | 1.9 | .6 | <.01 | - | - |
| RA 05 | MODRUDALUR | 6/82 | 6.1 | .7 | .96 | .57 | .19 | .15 | 2.5 | 1.43 | .05 | 1.24 | .0 |
| RA 10 | " | 7/82 | 5.4 | .6 | .64 | .28 | .09 | .06 | .6 | 1.23 | .03 | .82 | <.05 |
| RA 19 | " | 8/82 | 4.3 | .7 | .38 | .17 | .06 | .05 | .9 | .6 | <.01 | .90 | - |
| RA 20 | " | 9/82 | 4.6 | 2.8 | .90 | .64 | .03 | .16 | .8 | .4 | <.01 | 1.09 | - |
| RA 37 | " | 4+5/83 | - | .1 | .96 | .66 | .79 | .20 | 3.0 | 2.3 | <.01 | - | - |
| RA 38 | " | 6/83 | - | .2 | .26 | .25 | .10 | .05 | .8 | .5 | <.01 | - | - |
| RA 39 | " | 7/83 | - | .1 | .50 | .23 | .39 | .05 | 2.8 | .6 | <.01 | - | - |

[1] pH measured 1 to 4 months after sampling

[2] Total carbonate expressed as $CO_2$ calculated from pH assuming electrical neutrality

Table 2.--The composition of snow collected on Vatnajokull Glacier in northeastern Iceland in April 1982 expressed in milligrams per liter

| Sample No. | Sample Depth | pH at 26°C 1/ | $SiO_2$ | Na | Ca | K | Mg | $SO_4$ | Cl | F | $CO_2$ 2/ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| SN 001 | 0-25 cm | 6.5 | 0.7 | 1.59 | 0.53 | 0.60 | 0.16 | 2.0 | 2.00 | 0.03 | 1.98 |
| SN 002 | 50-75 cm | 6.5 | .5 | 1.83 | .51 | 1.16 | .13 | 3.0 | 2.12 | .03 | 1.98 |
| SN 003 | 100-125 cm | 6.3 | .9 | 2.34 | .61 | .35 | .26 | 3.6 | 3.36 | .03 | 1.66 |
| SN 004 | 160-176 cm | 7.1 | .5 | 2.97 | .67 | 1.54 | .23 | 2.7 | 3.96 | .03 | 4.66 |
| SN 005 | 196-213 cm | 6.4 | .7 | 1.77 | .61 | .37 | .20 | 1.9 | 2.39 | .03 | 1.80 |
| SN 006 | 229-247 cm | 6.9 | 1.0 | 1.77 | .79 | .82 | .19 | 2.5 | 2.08 | .03 | 3.34 |
| SN 007 | 262-295 cm | 7.2 | .5 | 2.02 | 1.10 | 1.12 | .17 | 2.4 | 2.68 | .03 | 5.60 |
| SN 008 | 305-317 cm | 6.7 | 1.8 | 2.70 | 1.08 | .44 | .33 | 2.6 | 3.68 | .04 | 2.51 |
| SN 009 | 328-347 cm | 6.8 | 1.8 | 2.40 | 1.49 | .65 | .31 | 4.4 | 2.96 | .06 | 2.29 |
| SN 010 | 360-395 cm | 6.9 | .5 | 1.22 | .55 | .60 | .13 | 1.4 | 1.49 | .04 | 3.34 |
| SN 011 | 385-398 cm | 7.3 | 1.2 | 2.58 | 1.09 | 1.18 | .24 | 3.2 | 3.48 | .04 | 6.76 |
| SN 012 | 407-419 cm | 5.9 | .9 | 1.33 | .64 | .47 | .13 | 2.5 | 1.50 | .04 | 1.31 |

1/ pH measured 1 to 4 months after sampling

2/ Total carbonate expressed as $CO_2$ calculated from pH assuming electrical neutrality

Table 3.--The composition of spring waters in northeastern Iceland, expressed in milligrams per liter
[T is temperature of ph measurements]

| Sample | Date | Flow (L/s) | Temp. | pH/°C | $SiO_2$ | Na | Ca | K | Mg | $SO_4$ | $H_2S$ | Cl | F | $F^{1/}$ | $CO_2$ | (2) Fe | (3) Fe | (4) Al | (5) Al | Sr | Li |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SP 01 | 7/15/82 | 1 | 4.4 | 9.00/4 | 18.1 | 15.8 | 4.35 | 1.11 | 2.44 | 8.6 | <.07 | 2.30 | .28 | | 35.6 | .061 | - | .11 | - | <.05 | 0.00 |
| SP 02 | 7/16/82 | 5 | 4.6 | 9.15/7 | 16.3 | 14.4 | 4.93 | 1.01 | 2.15 | 7.3 | " | 1.59 | .26 | | 30.0 | .038 | - | .10 | - | <.05 | " |
| SP 03 | 7/16/82 | 50 | 4.4 | 9.17/6 | 16.9 | 14.6 | 5.07 | 1.00 | 2.15 | 7.2 | " | 1.62 | .25 | | 31.0 | .022 | - | .06 | - | 0.00 | " |
| SP 04 | 7/18/82 | 1 | 2.6 | 9.22/5 | 14.4 | 14.9 | 5.57 | 1.00 | 1.13 | 6.9 | " | 2.83 | .20 | | 29.6 | .024 | - | .08 | - | 0.00 | " |
| SP 05 | 7/19/82 | 5 | 4.4 | 9.18/6 | 16.5 | 17.0 | 5.40 | .86 | 2.17 | 8.8 | " | 2.70 | .24 | | 35.3 | .026 | - | .09 | - | 0.00 | " |
| SP 06 | 7/19/82 | 5 | 5.4 | 9.26/7 | 18.2 | 17.4 | 5.58 | .92 | 2.11 | 10.4 | " | 2.83 | .24 | | 32.7 | .020 | - | .05 | - | <.05 | " |
| SP 07 | 7/19/82 | 50 | 4.9 | 9.17/6 | 17.4 | 17.0 | 6.48 | .85 | 2.78 | 14.6 | " | 2.87 | .21 | | 33.0 | .015 | - | .05 | - | .00 | " |
| SP 08 | 7/20/82 | 100 | 6.2 | 8.82/8 | 17.4 | 22.6 | 5.06 | 1.01 | 2.39 | 10.9 | " | 3.15 | .28 | | 44.0 | .031 | - | .09 | - | <.05 | " |
| SP 09 | 7/21/82 | 1 | 6.9 | 8.88/8 | 22.2 | 20.2 | 5.54 | 1.67 | 2.71 | 16.2 | " | 3.23 | .27 | | 38.2 | .024 | - | .07 | - | .00 | " |
| SP 10 | 7/22/82 | 0 | 5.2 | 7.73/6 | 93.2 | 127.5 | 74.1 | 9.5 | 21.8 | 400 | " | 20.18 | .88 | | 85.4 | .345 | - | .09 | - | .10 | .03 |
| SP 11 | 7/22/82 | 0 | 0.5 | 6.15/3 | 0.6 | .93 | .22 | .03 | .07 | 2.2 | " | .57 | .02 | | 1.2 | .060 | - | .09 | - | .00 | 0.00 |
| SP 12 | 7/23/82 | 5 | 8.5 | 7.00/10 | 3.6 | 1.48 | 1.02 | .09 | .18 | 0.2 | " | .47 | .02 | | 3.3 | .025 | - | .07 | - | <.05 | " |
| SP 13 | 7/23/82 | 50 | 4.4 | 9.10/5 | 17.8 | 19.2 | 5.38 | .91 | 2.55 | 10.0 | " | 2.93 | .26 | | 39.6 | .083 | - | .12 | - | <.05 | " |
| SP 14 | 7/27/82 | 5 | 2.0 | 9.28/5 | 14.8 | 9.48 | 3.30 | .72 | 1.98 | 2.7 | " | 1.53 | .15 | | 23.3 | - | - | - | - | <.05 | " |
| SP 15 | 7/27/82 | 1 | 2.6 | 9.13/4 | 15.4 | 9.31 | 3.39 | .68 | 2.17 | 2.9 | " | 1.60 | .15 | | 24.2 | .046 | - | .09 | - | <.05 | " |
| SP 16 | 7/27/82 | 1 | 1.7 | 8.51/4 | 12.4 | 7.21 | 3.36 | .45 | 1.95 | 2.5 | <.07 | 2.10 | .12 | | 21.6 | .027 | - | .05 | - | .00 | " |
| SP 17 | 7/28/82 | .5 | 34.2 | 10.23/17 | 45.5 | 37.3 | 1.27 | .95 | .04 | 11.2 | " | 3.41 | .46 | | 23.6 | .054 | - | .13 | - | | " |
| SP 18 | 7/30/82 | 100 | 0.3 | 6.88/2 | 1.4 | 1.77 | 1.03 | .11 | .20 | .20 | " | .42 | .02 | | 6.7 | - | - | - | - | - | " |
| SP 19 | 7/30/82 | 0 | 0.0 | 5.22/0.6 | .4 | .95 | 0.12 | .02 | .08 | .96 | " | .81 | .02 | | 3.0 | - | - | - | - | - | " |
| SP 20 | 8/02/82 | 5 | 6.1 | 8.74/8 | 16.7 | 16.1 | 10.1 | 2.03 | 7.83 | 9.9 | " | 6.60 | .16 | | 66.0 | - | - | .03 | - | - | " |
| SP 21 | 8/02/82 | 100 | 8.7 | 8.66/10 | 20.7 | 20.2 | 9.68 | 2.38 | 8.95 | 9.7 | " | 6.18 | .21 | | 75.1 | - | - | .05 | - | - | " |
| SP 22 | 8/19/83 | 2 | 7.2 | 8.40/7.3 | 35 | 21.6 | 8.20 | .94 | 10.4 | 21.0 | " | 2.2 | .31 | .45 | 76.3 | .173 | .020 | .10 | .034 | .04 | .01 |
| SP 23 | 8/20/83 | .5 | 4.2 | 8.93/4.3 | 15 | 8.23 | 3.61 | .45 | 1.72 | 2.6 | " | 1.8 | .12 | .24 | 18.9 | .033 | .001 | .06 | .035 | .00 | .00 |
| SP 24 | 8/21/83 | 2 | 3.1 | 9.15/3.6 | 15 | 7.63 | 3.52 | .42 | 1.70 | 2.5 | " | 1.7 | .11 | .27 | 18.6 | .014 | .000 | .05 | .036 | .00 | " |
| SP 25 | 8/21/83 | 7 | 3.9 | 9.18/4.7 | 15 | 8.00 | 3.51 | .41 | 1.66 | 2.4 | " | 1.7 | .11 | .28 | 19.8 | .006 | .001 | .04 | .043 | <.05 | " |
| SP 26 | 8/21/83 | 1 | 3.9 | 9.45/4.6 | 16 | 9.23 | 3.46 | .44 | 1.50 | 2.3 | " | 1.8 | .12 | .31 | 19.1 | .010 | .002 | .06 | .040 | <.05 | " |
| SP 27 | 8/21/83 | .5 | 2.8 | 8.54/4.0 | 13 | 6.63 | 3.50 | .34 | 1.70 | 1.7 | " | 1.8 | .09 | .26 | 19.4 | .022 | .000 | .05 | .028 | <.05 | " |
| SP 28 | 8/21/83 | 1 | 2.0 | 8.16/2.8 | 14 | 6.70 | 3.48 | .43 | 1.96 | 2.3 | " | 1.7 | .11 | .31 | 21.8 | .018 | .000 | .04 | .029 | 0.0 | " |
| SP 29 | 8/21/83 | 1 | 2.3 | 8.11/2.3 | 16 | 8.30 | 3.82 | .58 | 2.36 | 3.1 | " | 1.6 | .14 | .32 | 27.5 | .003 | .000 | .03 | .029 | <.05 | " |
| SP 30 | 8/21/83 | 5 | 2.8 | 9.20/3.0 | 16 | 8.48 | 3.41 | .54 | 2.10 | 2.7 | " | 1.5 | .14 | .33 | 23.9 | .010 | .003 | .04 | .035 | <.05 | " |
| SP 31 | 8/22/83 | 5 | 2.3 | 8.60/2.7 | 15 | 7.00 | 3.57 | .43 | 1.96 | 2.5 | " | 1.7 | .11 | .36 | 21.2 | .009 | .002 | .04 | .032 | <.05 | " |

(1) Measured colorimetrically
(2) Acidified sample
(3) Unacidified sample
(4) Acidified sample
(5) Unacidified sample

Table 4.--The concentration, in milligrams per liter, of elements and gases in geothermal water and steam as collected at the wellhead, and selected physical properties

| Sample | Date | pH/T°C 1/ | Sampling Temp.(°C) | $SiO_2$ | Na | K | Ca | Mg | $CO_2$ | $SO_4$ | $H_2S$ | Cl | F | Al | Fe | Sr | $PO_4$ | Li |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Krafla Well 6 | 7/02/81 | 6.62/23 | 300 | 799.90 | 165.80 | 33.04 | 1.68 | 0.017 | 291.30 | 106.50 | 27.50 | 30.00 | 1.07 | 0.10 | 0.019 | 0.00 | 0.13 | 0.23 |
| Krafla Well 11 | 7/01/81 | 7.80/23 | 253 | 468.80 | 192.30 | 32.87 | 1.07 | .024 | 193.00 | 123.00 | 21.50 | 26.30 | 1.41 | .60 | .028 | .00 | .35 | .28 |
| Krafla Well 8 | 8/18/81 | 9.75/27 | 215 | 410.10 | 193.00 | 25.46 | 1.60 | .000 | 46.40 | 202.40 | 37.10 | 53.20 | .92 | .88 | .017 | < .05 | .06 | .13 |
| Krafla Well 9 | 7/02/81 | 7.55/20 | 240 | 557.40 | 171.50 | 25.40 | 1.42 | .000 | 180.80 | 182.40 | 35.40 | 50.70 | .59 | .66 | .024 | < .05 | .06 | .17 |
| Krafla Well 7 | 8/19/81 | 6.75/20 | 256 | 734.70 | 190.40 | 34.30 | 1.24 | .006 | 277.40 | 159.80 | 36.90 | 56.60 | .73 | .66 | .024 | < .05 | .06 | .19 |
| Krafla Well 13 | 8/20/81 | 9.15/20 | 325 | 902.50 | 223.60 | 46.16 | 1.72 | .006 | 129.20 | 182.60 | 29.60 | 40.90 | 1.20 | .28 | 2.21 | .00 | .08 | .29 |
| Krafla Well 14 | 8/21/81 | 7.55/20 | 295 | 775.20 | 146.20 | 32.40 | .32 | .000 | 193.70 | 13.50 | 44.90 | 91.00 | 3.14 | .33 | .035 | .00 | .08 | .25 |
| Krafla Well 16 | 8/21/81 | 8.70/20 | 300 | 633.30 | 142.60 | 30.47 | .51 | .006 | 158.50 | 39.40 | 53.70 | 70.00 | 1.90 | .79 | .013 | .00 | .08 | .33 |
| Namafjall 11 | 7/03/81 | 8.15/24 | 320 | 486.80 | 89.20 | 16.96 | .39 | .021 | 10.90 | 22.00 | 97.80 | 40.50 | .52 | .95 | .020 | .00 | - | .10 |
| Namafjall 12 | 7/03/81 | 8.48/24 | 253 | 509.30 | 113.60 | 18.40 | .09 | .010 | 18.10 | 28.50 | 136.10 | 23.00 | .54 | 1.04 | .058 | .00 | - | .13 |

| Sample | $CO_2$ 2/ | $H_2S$ 3/ | $H_2$ 3/ | $CH_4$ 3/ | $N_2$ 3/ | Ar 3/ | Sampling pressure (kPa) | Measured enthalpy (MJ/kg) | Discharge (kg/s) | Depth of fluid inflow (m) | Liters gas per kg of condensate at 20°C |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Krafla Well 6 | 11171.00 | 131.00 | 8.53 | 0.92 | 88.06 | 2.49 | 2.8 | 1.940 | - | 1100,1520 | 1.73 |
| Krafla Well 11 | 36912.00 | 498.00 | 12.95 | .25 | 85.72 | 1.18 | 8.2 | 2.075 | 4.7 | - | 3.45 |
| Krafla Well 8 | 1977.00 | 193.30 | 8.52 | 13.40 | 76.39 | 1.69 | 2.5 | .919 | - | - | .05 |
| Krafla Well 9 | 6955.00 | 353.00 | 55.29 | 5.67 | 38.05 | .99 | 7.8 | 1.036 | 40.3 | - | .09 |
| Krafla Well 7 | 15678.00 | 14.00 | 9.10 | .22 | 82.88 | 7.80 | 8.3 | 1.762 | 4.8 | - | 2.75 |
| Krafla Well 13 | 9343.00 | 402.30 | 38.70 | .66 | 59.65 | .99 | 4.1 | 1.877 | 4.7 | 1650 | .88 |
| Krafla Well 14 | 26914.00 | 95.90 | 18.88 | .41 | 78.33 | 2.38 | 13.7 | 2.663 | 12.9 | 1030,2030 | 3.75 |
| Krafla Well 16 | 13863.00 | 839.50 | 63.20 | 2.01 | 34.13 | .65 | 7.3 | 1.607 | 8.3 | 1050 | .74 |
| Namafjall 11 | 2489.00 | 1307.00 | 40.47 | .08 | 58.17 | 1.28 | 21.2 | 2.355 | 26.5 | 1430 | 4.80 |
| Namafjall 12 | 2615.00 | 1408.00 | 58.36 | .19 | 40.79 | .65 | 22.0 | 2.380 | 20.6 | - | 3.64 |

1/ Temperature calculated by the Na-K chemical geothermometer (Arnorson et al., 1983).
2/ Concentration of gases (mg/l) in $N_aOH$ condensation.
3/ Volume percent of a gas in a known volume of gas, coexisting with a known mass of condensation at room temperature.

# REFERENCES CITED

American Public Health Association, 1976, Standard Methods for the Examination of Water and Wastewater, 14th Ed.: p. 393-394.

Archer, E. E., 1955, The determination of small amounts of sulphate by reduction to hydrogen sulphide, and titration with mercuric or cadmium salts with dithizone as an indicator: Analyst, v. 81, p. 181-182.

Arnorsson, S., Gunnlaugsson, E., and Svavarsson, H., 1983, The chemistry of geothermal waters in Iceland. II. Mineral equilibria and independent variables controlling water compositions: Geochimica et Cosmochimica Acta, v. 47, p. 547-566.

Bjornsson, H., 1979, Glaciers in Iceland: Jokull, v. 29, p. 74-80.

Fritz, J. S., and Yamamura, S. S., 1955, Rapid microtitration of sulfate: Analytical Chemistry, v. 27, p. 1461-1464.

Gunnlaugsson, E., and Arnorsson, S., 1980, Sampling and analytical methods for geothermal fluids and gases: United Nations geothermal training program, Iceland.

Hauksson, T., 1980, Leidbeiningar um notkun a carle AGC III H, gasgreini: National Energy Authority TH-81/03, Reykjavik, Iceland.

## REFERENCES CITED--continued

Icelandic Meteorological Office, 1939-1979, The annual reports, from 1939 to 1979 (vedrettan) of the Icelandic Meteorological Office: Reykjavik, Iceland.

James, R., 1962, Steam-water critical flow through pipes: Proceedings of the Institute Mechanical Engineering, London 176, p. 741-745.

Skougstad, M. W., Fishman, M. J., Friedman, L. C., Erdmann, D. E., and Duncan, S. S., 1979, Methods for determination of inorganic substances in water and fluvial sediments: U.S. Geological Survey Techniques of Water-Resources Investigations Book 5, Chapter A-1, 626 p.

Tabatabai, M. A., 1974, Determination of sulphate in water samples: Sulphur Institute Journal, v. 10, no. 2, p. 11-13.