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1983 and 1984 DGGs GEOTHERMAL FLUIDS SAMPLING AND WELL
LOGGING AT THE MAKUSHIN GEOTHERMAL AREA

By

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1983 and 1984 DGGs Geothermal Fluids Sampling and Well-logging at the
- Makushin Geothermal Area

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INTRODUCTION

This report presents preliminary results of DGGGS geothermal fluid and mineral alteration investigations conducted on the Makushin geothermal area during the 1983 and 1984 field seasons. The report focuses primarily on the sampling and analyses of thermal fluids from test-well ST-1 and on the logging of core from the test-well and the thermal gradient holes. Also included are updated tables of geochemical data on fumaroles, thermal springs, and cold waters. The report is intended for rapid interagency transfer of data and information. Interpretive discussions are therefore kept brief and are considered preliminary. The format is informal with rough drafted figures and tables and a minimum of references.

Under the provisions of the FY-85 RSA extension agreement with the Alaska Power Authority, DGGGS primary responsibilities were to be:

- 1) The sampling and analysis of fluids encountered during the deepening of ST-1;
- 2) Shipment of rock core from thermal gradient hole A-1 and from ST-1 from Unalaska to Fairbanks.

The first task could not be carried out because of APA's decision not to deepen ST-1. The second task was accomplished for core retained from A-1. Approximately 1,860 ft of rock core was shipped and is being temporarily stored at the DGGGS Fairbanks Warehouse.

In the RSA agreement, DGGGS also stated its intent to perform several additional tasks if time and funding were available:

- 1) Sampling and analyses of thermal fluids from ST-1 during the terminal stages of the 40-day flow test of ST-1: this task was accomplished during the week of August 1-8, 1984. Description of

the sampling procedures and preliminary results of analyses are presented in this report.

- 2) Trace element analyses of volcanic rocks associated with Makushin area magmatic systems: funds for this task have not become available and it is probable that trace element information will not be included in our final report to APA. It is our intent to standardize and calibrate our in-house X-ray fluorescence unit for trace element research. Results from this effort, however, are unlikely to be available until late next spring.
- 3) Compilation and interpretation of available volcanic rock geochemical data: analyses of whole rock geochemical data is currently underway and should be available for our final report.
- 4) X-ray and petrographic identification of hydrothermal alteration mineralogy in rock cores obtained from drilling: this task has been accomplished for thermal gradient holes B1, E1, and I1 and for test-well ST-1. Lack of funding has limited investigation of core from A-1 to hand specimen analyses with only minimal thin-section and X-ray work.
- 5) Production of a geologic plate showing lithologic logs and alteration mineralogy of core from ST-1 and thermal gradient holes. This has been accomplished for D1, E1, I1, and ST-1 and has been published as a Report of Investigation which is included as Appendix A of this report. Hand specimen log and discussion of alteration mineralogy in A-1 are presented in this report.

GEOHERMAL FLUIDS FROM ST-1

Introduction

DGGS undertook the sampling of geothermal fluids from test-well ST-1 as part of an overall geothermal exploration drilling program at Unalaska Island funded by the State of Alaska. The program is administered by the Alaska Power Authority with Republic Geothermal, Inc. of California the prime contractor. Fluid sampling by DGGS was accomplished through the helpful cooperation of both these organizations.

Test-well ST-1 is located near the head of Makushin Valley (fig. 1). The wellhead sits upon the upper edge of an apron of pyroclastic debris that fills the bottom of upper Makushin Valley (Nye and others, 1984). Except for the top 10 meters which are composed of pyroclastics, ST-1 penetrates a gabbro-noritic pluton to a depth of 1,946 ft (Queen, 1984). The production zone for the well is an approximately 3 foot wide open fracture at the bottom of the hole. Bottom hole temperatures during the 1983 and 1984 flow tests were measured to be 193°C by RGI scientists. A static hole temperature check made July 2, 1984 by RGI gave a bottom hole temperature of ~202°C with a maximum temperature of ~204°C occurring at the 1,600 foot depth. Water table in the system as estimated from down-hole pressure measurements appears to lie between 750 and 800 feet below the surface.

Samples of fluids produced from the test-well were collected both in 1983 and 1984. The majority of the samples are of fluids from the major production zone at 1,946 foot depth. These samples were obtained between 8/27/83 and 9/3/83 and between 8/1/84 and 8/7/84. The test-well was closed from 9/3/83 until 7/4/84, then run nearly continuously until shut-down on 8/8/84.

Objectives of the geothermal fluids investigations include:

- 1) Characterization of reservoir water and gas chemistry.
- 2) Determination of potential scaling and environmental pollution problems.
- 3) Provision of pre-development geochemical data base.
- 4) Study of fluid-mineral equilibria.
- 5) Information on deeper reservoir characteristics and origin of chemical constituents in reservoir waters.
- 6) Geothermometry.
- 7) Mixing relationships.
- 8) Comparison of isotopic and chemical composition of reservoir fluids to neighboring fumaroles and springs.
- 9) Research data base for understanding Aleutian-arc type hydrothermal systems.

With regard to the latter, the Makushin hydrothermal system is the first in the Aleutian-arc to be successfully drilled and produce thermal fluids at temperatures above atmospheric boiling.

Sampling Procedures

Samples of gases and waters from test-well ST-1 were collected using a Webre type mini-cyclone separator. Design and use of the separator are described in Nehring and Truesdell, 1983. The separator was attached off the side of exhaust manifold at a point about 15 feet from the wellhead and several feet before the throttling orifice. Separator pressure was monitored with a high pressure gauge located before the separator's water exhaust valve. Fluid collection pressures and temperatures together with sampling dates and steam fractions are given in table 1.

The separator was first adjusted for collection of the water fraction. Fluids emerging from the water exhaust port of the separator were routed through a condensing coil immersed in an ice bath, then collected and filtered through 0.45 micron filters. The sample suite normally consisted of 1 liter filtered untreated, 1 liter filtered acidified (HCl), 1 liter filtered and treated with formaldehyde for ^{18}O - SO_4 determinations, 100 ml of water at a dilution of 1:10 and 1:5 for silica determinations, 1 liter of untreated water for tritium determinations, and 30 ml of water for stable isotope determinations. In addition, raw untreated samples were collected for in-field determination of HCO_3 , pH, H_2O , and NH_3 . In two cases (samples 77 and 02), waters were filtered through 0.1 micron filter and treated in the field for Al analysis following methods described by Presser and Barnes, 1974.

As an additional check on chemistry, water samples were collected from the end of the exhaust manifold. This was done by placing a bucket beneath the pipe-end and allowing the flashed water to flow into the bucket.

Steam and gas samples were then collected after first adjusting the separator for pure steam phase flow. The steam and gases were routed through the condensing coil then collected in sodium hydroxide charged evacuated flasks. Additional samples were collected in uncharged evacuated flasks for $^3\text{He}/^4\text{He}$ analyses. A 500 ml sample of the steam condensate was collected for Cl analyses as a check against water phase contamination. 30 ml samples of the condensate were also collected for stable isotope analyses.

Methods of Analyses

Water: HCO_3 , pH, H_2S , and NH_3 were determined in the field following methods described in Presser and Barnes (1974). The remaining constituents were analyzed at the DGGG Geothermal Fluids Laboratory in Fairbanks. Major and minor cation concentrations were determined using a Perkin-Elmer atomic absorption spectrometer following standard procedures. Sulfide and bromide were determined on a Dionex ion chromatograph. Fluoride was determined using the specific ion electrode methods. Chlorides were analyzed by Mohr titration and boron, by carminic acid method. Aluminum, arsenic, and iron were determined by atomic absorption spectroscopy. Silica concentrations were determined by the molybdate blue method.

Stable isotopes ($^{18}\text{O}/^{16}\text{O}$ and D/H) were analyzed at Southern Methodist University, Dallas, Texas and at U.S. Geological Survey, Menlo Park, California. Tritium concentrations were determined at the University of Miami, Miami, Florida.

Gases: Residual gases, i.e., gases not absorbed in the sodium hydroxide solution (He , H_2 , Ar , O_2 , N_2 , and CH_4) were analyzed on a dual-column gas chromatograph with both argon and helium carrier gases at the U.S. Geological Survey, Menlo Park, California. Moles of residual gas were calculated from measured gas pressure and head space volume. Carbon dioxide and hydrogen sulfide concentrations in the sodium hydroxide solutions were determined by titration and by ion chromatography respectively.

Concentrations of these gases were also checked by gravimetric methods using SrCl_2 and BaCl_2 to precipitate SrCO_3 and BaSO_4 . The SrCO_3 precipitate was then reacted with phosphoric acid to determine CO_2 yield. The evolved gas was saved and analyzed for $^{13}\text{C}/^{12}\text{C}$. Steam content

of the gases was determined by weight difference before and after sampling. Ammonia was analyzed by specific ion electrode method.

Adjustments were made for head space gases dissolved in the solution using Henry's Law. Moles of each constituent collected were then determined and mole % of each constituent was calculated. A correction was then made for air contamination by using the ratio of oxygen in the sample to oxygen in air. The gas concentrations in mole % were then recalculated on an air-free basis.

Helium isotope ratios ($^3\text{He}/^4\text{He}$) were determined at the Scripps Institute of Oceanography, La Jolla, California. Carbon isotope ratios in carbon dioxide ($^{13}\text{C}/^{12}\text{C}$) were analyzed at U.S. Geological Survey, Menlo Park, California.

Results

The results of the geochemical and isotopic analyses of the geothermal fluids from ST-1 are presented in tables 2 through 17. New analyses and updates of previous analyses of waters and gases from fumarole fields, hot springs and cold waters in the Makushin geothermal area are given in tables 18 through 30.

Waters: Reservoir water chemistry calculated from separator conditions are given in tables 4 and 5. The reservoir chemistry calculated from exhaust water analyses gives concentrations of constituents 10 to 15 percent higher than separator values if the exhaust water fraction is calculated on the assumption of atmospheric pressure-boiling point conditions. D. Michaels (pers. comm., RGI, 1984) however believes flashing at the exhaust end occurs to pressures well-below atmospheric. Supporting evidence comes from a

temperature measurement made by P. Parmentier (RGI) of the center of fluid flow from the exhaust. The temperature measured was $\sim 60^{\circ}\text{C}$ indicating that low-pressure effects that are not yet well understood is causing increased flashing of the exhaust fluid. Using the 60°C temperature as the end point results in an exhaust-end water fraction of 0.75. Applying this water fraction to exhaust chemistry gives results in close harmony with those obtained from the separator chemistry.

Additional support for basing reservoir chemistry on the analysis of the separator water fraction comes from RGI's reported analyses of 1983 ST-1 water samples. Two of their samples were obtained under high-pressure conditions using a technique entirely different than DGGS used. These high pressure water samples yielded results nearly identical to DGGS results when back-calculated to reservoir conditions (RGI, 1983, pg. XII).

The reservoir waters can be characterized as moderately saline low-bicarbonate waters. Comparison of 1983 to 1984 chemistry show the waters to be nearly identical; the 1984 waters are slightly less saline and slightly richer in HCO_3 . The reservoir waters are high in arsenic which may pose a potential water pollution problem.

Using the average back-calculated isotopic composition (table 8) the reservoir waters appear to be shifted approximately 1.5 to 2.0 mils with respect to meteoric waters.

The results of applying geothermometers based on water chemistry and isotopic composition to the Makushin reservoir waters are given in tables 9, 10, and 11. Silica concentration appears to be slightly out of equilibrium with quartz at the measured flowing bottom hole temperature (BHT) of 193°C but is near equilibrium with quartz at the measured maximum static BHT of 204°C .

Since the host rock is a gabbro-norite the basaltic Na/K geothermometer of Arnorsson (1983) is probably the most applicable of the Na/K geothermometer. The results of this geothermometer are in close agreement with the Na-K-Ca geothermometer of Fournier and Truesdell (1973). These cation geothermometers suggest that either the system is out of equilibrium or that the waters were warmer and have cooled before entering the borehole. Cooling could come about either by conduction or mixing of cooler waters or combination of both processes.

The $^{18}\text{O}/^{16}\text{O}$, $\text{SO}_4\text{-H}_2\text{O}$ geothermometer of McKenzie and Truesdell (1977) predict even higher reservoir temperatures. Using the reservoir isotopic value for $^{18}\text{O}/^{16}\text{O}$, gives reservoir temperatures of 245-250°C.

Gases: Air corrected analyses of gases in mole per cent are given in table 12. Gas content in total discharge and partial pressure of CO_2 in the reservoir are given in tables 13 and 14 respectively. Of the 1984 gas samples, MVTW-2G-B is the least air contaminated and its analyses is considered the most reliable and representative of the geothermal system. Inspection of the gas tables shows a slight decline in the overall concentration of gases in the total mass discharge between 1983 and 1984. Hydrogen content appears to have dropped significantly, nearly an order of magnitude since the well was first opened in 1983. Methane concentration appears to have also dropped and was present in only trace amounts in the 1984 samples.

Overall gas concentrations in the reservoir fluid is extremely low, 0.02 % of total discharge. Hydrogen sulfide, although 2 to 2.5 % of the total gases on a steam-free basis, is in such low concentration in the overall discharge it should not pose any significant health hazard or pollution problems.

Application of three different gas geothermometers to the ST-1 gas analyses is given in table 15. In the majority of cases the three thermometers agree quite closely with temperature estimates varying between 190°C and 250°C. The majority of estimates, however, fall between 210 and 225°C which is in fairly close agreement with the cation geothermometers. Note that for cases in which CH₄ concentration is not known, a valve of 0.001 was used in the D'Amore-Panichi geothermometer.

Carbon isotope analyses given in table 16, show a drop of 1.7 mil in ¹³C composition of CO₂ between 1983 and 1984. The ¹³C values of -13 to -15 suggest a possible organic-sedimentary origin for CO₂ in the geothermal system.

With the exception of a brief comment on gas geothermometry, the tables of data on chemistry and isotopic composition of fumarolic gases, thermal spring waters, and cold waters (tables 18 through 20) are presented here without comment. Discussion of much of this data can be found in Motyka and others, 1983.

The gas geothermometer of D'Amore and Panichi applied to analyses of fumarole gases is given in table 26. Temperatures T1 were calculated using a partial pressure of CO₂ equal to one bar as per instructions in D'Amore and Panichi, 1980. Temperatures T2 were calculated using a partial pressure of 0.5 bar, approximately that found at ST-1. From comparison of the two temperatures it is apparent that the geothermometer is quite sensitive to CO₂ partial pressure. However, even the T2 temperatures average about 20°C lower than the T1 temperatures, in many cases the temperatures are still substantially higher than temperatures found at ST-1. This is particularly true for fumaroles in field #3, suggesting either that the D'Amore-Panichi geothermometer is not accurate when applied to fumaroles or that the system is much hotter at the head of Glacier Valley.

DESCRIPTION OF CORE FROM A-1

Rock Units

A preliminary log of core from drill hole A-1 is given in Appendix B. The rocks from the core can be divided into three basic units. The unaltered volcanics, the Unalaska Formation, and the gabbro-hornfels complex: the unaltered volcanics are present at the surface and extend to a depth of 122 ft. This unit includes surface ash and cinders, andesite flows and a basal lahar. These rocks are Quaternary in age and are essentially unaltered except for surface weathering.

The Unalaska Formation includes the Unalaska clastics and the Unalaska volcanics. Both are metamorphosed to lower greenschist facies and are similar in composition and permeability. The Unalaska Formation extends from 122 ft to about 1,620 ft. There are two minor gabbro dikes in this interval. One from 458-478 ft and the other from 942 to 1,020 ft. The former lacks a hornfels envelope and the latter has only a minor hornfels aureole.

The gabbro-hornfels complex extends from 1,620 ft to the bottom of the hole at 1,864 ft. From 1,620-1684 the complex consists of gabbro dikes cutting hornfelsed Unalaska Formation. Below this the well appears to intersect the pluton proper.

Alteration

The alteration pattern observed in A1 is, in general, consistent with the present temperature profile. In addition, the changes in the alteration

appear to mark changes in the fluid composition of the different portions of the reservoir. Only in the lower portions of the core are alteration assemblages indicative of higher temperatures present.

The upper 122 ft of the core consists of unaltered Quaternary volcanics. Below these, down to about 400 ft, the alteration is argillic. This clay-bearing alteration is indicative of low to moderate temperature, acidic waters. These conditions are typical of surface weathering and steam dominated portions of the geothermal system.

From 400 ft down to approximately 900 ft the alteration consists of bladed calcite, amorphous silica, pyrite and some clay. Much of this alteration is localized around the breccia zones which mark this section. The noted assemblage was shown to be related to boiling of low salinity, near-neutral waters in the Yellowstone area. The temperature profile is isothermal, at about 100°C, through this section indicating it is likely a zone of steam.

Below 900 ft the boiling related assemblage is replaced by "dogs-tooth" calcite, quartz, anhydrite, and zeolites. Pyrite, while still present, is less abundant. These changes result from an increase in temperature and a cessation of boiling (due to increased pressure). The fluids depositing these minerals are likely slightly saline and near neutral. The presence of zeolites (mordenite to about 1,200 ft and laumontite from 1,500-1,780 ft) indicates that the CO₂ partial pressure is low.

While zeolites are somewhat indicative of temperature they are not abundant in this core. However, the presence of laumontite at 1,780 ft indicates that since its deposition the temperature at this depth has not exceeded 200°C.

While most of the alteration can be assumed to reflect current condition, there are some veins present which seem to be relicts of an earlier, hotter stage of geothermal activity. These veins have an assemblage of epidote + anhydrite + magnetite + calcite. The theoretical stability limits of this assemblage exceeds the current bottom hole temperature of this well.

The veins are locally cut by younger veins indicating they are not in equilibrium with the present system. The veins bearing the assemblage occur from 1,100 ft to the bottom of the hole. Similar veins occur in E1 and ST-1.

FLUID INCLUSION STUDIES.

Fluid inclusions in hydrothermal quartz from cores E1 and ST-1 have been examined on a heating-cooling stage to determine fluid compositions and homogenization temperatures. The fluid compositions agree well with the current reservoir conditions as indicated by waters sampled from ST-1. All the inclusions measured indicate a freezing point depression of between -0.1 and -0.7°C . The mean depression is -0.35°C . This gives a composition of approximately 6,200 ppm NaCl equivalent, thus it seems that the fluid composition has not varied greatly with time.

The homogenization temperatures indicate the temperature at which the mineral enclosing the fluid inclusion formed and thus give the past temperature of the system. The mean temperatures measured are consistently $80-100^{\circ}\text{C}$ higher than the current temperature at the depth from which the sample was recovered. Some samples exhibit a systematic decrease in temperature indicating that the higher temperatures represent an earlier stage of the present system. The lack of abundant fluid inclusion at the

present thermal gradient indicates that the system is either not depositing minerals or has not been at the current state for a geologically significant amount of time.

DISCUSSION OF OTHER PRELIMINARY RESULTS

Evidence gathered from geologic mapping and detailed study of volcanic stratigraphy indicate massive fluxes of magma passed through the crust and were erupted onto the surface in the period between the end of the Wisconsin Glaciation (10,000 yrs ago) and about 6,000 yrs, the time of a neoglacial advance. Heat transferred from this magma to the shallow crust during its ascent and heat from residual magma emplaced in the shallow crust during this episode may be the source of heat driving the present day hydrothermal system at Makushin.

Evidence for a recent and rapid change in water table and cooling of the upper part of the Makushin geothermal system continues to mount:

- 1) Alteration mineral assemblages and trace-element geochemistry found in the rock cores indicate a hot-water system existed nearly to the present day surface in the very recent past.
- 2) Evidence of fossilchloride thermal springs on neoglacial moraines in the upper part of Glacier Valley also indicates a hot-water system reached the surface in recent times.
- 3) Present-day water table depth, as determined from drill-holes, lies at a depth of 750-800 feet below the surface in upper Makushin Valley. Thus, a vapor-dominated zone presently extends, from this depth to the surface.

- 4) Fluid inclusion studies on vein-deposited quartz and anhydrite geothermometry indicate temperatures in this upper zone were 50 to 100°C hotter than present-day temperatures.
- 5) The fluid inclusion studies also indicate the waters from which the quartz veins were precipitated had a salinity nearly the same as the present-day hydrothermal system.

Our working hypothesis to explain these phenomena is that the elevated temperatures recorded by the fluid inclusions were the result of an increase in hydrostatic pressure caused by ice-loading during a neoglacial advance. Fluid inclusion temperatures indicate hydrostatic head would have to have been 300 meters higher than the present-day surface at ST-1. This head could easily have been supplied by a valley glacier. Subsequent deglaciation would decrease the pressure rapidly causing boiling in the upper zone of the hydrothermal system. A net loss of water from the boiling and perhaps from decrease of recharging glacier meltwater would cause the water table to drop.

The drop in temperature in the upper part of the system then, may reflect an episode of intense boiling and water loss rather than overall cooling of the system. If so, then the deeper part of the hydrothermal system might still be expected to be at temperatures similar or greater than the fluid inclusion temperatures found in the upper part of the system. The sulfate-water isotope geothermometry does predict a maximum reservoir temperature of ~250°C which is similar but lower than fluid inclusion temperatures.

The question of whether or not the Makushin geothermal system is in retrograde (i.e., cooling) is important for estimating the geothermal energy potential of the area and its future development.

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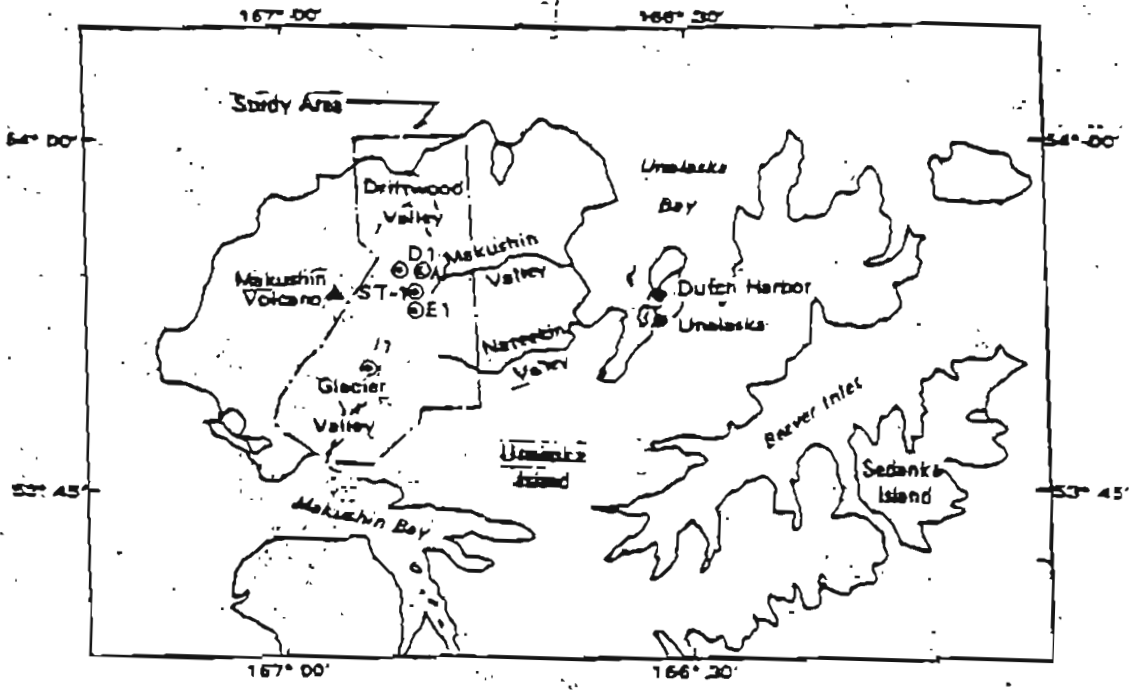


Figure 1. Well locations, Makushin geothermal area.

Table 1. Fraction of Steam Separated from Flashed Well Fluids¹

Sample #	Date	Time ²	Collection Pressure, Bars ³	Collection Temperature, °C ⁴	Steam Fraction ⁵
71	8-27-83	(+1.5 hr)	2.00	120	0.144
74	9-1-83	17:30	3.17	135.5	0.116
75	9-2-83	10:10	3.03	134	0.119
76	9-2-83	16:20	4.48	147.5	0.093
77	9-3-83	19:50	4.55	147.5	0.092
84-1	8-4-84	15:00	2.65	129.5	0.127
84-2	8-7-84	13:00	2.79	131	0.124

1. Fluids collected using Webre type mini-cyclone separator.

2. Parenthetical value for 71 is the time elapsed after initial discharge from fracture zone at 1946' depth. Well was then shut-off until 9-1-83. Well was re-opened at 14:40, 9-1-83 and was run continuously until about 22:00, 9-3-83. Well was re-opened again on 7-4-84 and run nearly continuously until 8-8-84.

3. At the separator. These are absolute values calculated from gauge pressure plus atmosphere pressure which was assumed to be 0.96 bars.

4. Determined from the collection pressure assuming liquid-vapor equilibrium (Keenan et al., 1969).

5. Steam fraction calculated using a BHT=193°C and reservoir enthalpy value of 821 kJ/kg (Keenan et al., 1969).

Table 2. Chemical analyses of waters collected from Hakushin Valley test well ST-1, 1983.
(Concentrations in mg/l unless otherwise specified).

Cations	From Weber-separator ^b				Off End of Exhaust				
	71	74	75	76	77	76	75	76	77
Na	7120	2070	2010	1900	2010	2400	2470	2420	2460
K	270	280	270	250	250	180	310	300	310
Ca	150	139	140	178	146	175	175	175	181
Mg	0.2	0.1	0.1	0.1	0.1	0.3	0.2	0.2	0.2
Li	11	11	11	10	10	14	13	13	13
Str	2.4	2.3	2.8	2.5	2.6	3.1	3.3	3.3	3.1
Cl	1.4	1.4	1.4	1.4	1.4	1.6	nd	nd	nd
NO ₃	nd	nd	nd	nd	< 1	nd	nd	nd	nd
Total ^c	108.5	103.5	103.0	97.0	102.6	145.6	126.0	123.7	125.7
Anions									
HCO ₃	< 5	< 5	< 5	< 5	< 1.0	< 5	nd	nd	nd
SO ₄	91	86	85	77	80	190	nd	nd	nd
F	1.2	1.2	1.2	1.0	1.0	1.6	nd	nd	nd
Cl	3670	3540	3500	3230	3370	4870	4240	4200	4220
Br	14	13	12	12	13	19	nd	nd	nd
Total ^c	105.7	101.8	100.6	93.0	96.9	141.8	119.7	118.5	119.1
Balance ^c	2.6	1.7	2.4	4.2	5.7	2.7	5.2	4.3	5.4
SIO ₂	740	335	340	306	323	450	395	602	395
SiO ₂ B	nd	7.7	1.5	nd	nd	nd	nd	nd	nd
Fe	68	64	65	59	62	86	76	77	78
Al	nd	nd	nd	nd	0.02	nd	nd	nd	nd
Am	12	11	13	12	12	16	15	15	15
Fe	nd	nd	nd	nd	0.13	nd	nd	nd	nd
TDS ^d	6760	6500	6450	5990	6280	9070	---	---	---
pl, field ^e	8.1	8.0	7.8	7.6	7.9	7.8	nd	nd	nd
Date									
Sampled	8/27/83	9/1/83	9/7/83	9/2/83	9/3/83	8/24/83	9/1/83	9/2/83	9/3/83

a) Alaska Division of Geological and Geophysical Surveys, Fairbanks, M.A. Moorman and R.J. Motyka, analysts.

b) Sampling conditions and steam fraction given in Table 1.

c) Cation and anion totals in milliequivalents/liter.

d) Calculated.

e) Sample 64 measured at 1-50°C; all others measured after cooling to 15°C.

nd= not determined

Table 3. Chemical analyses of waters collected from Makushin Valley test well ST-1, 1984.^a (Concentrations in mg/l unless otherwise specified).

	From Webre-separator ^b		Off end of exhaust	
	1W	2W	1E	2E
Cations				
Na	1910	1930	2290	2290
K	260	250	300	310
Ca	129	133	155	149
Mg	0.2	0.2	1.3	0.6
Li	10	10	12	11.5
Sr	2.7	2.7	3.2	3.2
Cs	1.4	1.3	1.6	1.5
NH ₄	< 1	< 1	nd	nd
Total^c	97.6	98.5	116.9	116.7
Anions				
HCO ₃	26	12	nd	nd
SO ₄	95	97	115	112
F	1.2	1.2	1.4	1.4
Cl	3480	3500	4180	4170
Br	12	12	14	14
Total^c	100.9	101.3	120.5	120.2
Balance^z	-3.3	-2.8	-3.1	-3.0
SiO ₂	—	328	397	384
H ₂ S	< 1	1	nd	nd
B	—	67	78	79
Al	nd	0.004	nd	nd
As	12	11	15	14
Fe	0.26	0.20	0.32	0.24
TDS^d	nd	6360	7560	7540
pH, field^e	7.7	7.6	nd	nd
Date				
Sampled	8/4/84	8/7/84	8/4/84	8/7/84

a) Alaska Division of Geological and Geophysical Surveys, Fairbanks, R.J. Motyka and M.A. Moorman, analysts.

b) Sampling conditions and steam fraction given in Table 1.

c) Cation and anion totals in milliequivalents/liter.

d) Calculated.

e) pH measured after waters cooled to 15°C.

nd= not determined

Table 4. Chemical analyses of 1983 waters from Makushin Valley test well ST-1, corrected to reservoir conditions. (Concentrations in mg/l unless otherwise specified).

	71	74	75	76	77	Average
Cations						
Na	1820	1780	1780	1730	1820	1790
K	230	250	240	230	230	240
Ca	128	123	124	116	131	124
Mg	0.2	0.1	0.1	0.1	0.1	0.1
Li	9	9	10	9	9	9
Sr	2.1	2.0	2.5	2.3	2.4	2.3
Cs	1.2	1.2	1.2	1.3	1.3	1.2
NH ₄	nd	nd	nd	nd	1.0	1.0
Anions						
HCO ₃	< 5	< 5	< 5	< 5	< 1.0	< 5
SO ₄	78	76	75	70	73	74
F	1.0	1.1	1.1	1.1	0.9	1.0
Cl	3140	3130	3080	2930	3060	3070
Br	12	11	11	11	12	11
SiO ₂	294	296	300	278	293	292
H ₂ S	nd	2.4	1.3	nd	nd	1.9
B	58	57	57	54	56	56
Trace						
Al	nd	nd	nd	nd	0.02	0.02
As	11	10	11	11	11	10.5
Fe	nd	nd	nd	nd	0.12	0.12
TDS	5790	5750	5680	5430	5700	5670
Date Sampled	8/27/83	9/1/83	9/2/83	9/2/83	9/3/83	

nd = not determined

Table 5. Chemical analyses of 1984 waters collected from the Makushin Valley test well SF-1, corrected to reservoir conditions.
(Concentrations in mg/l unless otherwise specified).

	<u>1W</u>	<u>2W</u>	<u>Average</u>
Cations			
Na	1670.	1690.	1680.
K	230.	220.	225.
Ca	112.	116.	114.
Mg	0.2	0.2	0.2
Li	9.	9.	9.
Sr	2.3	2.4	2.4
Cs	1.2	1.1	1.2
NH ₄	< 1.	< 1.	< 1.
Anions			
HCO ₃	23.	11.	17.
SO ₄	83.	85.	84.
F	1.0	1.1	1.1
Cl	3040.	3070.	3060.
Br	10.	10.	10.
SiO ₂	nd	287.	287.
H ₂ S	nd	1.	1.
B	nd	59.	59.
Al	nd	0.004	0.004
As	10.	10.	10.
Fe	0.23	0.18	0.2
TDS	--	5570.	5570.
Date			
Sampled	8/4/84	8/7/84	

nd= not determined

Table 7. Makushih Valley test well ST-1, Oxygen and deuterium isotope analyses - steam and water. (Parts per mil with respect to SMOW).

Sample #	USGS	Date	Water			Steam		
			D/H (SMU)	$^{18}\text{O}/^{16}\text{O}$ (SMU)	$^{18}\text{O}/^{16}\text{O}$ (USGS)	D/H (SMU)	$^{18}\text{O}/^{16}\text{O}$ (SMU)	$^{18}\text{O}/^{16}\text{O}$ (USGS)
71	1	8/27/83	-79	-9.7	-9.2	-97	-13.9	-13.45
74	2	9/1/83	-77	-10.05	-9.5	-90	-13.2	-13.05
75	3	9/2/83	-77.5	-9.95	-9.6	-90	-13.2	-13.05
76	4	9/2/83	-77.5	-8.4	-9.6	-87.3	-13.15	-12.85
77	5	9/3/83	-77.6	-9.8	-9.6	-88.3	-13.1	-13.0
84-1		8/4/84	-66	-10.25	-	-86	-11.25	-
84-2		8/7/84	-81.5	-9.95	-	-90	-12.3	-

SMU = Southern Methodist University, Stable Isotope Laboratory, R. Harmon and J. Borthwick, analysts.

USGS = U.S. Geological Survey, Menlo Park, C. Janik, analyst.

Table 8. Makushin Valley test well ST-1, stable isotope analyses corrected to reservoir conditions. (Parts per mil with respect to SMOW).

	<u>71</u>	<u>74</u>	<u>75</u>	<u>76</u>	<u>77</u>	<u>Average</u>
D/H (SMU)	-81	-78.5	-79	-78.5	-78.5	-79
$^{18}\text{O}/^{16}\text{O}$ (SMU)	-10.3	-10.4	-10.3	(-8.8) ^a	-10.1	-10.3
$^{18}\text{O}/^{16}\text{O}$ (USGS)	-10.2	-9.9	-10.0	-9.9	-9.9	-10.0
<u>1984</u>	<u>84-1^b</u>	<u>84-2</u>				
D/H (SMU)	-69	-83				
$^{18}\text{O}/^{16}\text{O}$ (SMU)	-10.4	-10.2				

a) Suspect value; not used in computing average.

b) A large amount of chloride was detected in the 84-1 condensate indicating incomplete separation. Values for this sample are therefore not considered to accurately represent reservoir isotope composition.

Table 9. Geothermometry for Wehre separator waters from Makushin Valley test well ST-1 corrected for reservoir conditions. (Temperatures in °C).

Sample #	Date	Qz. cond (1)	Chal. cond (2)	Na/K (3)	Na/K (4)	Na/K (5)	Na-K-Ca (6)	Na/1.1 (7)
RM83-71	8-27-83	208	191	240	216	222	224	193
RM83-74	9-01-83	208	192	247	226	231	229	194
RM83-75	9-02-83	209	193	243	221	227	227	196
RM83-76	9-02-83	203	186	241	218	224	225	194
RM83-77	9-03-83	208	191	238	213	220	223	193
RM84-01	8-04-84	nd	nd	245	223	229	227	194
RM84-02	8-07-84	206	189	240	217	223	224	193

(1) Fournier, 1983, Improved SiO₂.

(2) Fournier, 1983, Improved SiO₂.

(3) Fournier, 1981, Na/K.

(4) Truesdell, 1976, Na/K.

(5) Arnorsson, 1983, Na/K, Basalt.

(6) Fournier & Truesdell, 1973.

(7) Fournier & Richard, 1981.

Table 10. Geothermometry for exhaust pipe waters from makushin Valley test well ST-1 corrected for reservoir conditions assuming 60 °C end point flash temperature. (Temperatures in °C).

Sample #	Date	Qz. cond (1)	Chal. cond (2)	Na/K (3)	Na/K (4)	Na/K (5)	Na-K-Ca (6)	Na/Li (7)
RMBJ-64	8-24-83	218	204	238	214	220	224	191
RMBJ-74	9-01-83	208	191	(193) ^a	(157) ^a	(166) ^a	(190) ^a	194
RMBJ-75	9-02-83	208	192	236	211	218	222	193
RMBJ-76	9-02-83	210	193	236	212	218	222	196
RMBJ-77	9-03-83	208	192	237	213	219	222	195
RMB4-01	8-04-84	209	192	241	218	224	225	192
RMB4-02	8-07-84	206	189	244	222	228	228	189

(1) Fournier, 1981, Improved SiO₂.

(2) Fournier, 1983, Improved SiO₂.

(3) Fournier, 1981, Na/K.

(4) Truesdell, 1976, Na/K.

(5) Arnorsson, 1983, Na/K, Basalt.

(6) Fournier & Truesdell, 1973.

(7) Fournier & Richard, 1981.

(a) Potassium analysis anomalously low.

Table 11. Sulfate-water 180/160 isotope temperatures, Makushin Valley test well, ST-1.^a

Sample #	Date Collected	Temp sep, °C	180/160-SO ₄ , WRT SMOW	180/160-H ₂ O, WRT SMOW at sep	180/160-H ₂ O, WRT SMOW, res	T1, °C ^c	T2, °C ^d
MVTW-74	9-01-83	135	-3.8	-9.5	-9.9	245	256
MVTW-75	9-02-83	134	-3.4	-9.6	-10.0	235	245
MVTW-76	9-02-83	148	-3.4	-9.6	-9.9	235	248
MVTW-77	9-03-83	148	-3.3	-9.6	-9.9	235	244
MVTW-1W	8-04-84	130	-3.9	-10.3 ^b	-10.4 ^b	230	246
MVTW-2W	8-07-84	131	-3.6	-10.0 ^b	-10.2 ^b	232	246

a) Isotope analyses performed at U.S. Geological Survey, Menlo Park, except as noted.

b) Analysis performed at Southern Methodist University, Stable Isotope Laboratory.

c) Temperature calculated using method described in McKenzie and Truesdell (1977) for the case of single-stop steam-loss. The separator water composition was used for 180/160 - H₂O.

d) Temperature calculated using the 180/160 - H₂O value determined for the reservoir water and the equilibrium fractionation equation of Mizutani and Rafter (1969): $1000 \ln \alpha = 2.88 (10^6/T^2) - 4.1$, T=°K.

Table 12. Makushin test well, air corrected gas analyses, mole %.

Sample Code	Date Sampled	RO2	Xg	CO2	H2S	H2	CH4	NH3	N2	Ar	N2/Ar	C/S
MVTW-1 DS/CJ	8-27-83	0.00	0.070	87.74	1.80	0.28	0.006	0.76	9.24	0.18	50.4	48.9
MVTW-2A DS/CJ	9-01-83	0.00	0.098	89.61	2.71	0.46	0.007	0.18	6.92	0.10	67.3	33.0
MVTW-3B DS/CJ	9-02-83	0.00	0.081	92.54	2.27	0.17	0.006	0.25	4.68	0.07	66.8	40.7
MVTW-4B DS/CJ	9-02-83	0.00	0.109	91.61	3.15	0.12	0.007	0.20	4.84	0.08	63.8	29.1
MVTW-5A DS/CJ	9-03-83	0.00	0.105	92.73	2.28	0.10	0.006	0.18	4.63	0.07	63.2	40.7
MVTW-1G-C RM/CJ	8-04-84	0.27	0.089	86.26	2.52	0.04	tr	0.46	10.57	0.15	70.5	34.2
MVTW-2G-A RM/CJ	8-07-84	0.50	0.056	85.94	2.52	0.06	tr	0.67	10.69	0.12	89.6	34.1
MVTW-2G-B RM/CJ	8-07-84	0.14	0.064	93.81	2.02	0.02	tr	0.30	3.77	0.07	51.7	46.3

DS/CJ = D. Sheppard, DSIR, New Zealand, and C. Janik, USGS, Menlo Park, analysts.

RM/CJ = R. Motyka, ADGGS, Fairbanks, and C. Janik, USGS, analysts.

Xg = Ratio, moles gas to moles steam in %.

RO2 = Ratio, oxygen in sample to oxygen in air.

Table 14. Partial pressure CO₂ in solution, reservoir conditions.

Sample #	Mole fraction CO ₂ in total fluid ^a	P CO ₂ , bars ^b
MVTW-1 DS/CJ	8.824E-05	0.57
MVTW-2A DS/CJ	1.019E-04	0.66
MVTW-3B DS/CJ	8.881E-05	0.58
MVTW-4B DS/CJ	9.323E-05	0.61
MVTW-5A DS/CJ	8.998E-05	0.58
MVTW-1G-C RM/CJ	9.739E-05	0.63
MVTW-2G-A RM/CJ	5.972E-05	0.39
MVTW-2G-B RM/CJ	7.446E-05	0.48

a) Computed from $CO_2 = \frac{XCO_2 Xg Xs}{1 + Xg Xs}$

where XCO_2 and Xg are the CO_2 and gas fractions from Table 8 and Xs is the steam fraction from Table 1.

b) Computed from the $PCO_2 = Kh CO_2$ where Kh is Henry's law constant (6500 bars/mole fraction at $T = 193^\circ C$).

Table 15. Gas geothermometers applied to Makushin test well.

Sample #	Date Sampled	T C (a)	T C (b)	T C (c)
MVTW-1 DS/CJ	8-27-83	228	212	220
MVTW-2A DS/CJ	9-01-83	250	222	227
MVTW-3B DS/CJ	9-02-83	217	216	222
MVTW-4B DS/CJ	9-02-83	213	223	223
MVTW-5A DS/CJ	9-03-83	204	216	222
MVTW-1G-C RM/CJ	8-04-84	218	220	225
MVTW-2G-A RM/CJ	8-07-84	216	211	199
MVTW-2G-B RM/CJ	8-07-84	190	212	213

(a) Gas geothermometer of D'Amore and Panachi, 1980.

(b) H₂S geothermometer of D'Amore and Truesdell, 198.

(c) CO₂ geothermometer of Arnorsson and others, 1983.

Table 16. Makushin Valley test well ST-1, Unalaska Island, Alaska, carbon isotope analyses, CO₂ in gas and steam.^a

<u>Sample #</u>	<u>Date Collected</u>	<u>T, °C Sep</u>	<u>δ¹³C_{PDB}</u>
MVTW-1	8/27/83	120	-13.3
MVTW-3	9/02/83	134	-13.5
MVTW-4	9/02/83	148	-13.3
MVTW-5	9/03/83	148	-13.3
MVTW-1G-C	8/04/84	130	-15.1
MVTW-2G-A	8/07/84	131	-15.0
MVTW-2G-B	8/07/84	131	-15.1

a) C. Janik, U.S. Geological Survey, Menlo Park, analyst.

Table 17. 180/160 in anhydrite obtained from test well core.^a

Depth, m(ft)	180/160 - CaSO ₄ , WRT SMOW	T °C, equil ^b .	
		(c)	(d)
148 (486)	-2.98	351	249
592.5 (1944)	-1.87	319	226
593.1 (1946)	-0.91	295	208

a) Analyzed at USGS, Menlo Park.

b) T °C, equil. = equilibration fractionation temperature assuming 180/160 for H₂O is -10.0, the current reservoir water value (USGS analysis).

c) Temperature computed using Lloyd (1968) fractionation equation:

$$1000 \ln \alpha = 3.88 (10^6)/T^2 - 2.90, T = \text{°K.}$$

d) Temperature computed using fractionation equation of Chiba and others (1981):

$$1000 \ln \alpha = 3.21 (10^6)/T^2 - 4.72, T = \text{°K.}$$

Table 18. Chemical analyses of sulfate-carbonate spring water in the Makushin geothermal area.^a
(Values in mg/l unless otherwise specified).

Well Name	Date	pH ^b	Na	K	Ca	Mg	Li	Sr	HCO ₃ ^b	SO ₄	F	Cl	SiO ₂	N	Fe	TDS	SC
NV-GA1	8-11-80	6.4	52	4.8	12	4.0	<0.01	0.1	37	129	0.1	10.0	94	<0.5	0.10	325	360
NV-Gd2	8-11-80	6.5	87	5.7	12	1	0.02	0.3	288	95	0.3	5.0	175	<0.5	<0.01	506	580
NV-Gd3	7-05-81	4.3	62	5.2	7.5	8.0	0.01	0.2	3	218	<0.1	6.1	120	<0.5	nd	447	9250
NV-Ge	7-05-81	nd	61	3.3	260	9.6	0.04	1.1	nd	491	0.3	2.3	138	<0.5	0.02	nd	1400
NV-Gf	8-11-80	6.1	78	4.5	nd	nd	nd	nd	nd	42	nd	10.0	125	nd	nd	nd	nd
NV-Gf	7-05-81	6.4	81	4.8	210	7.8	0.03	1.1	256	476	0.2	7.5	142	<0.5	0.21	1050	1200
NV-Gh	7-11-82	6.0	64	3.8	240	11	0.03	1.2	358	472	<1.0	5.8	145	<0.5	0.40	1120	1320
NV-Gj	7-10-82	6.1	53	3.4	280	11	0.03	1.4	332	581	<1.0	6.6	120	<0.5	0.70	1220	1430
NV-Gj	7-13-82	6.0	63	4.5	260	10	0.03	1.2	325	542	<1.0	6.6	135	<0.5	0.50	1190	1370
NV-Ha	7-17-82	6.0	54	9.0	65	13	0.02	0.3	nd	344	<1.0	nd	155	<0.5	2.5	nd	nd
NV-Hb	8-13-80	5.5	28	5.9	67	12	0.01	0.3	191	155	0.1	5.0	140	nd	0.09	508	600
NV-Hc	7-04-81	5.3	74	3.2	73	5.5	0.01	0.1	nd	25	0.1	7.0	80	<0.5	0.07	nd	250
NV-Hc	7-18-82	6.8	72	4.3	34	6.1	<0.01	0.1	201	15	1.0	7.9	105	<0.5	0.10	305	351
NV-Hd	8-13-80	5.3	14	3.4	23	8.0	0.01	0.1	116	21	0.1	5.0	88	nd	0.03	220	255
NV-Na	8-20-83	6.1	88	4.2	390	36	0.14	3.1	678	710	0.7	5.6	110	<0.5	nd	1680	nd

NV - Glacier Valley, NV - Makushin Valley, NV - Nuteckin Valley

a) Alaska Division of Geological and Geophysical Surveys, Fairbanks, Alaska. M.A. Hoorani, analyst.
b) Determined in the field.

Table 19. Chemical analyses of chloride spring waters in the Makushin geothermal area.^a
(Values in mg/l unless otherwise specified).

Site Name	Date	T ^b	pH ^b	Na	K	Cations			I.I	Sr	MgCO ₃ ^h	Anions			Cl	SiO ₂	R	Fe	TDS	SC
						Ca	Mg	SO ₄				F								
DV - ptrem	8-21-83	14	6.9	36	3	8.8	2	0.15	< 0.7	35	6	nd	56	43.6	0.7	nd	175	nd		
GV - Cm	7-20-82	39	5.9	180	19	200.0	15	0.48	1.1	463	360	< 1.0	160	113	4.2	1.7	1290	1380		
GV - Gm	7-20-82	27	5.8	180	19	180.0	23	0.40	1.0	563	320	< 1.0	140	119	4.0	1.9	1260	1760		
GV - Gp	7-20-82	40	6.3	300	31	160.0	39	0.86	1.4	590	180	< 1.0	380	104	9.9	2.1	1500	nd		

DV - Driftwood Valley, CV - Glacier Valley

^a) Alaska Division of Geological and Geophysical Surveys, Fairbanks, Alaska, M.A. Moorman, analyst.

^b) Determined in the field.

Table 20. Chemical analyses of cold waters in the Makushin geothermal area.^a
(Values in mg/l unless otherwise specified)

Site name	Date	T ^b	pH ^b	Cations							Anions				SI02	B	Aa	Fe	TDS	SC
				Na	K	Ca	Mg	Li	Sr	MG03 ^b	SO4 ^b	F	Cl	Br						
DV - stream	8-21-83	14	6.9	36	3.4	8.8	2.0	0.15	<0.1	35	6	nd	56	43.6	0.7	0.10	nd	175	nd	
CV - Cd spring	7-05-81	5	nd	4.7	0.8	8.9	1.9	<0.01	<0.1	nd	29	<0.1	5.6	20.0	<0.5	nd	nd	nd	100	
CV - Cd stream	8-11-80	7	6.0	78	4.5	nd	0.1	0.01	nd	nd	418	nd	10	125.0	nd	nd	nd	nd	nd	
CV - Ck spring	7-15-82	16	6.6	4.1	0.3	20	1.1	<0.01	0.1	38	27	<1.0	5.9	9.4	<0.5	nd	0.10	88	141	
CV - Cl stream	7-18-82	5	6.5	8.5	1.4	52	6.6	<0.01	0.1	13	150	<1.0	12	28.0	<0.5	nd	0.40	264	375	
CV - Cn spring	7-09-83	6	6.4	5.6	0.2	6.4	1.0	<0.01	0.2	26	4	nd	5.5	6.0	0.10	0.002	nd	42	nd	
CV - clear river mouth	7-19-83	7	6.4	7.5	0.5	53	1.8	0.01	<0.1	37	14	nd	8.8	16.2	0.02	0.001	nd	117	nd	
CV - kettle pond	8-19-86	nd	nd	1.9	0.1	0.5	0.3	<0.01	<0.1	nd	1	nd	2.0	3.0	0.04	<0.001	nd	nd	nd	
CV - muddy river mouth	7-19-83	5	6.5	6.3	0.7	12	2.2	0.01	0.1	11	36	nd	7.0	12.0	0.16	0.001	nd	82	nd	
MV - spring	7-19-82	6	6.6	2.6	0.2	1.8	0.6	<0.01	<0.1	11	3	<1.0	3.7	13.0	<0.5	nd	0.1	328	34	

DV = Driftwood Valley, CV = Glacier Valley, MV = Makushin Valley

^a Alaska Division of Geological and Geophysical Surveys, Fairbanks, M.A. Moorman, analyst.

^b Determined in the field.

Table 21. Stable isotope analyses of sulfate-carbonate spring waters in the Makushin geothermal area.^a

Site Name	Date	T	D/H ^b	18O/16O ^b
GV - Ga	7-05-81	nd	-83	-11.9
GV - Gb	7-05-81	nd	-80	-12.2
GV - Gc	7-05-81	nd	+83	-12.5
GV - Gd1	8-11-80	97	-70	-8.9
GV - Gd2	8-11-80	82	-80	-11.6
GV - Gd3	7-05-81	78	-83	-11.9
GV - Ge	7-05-81	68	-80	-12.2
GV - Gf	7-05-81	79	-83	-12.5
GV - Gh	7-11-82	61	-82	-11.7
GV - Gj	7-10-82	41	-79	-11.0
GV - G1	7-13-82	62	-83	-11.9
MV - Ma	7-17-82	84	-77	-11.1
MV - Mb	7-04-81	nd	-81	-12.4
MV - Mb	8-13-80	87	-78	-11.9
MV - Mc	7-04-81	58	-81	-12.4
MV - Mc	7-18-82	55	-84	-11.7
MV - Md	8-13-80	67	-81	-12.1
NV - Na	8-20-83	23	-78	-11.3

GV - Glacier Valley
 MV - Makushin Valley
 NV - Nateekin Valley

- a) Analyzed at Stable Isotope Laboratory, Southern Methodist U., Dallas, Texas.
 b) Values are in permil with respect to SMOW.

Table 22. Stable isotope analyses of chloride spring waters in the Makushin geothermal area.^a

Site Name	Date	T	D/H ^b	180/160 ^b
DV - stream	8-21-83	14	-76	-9.9
GV - Gn	7-20-82	39	-80	-11.1
GV - Gn	7-20-82	27	-82	-11.1
GV - Gp	7-20-82	40	-78	-10.9
GV - Gp	7-16-83	44	-80	-11.2

DV - Driftwood Valley

GV - Glacier Valley

a) Analyzed at State Isotope Laboratory, Southern Methodist U., Dallas, Texas.

b) Values are in permil with respect to SMOW.

Table 23. Stable isotope analyses of cold waters in the Makushin geothermal area.^a

Site Name	Date	T	D/H ^b	180/160 ^b
DV - stream	8-21-83	14	-76	-9.9
FF 1 - stream	7-18-83	nd	-81	-11.2
FF 3 - stream	7-11-83	nd	-89	-13.5
FF 6 - snow	7-18-82	nd	-121	-15.9
FF 7 - snow melt	8-20-83	nd	-88	-12.7
FF 9 - snow melt	7-11-83	nd	-65	-11.0
GV - Gd spring	7-05-81	5	-93	-14.2
GV - Gd spring	8-11-80	nd	-77	-11.1
GV - Gd stream	8-11-80	7	-87	-12.0
GV - Gk spring	7-15-82	16	-77	-10.0
GV - Gl stream	7-18-82	5	-88	-12.6
GV - Gn spring	7-09-83	nd	-78	-11.3
GV - West Fork River	7-05-81	5	-93	-14.2
GV - clear river mouth	7-19-83	7	-77	-11.5
GV - muddy river mouth	7-19-83	5	-85	-12.8
GV - snow melt	8-11-80	nd	-76	-11.2
MV - Camp spring	7-19-82	nd	-67	-9.7
MV - Mb stream	8-13-80	nd	-89	-13.0
MV - Mc stream	7-04-81	nd	-82	-11.9
MV - Md stream	8-11-80	nd	-83	-11.3
MV - spring	7-19-82	6	-82	-11.9
NV - stream	8-20-83	nd	-88	-12.7

DV - Driftwood Valley
 FF - Fumarole field
 GV - Glacier Valley
 MV - Makushin Valley
 NV - Nateekin Valley

- a) Analyzed at Stable Isotope Laboratory, Southern Methodist U., Dallas, Texas.
 b) Values are in permil with respect to SMOW.

Table 24. Analyses of tritium in waters from Makushin geothermal area.

Sample code	Locality	Date collected	TU
MVTW-3	ST-1	9-02-83	0.46±0.08
MVTW-5	ST-1	9-03-83	0.29±0.08
RM82MV-cs	cold str., Mk. Val	7-21-82	11.3±0.3
RM82MV-ru	hot spr. M-c	7-22-82	16.4±0.4
RM82GV-E	hot spr. G-j	7-20-82	36.5±0.8
RM82GV-wv	hot spr. G-l	7-20-82	28.2±0.7
RM82GV-24	hot spr. G-m	7-20-82	10.5±0.3
RM82PV	hot spr. G-p	7-20-82	6.1±0.2

Analyst: H. Gote Ostlund, U. of Miami, Miami, Florida.

TU = Tritium units

Table 25. Geothermometry of chloride spring waters in Mukushin geothermal area.
(Temperatures in °C).

Site Name	Date	Qz. cond. (1)	Chnl. cond. (2)	Na/K (3)	Na/K (4)	Na/K (5)	Na-K-Ca (6)	Na-K-Ca (7)	NI/LI (8)
DV - stream	8-21-83	96	65	210	178	187	157	71	171
GV - Gm	7-20-82	146	118	225	197	205	166	129	139
GV - Gn	7-20-82	147	122	225	197	204	167	99	126
GV - Gp	7-20-82	139	113	221	192	200	175	64	143

DV - Driftwood Valley, GV - Glacier Valley

- (1) Fournier, 1983, improved SiO₂.
- (2) Fournier, 1983, improved SiO₂.
- (3) Fournier, 1981, Na/K.
- (4) Truesdell, 1976, Na/K.
- (5) Arnorsson, 1983, Na/K, Basalt.
- (6) Fournier & Truesdell, 1973.
- (7) Fournier & Potter, 1979.
- (8) Fouillie & Michard, 1981.

Table 26. Analyses of gases collected from fumaroles and hot springs, Makushin geothermal area, in mole %.
Analyses corrected for air contamination using ratio of O₂ in sample to O₂ in air (RO₂).

Sample code	Location	Date sample	RO ₂	Xg	CO ₂	H ₂ S	H ₂	CH ₄	NH ₃	N ₂	Ar	Gas geothermometer (c) N ₂ /Ar C/S	T ₁	T ₂
Sodium-hydroxide charged flasks: (a)														
RM 83-46	FF1	7-17-83	0.01	0.17	82.19	2.28	0.21	0.039	0.38	14.73	0.17	86.4	36.1	227
RM 83-CV1-A	FF3 Superheated	7-08-83	0.00	0.16	88.04	6.38	0.95	0.010	0.13	4.43	0.06	80.2	13.8	298
RM 83-11b	FF3 West	7-10-83	0.06	0.50	83.72	1.69	0.22	0.001	0.04	14.16	0.17	84.1	49.4	234
RM 83-31	FF3 Far west	7-13-83	0.05	0.36	88.10	4.58	0.25	0.001	0.01	6.94	0.14	51.3	19.3	273
RM 83-57	FF7	8-20-83	0.01	2.63	82.15	1.81	1.10	2.482	0.18	12.21	0.08	161.9	46.7	230
RM 83-19	FF9	7-11-83	0.00	0.78	91.55	3.94	0.85	0.004	0.01	3.63	0.02	146.3	23.2	294
DS 83 RN7 DS	FF3 superheated (98)	8-29-83	0.00	0.18	88.93	6.85	0.88	0.006	0.08	3.22	0.03	113.1	13.0	302
DS 83 RN13 DS	FF3 Far west	8-29-83	0.00	0.25	84.93	6.25	0.66	0.003	0.06	8.06	0.01	--	13.6	299
RM 82-CV1	FF3 Superheated	7-09-82	0.02	0.15	82.29	12.25	1.84	0.070	nd	3.56	0.07	54.7	6.7	313
RM 82-Ma eum	FF6 Summit	7-18-82	0.00	1.67	87.47	5.51	0.21	0.047	nd	6.63	0.11	60.2	15.8	235
RM 82-MV FF2	FF2	7-17-82	0.00	--	90.40	2.92	0.35	0.012	nd	6.24	0.07	87.8	30.9	252
RM 82 Ma west (L)	FF5	7-13-82	0.01	1.39	91.16	0.95	0.51	0.004	0.03	7.29	0.05	137.0	96.4	234
RP 81-A13	FF2	7-14-81	0.00	0.00	87.17	5.26	0.75	0.002	nd	6.76	0.06	120.2	16.6	308
RP 81-A15	FF3	7-05-81	0.00	0.00	87.42	1.23	1.80	0.002	nd	9.43	0.11	86.4	70.9	309
RM 80-MVZ	FF1	8-13-80	0.00	0.41	91.68	2.63	0.24	0.029	nd	5.36	0.07	78.4	34.9	231
RM 80-MV1	FF2	8-13-80	0.00	0.59	87.90	2.65	0.54	0.002	nd	8.81	0.09	95.4	33.2	283
Uncharged, evacuated flasks: (b)														
RM 83 G-P	Spring G-P	7-16-83	--	--	98.22	0.02	0.005	0.052	nd	0.96	0.02	48.0	--	--
RM 83 G-J	Spring G-J	7-21-83	0.04	--	25.43	0.02	0.02	0.010	nd	74.13	1.02	72.4	--	--
RM 82 CV 1W	FF4	7-14-82	0.01	--	92.73	0.84	1.21	0.01	nd	5.50	0.05	106.8	113.5	295
RM 82 Ma WF	FF5	7-13-82	0.00	--	94.89	0.68	0.59	0.01	nd	3.78	0.05	77.6	139.3	268
RM 82 Ma Sum	FF6	7-18-82	0.00	--	90.60	5.68	0.12	0.02	nd	3.43	0.01	--	16.0	226
RM 82 CV W	FF9	7-16-82	0.00	--	93.36	2.01	0.72	0.01	nd	4.33	0.04	108.3	46.4	293

(a) Samples RM 83 and RM 82 analyzed by R.J. Motyka, ADGGS; samples DS 83 analyzed by D.S. Sheppard, DSIR, New Zealand; samples RP 81 and RM 80 analyzed by J. Whelan, SIO, La Jolla, and R.J. Motyka, AMCGS, Fairbanks.

(b) Analyzed by W. Evona, USGS, Menlo Park, and R.J. Motyka, ADGGS.

(c) D'Amore and Pnlichki, 1980. T1 uses P CO₂ = 1 bar; T2 uses P CO₂ = 0.5 bar.

nd = not determined.

Table 27. Makushin geothermal area, analyses of $^{13}\text{C}/^{12}\text{C}$ in CO_2 emanating from fumaroles and hot springs.

Location	Year Collected	^{13}C , PDB	Type	Analyst
Fum. field #1	1983	-14.3	$\text{SrCO}_3/\text{NaOH}$	USGS
	1983	-13.9	$\text{SrCO}_3/\text{NaOH}$	USGS
Fum. field #2	1981	-12.2	$\text{SrCO}_3/\text{NaOH}$	GC
		-12.5	$\text{SrCO}_3/\text{NaOH}$	SMU
	1982	-11.6	$\text{SrCO}_3/\text{NaOH}$	USGS
Fum. field #3,sp	1981	-11.8	$\text{SrCO}_3/\text{NaOH}$	GC
		-12.4	$\text{SrCO}_3/\text{NaOH}$	SMU
lower	1981	-13.0	CO_2 -gas	GC
super heated	1982	-10.2	CO_2 -gas	SIO
	1983	-13.4	$\text{SrCO}_3/\text{NaOH}$	USGS
west	1983	-11.3	$\text{SrCO}_3/\text{NaOH}$	USGS
Fum. field #4	1982	-12.3	CO_2 -gas	USGS
Fum. field #5	1982	-12.4	$\text{SrCO}_3/\text{NaOH}$	USGS
		-12.4	CO_2 -gas	USGS
Fum. field #6	1982	-10.0	CO_2 -gas	USGS
		-11.5	$\text{SrCO}_3/\text{NaOH}$	SMU
Fum. field #9	1982	-12.1	CO_2 -gas	USGS
Spring G-j	1983	-15.4	CO_2 -gas	USGS
Spring G-p	1983	-13.3	CO_2 -gas	USGS

USGS = U.S. Geological Survey, Menlo Park, California.

SMU = Southern Methodist University, Stable Isotope Laboratory, Dallas, Texas.

GC = Global Geochemistry, Inc., Canoga Park, California.

SIO = Scripps Institute of Oceanography, Stable Isotope Laboratory, La Jolla, California.

Table 28. Helium isotope data, Makushin geothermal area.^a

Location	Year Collected	R/Ra ^b	(He/Ne)/air ^c	Rc/Ra ^d
Fum. field #1	1980	6.6	110.0	6.6
Fum. field #2	1980	4.9	37.0	5.1
Fum. field #2	1981	5.0	94.0	5.1
Fum. field #3, sp	1981	3.8	24.0	4.0
Fum. field #3	1981	4.4	53.0	4.5
Fum. field #3, SH	1982	4.1	11.4	4.4
Fum. field #5	1982	5.0	50.0	5.1
Fum. field #6, SU	1982	7.8	1500.0	7.8
Fum. field #7	1983	5.9	300.0	5.9
Spring G-p	1983	(1.3) ^e	(1.5) ^e	(1.9) ^e
Test well ST-1	1983	3.6	41.0	3.7

- a) R. Poreda analyst, Scripps Institute of Oceanography, Stable Isotope Lab.
- b) R = $3\text{He}/4\text{He}$ ratio in sample.
- c) Ra = $3\text{He}/4\text{He}$ ratio in air.
- d) Rc = Sample ratio corrected for air contamination using He/Ne ratios.
- e) Helium concentration in sample was extremely low.

Table 29. Makushin geothermal area, miscellaneous stable isotope analyses.

$^{13}\text{C}/^{12}\text{C}$ - HCO_3 , thermal waters. (USGS, Menlo Park, analysts).

Location	Year Collected	^{13}C ; PDB
Spring G-h	1982	-11.1
Test well ST-1	1984	-23.0

$^{13}\text{C}/^{12}\text{C}$ and $^{18}\text{O}/^{16}\text{O}$ in CaCO_3 , calcite sinter deposited on downhole instrument cable in test well ST-1, mid-July, 1984. (SMU analysts).

	$^{13}\text{C}/^{12}\text{C}$, PDB	$^{18}\text{O}/^{16}\text{O}$, PDB: CO_2
RM84-MVTW CaCO_3	-12.5	-29.3

$^{13}\text{C}/^{12}\text{C}$ in methane, fumarole gases.

Location	Year Collected	^{13}C , PDB	Analyst
Fum. field #2	1982	-42.3	USGS
Fum. field #6	1982	-30.6	SIO

D/H in hydrogen and methane, fumarole gases.

Location	Year Collected	D/H - H_2 , SMOW	D/H - CH_4 , SMOW	Analyst
Fum. field #3, sp	1981	-601	---	GC
Fum. field #3, superheated	1982	-582	---	USGS
Fum field #6, summit	1982	-719	-132.6	USGS

Table 30. St-1 whole rock oxygen isotope data.^a

Sample #	$^{18}\text{O}/^{16}\text{O}$	Description
ST-1-201	-4.0	Gabbro. Plagioclase altered to clays.
ST-1-664	-2.7	Gabbro altered to wairakite. Steam entry.
ST-1-1066	-2.0	Albite-K spar-biotite-epidote vein.
ST-1-1638	+2.8	"Unaltered" gabbro. Pyroxenes altered to anthophyllite-cumingtonite.
ST-1-1937	-0.1	Chloritically altered gabbro.
- -	+6.4	Average of 11 Makushin area volcanic rocks.

a) Analyzed at U.S. Geological Survey, Menlo Park, CA., I. Barnes lab.

APPENDIX A

Lithologic Log and Hydrothermal Alteration at Core from the Makushin
Geothermal Area, Unalaska Island, Alaska

by

L. D. Queen

APPENDIX B

Lithologic log and Hydrothermal Alteration of Core from Drill Hole A-1,
Makushin Geothermal Area, Unalaska Island, Alaska.

by

L. D. Queen