DOE/SF/15799--T14

DE92 014586

GEOTHERMAL RESEARCH AT THE PUNA FACILITY

DOE I.D. NO. DE-FG-03-85SF15799

FINAL REPORT

Received OSTI
MAY 20 1992

PRINCIPAL INVESTIGATORS:

Dr. Bill Chen
Dr. Patrick Takahashi
Dr. Donald Thomas

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Abstract

A research program has been undertaken in an effort to better characterize the composition and the precipitation characteristics of the geothermal fluids produced by the HGP-A geothermal well located on the Kilauea East Rift Zone on the Island of Hawaii. The results of these studies have shown that the chemical composition of the fluids changed over the production life of the well and that the fluids produced were the result of mixing of at least two, and possibly three, source fluids. These source fluids were recognized as: a sea water composition modified by high temperature water-rock reactions; meteoric recharge; and a hydrothermal fluid that had been equilibrated with high temperature reservoir rocks and magmatic volatiles. Although the major alkali and halide elements show clearly increasing trends with time, only a few of the trace transition metals show a similar trend. The rare earth elements, were typically found at low concentrations and appeared to be highly variable with time. Studies of the precipitation characteristics of silica showed that amorphous silica deposition rates were highly sensitive to fluid pH and that increases in fluid pH above about 8.5 could flocculate more than 80% of the suspended colloidal silica in excess of its solubility. Addition of transition metal salts were also found to enhance the recovery fractions of silica from solution. The amorphous silica precipitate was also found to strongly scavenge the alkaline earth and transition metal ions naturally present in the brines; mild acid treatments were shown to be capable of removing substantial fractions of the scavenged metals from the silica flocs yielding a moderately pure gelatinous by-product. Further work on the silica precipitation process is recommended to improve our ability to control silica scaling from high temperature geothermal fluids or to recover a marketable silica by-product from these fluids prior to reinjection.

**TRACE ELEMENT AND ISOTOPE GEOCHEMISTRY OF GEOTHERMAL FLUIDS, EAST RIFT
ZONE, KILAUEA, HAWAII:
FINAL REPORT TO THE DEPARTMENT OF ENERGY**

H. B. West¹, D. C. Gerlach², G. A. Delanoy¹, and D. M. Thomas¹

1 Hawaii Institute of Geophysics, University of Hawaii, Honolulu, Hawaii 96822 (U.S.A.).

2 Lawrence Livermore National Laboratory, Livermore, California 94550 (U.S.A.). Now at Charles Evans & Associates, 301 Chesapeake Drive, Redwood City, California 94063.

INTRODUCTION

There have been more than twenty wells drilled into Kilauea over the last thirty years, eight in the last decade (Thomas, 1989), primarily for the purpose of geothermal energy exploration and assessment. Prior to drilling the Scientific Observation Hole Project, which is ongoing, the two most important holes, from a scientific standpoint, were the summit research hole and the Hawaii Geothermal Project [HGP-A] well. The experimental geothermal test well, HGP-A (Fig. 1), was completed in 1976, on the Kilauea ERZ at an elevation of 205 m (Stone, 1977). This hole reached a depth of 1962 m, but only 1.4% of the hole was cored (28 m). Based on hand-sample examination of cutting chips, intense hydrothermal alteration begins at approximately 1350 m (Stone, 1977).

Fluids were sampled at 1-3 month intervals from the HGP-A well from the time the geothermal generator facility was installed in 1981 until its shutdown in December 1989. These fluids provide a valuable monitor of fluid compositions in the Kilauea geothermal system. Samples were analyzed routinely for major chemical constituents (Na, Cl, Ca, SiO₂). To better assess the chemistry of these fluids, 55 samples collected between June 23, 1981 and May 18, 1989 were analyzed for trace elements and total dissolved solids and a subset was analyzed for Sr isotopic compositions. The initial results of this study were presented by Gerlach et al. (1989).

The purpose of this report is to present the preliminary findings of our work on the major element, trace element, and isotope geochemistry of geothermal fluids collected from the HGP-A well. The trace elements were analyzed using a relatively new technique, inductively coupled plasma emission mass spectrometry [ICP-MS], that is capable of determining concentrations at the parts-per-trillion [ppt] level. The data set obtained for the HGP-A fluid samples using the ICP-MS technique is unusually exhaustive, and may be the most complete set available for geothermal fluids.

SAMPLING AND ANALYTICAL METHODS

Samples of the HGP-A fluids were collected in clean 1 lit HDPE bottles; both non-acidified, non-filtered and acidified, filtered samples were collected. Hydrochloric acid was added to the fluid samples to prevent silica flocculation. Approximately 8.3 ml of concentrated HCl (12.16 M) was

added to each bottle to bring the pH of the fluids ($\text{pH} \approx 6.85\text{--}7.75$) down to $\text{pH} \approx 1$.

Abundances of Li, Be, B, Ca, Ti, Cr, Mn, Fe, Co, Cu, Zn, Ge, Ga, As, Se, Br, Rb, Sr, Y, Zr, Nb, Mo, Ag, Cd, Sn, Sb, Te, I, Cs, Ba, rare-earth elements [REE], Hf, Ta, W, Au, Hg, Tl, Pb, Th, and U were determined by ICP-MS in the Nuclear Chemistry Division at Lawrence Livermore National Laboratory [LLNL] using analytical techniques developed there. Analyses were done on two instruments, a VG Elemental PlasmaQuad PQ1 and a VG Elemental PlasmaQuad PQ2. Detection limits are in the pg-g^{-1} range. For elements containing more than one isotope, all principal masses were measured and the mass most free of contributing mass interferences was identified. The masses used to determine concentrations are listed in Table 1. This procedure was important to follow because of the complex chemical matrix of the geothermal solutions. Chlorine complexes, in particular, produced observable contributions to certain masses. Mass contributions from doubly-charged ions (e.g., Ba^{+2}) appeared insignificant for these fluids.

Concentrations of SiO_2 , Na, Ca, and Cl were determined at the University of Hawaii by inductively coupled plasma emission spectroscopy [ICP] and atomic absorption spectroscopy [AA]. Total dissolved solids were also determined at the University of Hawaii. $^{87}\text{Sr}/^{86}\text{Sr}$ ratios were determined by thermal ionization mass spectrometry at LLNL.

RESULTS

A summary of geochemical data for fluids collected during 1981-1989 from the HGP-A Geothermal well is given in Tables 1 and 2. Table 1 includes the range in concentrations for all elements determined by ICP-MS. Table 2 contains data for additional chemical species and elements determined by ICP and AA and for total dissolved solids; also included is a summary of isotopic compositions. All geochemical data are shown in figure 2 and are plotted against the date of sample collection.

Total Dissolved Solids

The amounts of total dissolved solids in the geothermal fluids increase systematically between 1981 and 1985, after which they were constant. However, some samples have anomalously low total

dissolved solids that fall off the general trend. At higher pH values, dissolved silica polymerizes to form colloidal silica, resulting in flocculation and settling (Weres and Tsao, 1981). Because the samples with low total dissolved solids also tend to have lower SiO_2 contents than do other samples, silica flocculation probably occurred. The most likely explanation for this result is that samples with anomalously low total dissolved solids were acidified incorrectly during sampling.

Major Elements

Silicon

The SiO_2 contents of most of the Kilauea geothermal fluid samples are significantly higher than those of seawater but generally are lower than those observed in submarine hydrothermal fluids (≈ 600 -1000 ppm versus ≈ 1100 -1320 ppm). There is a general positive correlation between SiO_2 contents and collection date (Fig. 2). In actuality, Si may exist as Si(OH)_4 (Stumm and Morgan, 1981) in these fluids, as it does in seawater.

Chlorine, Sodium, Calcium

The Cl and Na abundances of the geothermal fluids are lower than those observed in both seawater and submarine hydrothermal fluids. Calcium abundances range from very low (37 ppm) to values (400-500 ppm, generally) similar to those of seawater (420 ppm). Abundances of these elements increased progressively with time between 1981 and 1986, after which abundances became constant. Thus, they mimic the trend observed for total dissolved solids.

Trace Elements

Lithium, Rubidium, Cesium

Rubidium abundances in the geothermal fluids generally range from ≈ 300 to over 1500 ppb, which is significantly higher than either seawater or submarine hydrothermal fluid values. Similarly, Cs abundances in most of these fluids are significantly higher than those in seawater. The Rb and Cs contents of the geothermal fluids follow the same temporal trend as does Na, with one notable exception. From early 1988 through 1989, Rb and Cs concentrations increased slightly, whereas Na abundances were constant.

Lithium abundances in these fluids range from low values (≈ 225 ppb), similar to those for seawater (180 ppb) to higher values (≈ 1 ppm). However, these abundances are significantly lower than those measured in either basalts or submarine hydrothermal fluids. Lithium abundances increased rapidly from 1981 until mid-1983, when abundances declined slowly. From 1988 on, Li abundances increased slightly, similar to the increase observed for Rb and Cs.

Titanium, Chromium

Titanium and chromium abundances in the geothermal fluids are low (< 80 ppb and < 25 ppb, respectively), but are much higher than those in seawater (typically < 1 ppb). Titanium abundances in the fluids increased systematically from 1981 to 1985, after which they were relatively constant. Samples with anomalously low Ti also contain low SiO_2 and low total dissolved solids. Chromium abundances in the fluids increased systematically from 1981 to mid-1985 and then, in contrast to Ti, decreased progressively through 1989.

Manganese, Iron, Cobalt

Manganese, iron, and cobalt abundances in the geothermal fluids are much greater than those in seawater, but Mn and Fe abundances are significantly lower than those in submarine hydrothermal fluids or in Kilauea basalts. Iron and cobalt display similar temporal trends; abundances of both gradually increased through 1986, after which abundances showed greater short-term variability but did not systematically increase. In contrast, temporal variations in Mn abundances paralleled those of Rb.

Copper, Zinc

Copper abundances in the geothermal fluids are much higher than those in seawater but are significantly lower than those in submarine hydrothermal fluids or in Kilauea basalts. In general, Cu abundances in these fluids increased with time but were highly variable from mid-1984 through 1989.

Zinc abundances in the geothermal fluids are very low; with the exception of two samples, one of which is a low-Si sample, the fluids range from ≈ 1 -15 ppb Zn. These values are higher than Zn

abundances in seawater but are significantly lower than those in submarine hydrothermal fluids or in Kilauea basalts. Zn abundances appear to have remained systematically low and constant with time.

Iodine, Bromine

Iodine abundances in most of the geothermal fluids are much higher than those in seawater. The temporal trend for I differs from those displayed by the alkali metals. Iodine abundances generally increased until mid-1985, after which they generally declined through 1989. This trend is similar to that shown by Cr.

Bromine abundances in the geothermal fluids typically range from ≈ 250 -1500 ppb, which are significantly lower than those observed for either seawater or submarine hydrothermal fluids. Bromine abundances follow the same temporal trend as does Na.

Strontium, Barium

Strontium abundances in the geothermal fluids are lower than those in seawater, submarine hydrothermal fluids, or Kilauea basalts. Strontium abundances follow a systematic temporal trend similar to that for Rb, although the initial increase from 1981 to 1985 is much more dramatic. Barium abundances are much higher than those in seawater or submarine hydrothermal fluids but are significantly lower than those in Kilauea basalts. With time, Ba abundances in the fluids increase and concomitantly become more variable.

Rare Earth Elements, Yttrium

Rare earth element abundances in the geothermal fluids are higher than those in seawater but they are orders of magnitude lower than those observed in submarine hydrothermal fluids. For many of the samples, REE abundances were near the detection limit. Eu abundances increased with time, but were highly variable. No other REE displayed any systematic temporal variation. Y abundances in the fluids are low (< 50 ppb) and similar to those in seawater. Y abundances appear to have increased generally with time but, like Eu, were highly variable.

Zirconium, Hafnium, Niobium, Tantalum

For many of the samples, Zr, Hf, Nb, and Ta abundances in the geothermal fluids were near the detection limit. With the exception of three samples, Zr abundances in the geothermal fluids are < 0.5 ppb and are similar to or slightly higher than seawater abundances (0.03 ppb). Hafnium, niobium, and tantalum abundances in the fluids are also low and approach seawater values. There does not appear to have been any systematic temporal variation in the abundances of these elements. Hafnium and tantalum abundances, in particular, varied substantially.

Molybdenum, Tungsten

Molybdenum abundances in the geothermal fluids (< 10 ppb, with the exception of one sample) are similar to or lower than those in seawater but are significantly lower than abundances in typical Kilauea basalt. Unlike the abundances of other elements that display systematic temporal variations, Mo abundances decreased progressively from at least early-1982 through 1989.

Tungsten abundances in the fluids range from seawater values to about an order of magnitude higher than seawater values. Similar to Mo, W abundances appear to have decreased over the same time interval, although there is significantly more variability in the data.

Arsenic, Selenium, Tellurium

Arsenic, selenium, and tellurium abundances in the geothermal fluids are extremely variable. For the vast majority of samples, As and Se concentrations are higher than those in seawater but are substantially lower than those in typical Kilauea basalt. In contrast to the relatively restricted range in As observed for the HGP-A fluids, As concentrations in geothermal fluids from various settings span a large range (< 0.1 ppm to $\approx$ 50 ppm; Ballantyne and Moore, 1988). Tellurium concentrations in seawater are not well-constrained; Te abundances in the fluids are slightly lower than those in typical Kilauea basalt.

Gallium, Germanium, Tin, Antimony, Thallium

Gallium, germanium, tin, antimony, and thallium abundances in the geothermal fluids generally are higher than those in seawater, but are substantially lower than those in typical Kilauea basalt. The abundances of these elements in submarine hydrothermal fluids have not been estab-

lished adequately.

Gallium abundances are variable but appear to increase roughly with time. In contrast, Ge abundances in the fluids were constant over the entire collection period. The three samples with anomalously low Ga and Ge also have low SiO_2 and low total dissolved solids. The result for Ge is not surprising since both Ge and Si occur naturally in the same valence state (+4) and have similar atomic radii.

The majority of samples contain less than ≈ 0.2 ppb Sn and, like Zn abundances, Sn abundances appear to have remained systematically low and constant with time. Antimony and thallium abundances are low ($\text{Sb} < 2.5$ ppb, with the exception of one sample; $\text{Tl} < 3.5$ ppb) and variable, and do not appear to have changed systematically with time.

Ruthenium, Rhodium, Rhenium, Osmium, Iridium

Little is known about the distribution of the siderophile elements Ru, Rh, Re, Os, and Ir in most terrestrial materials due to their extremely low abundances. Due to the relatively large analytical uncertainties associated with determining these elements by ICP-MS, they are not reported in tables 1 and 3. Of these elements, Rh (≈ 0.07 -1.83 ppb) and Ru (8 ppb to 1.3 ppb) are the most abundant in the geothermal fluids. Iridium, Rhenium, and Osmium abundances in the fluids generally are below 30 ppb. Of these elements, only Rh displays any systematic temporal correlation. Rh abundances increased systematically until 1985, after which they were relatively constant. This behavior is similar to that observed for Co.

Cadmium, Mercury, Silver, Gold, Platinum, Palladium

The abundances of Cd, Hg, Ag, Au, Pt, and Pd in the geothermal fluids are near the detection limit. Abundances of these elements in the fluids are similar to or slightly higher than those in seawater but are significantly lower than abundances in typical basaltic rocks. With the exception of two samples, the geothermal fluids contain < 0.75 ppb Cd. A few samples contain elevated Hg abundances (i.e., 1-13 ppb). Cd, Hg, Ag, Au, and Pt abundances appear to have remained systematically low and constant with time, similar to what is observed for Zn. Pd abundances are more variable, but also show no systematic variation with time.

Lead, Thorium, Uranium

Lead abundances in the geothermal fluids are greater than those in seawater and fall within the range observed for submarine hydrothermal fluids. Between 1981 and 1986, Pb concentrations in the geothermal fluids varied substantially, ranging from ≈ 5 -80 ppb. Between 1986 and 1988, Pb abundances were significantly less variable (all samples contained $< \approx 15$ ppb Pb). From early 1988 through 1989, Pb abundances in the fluids were below the detection (probably < 0.2 ppb).

Thorium abundances in the geothermal fluids are significantly greater than those in seawater or submarine hydrothermal fluids. These abundances are extremely variable in the fluids and are not correlated with time of collection.

Uranium abundances in the geothermal fluids are near the detection limit. These abundances are lower than those in seawater (≈ 3.2 ppb). With the exception of two samples, the fluids contain < 19 ppb U and fall within the range observed for submarine hydrothermal fluids (0.7 ppb to 3.2 ppb). Uranium abundances, like those of Zn, Cd, Ag, and Pt, appear to have remained systematically low and constant with time.

Strontium Isotopes

The $^{87}\text{Sr}/^{86}\text{Sr}$ compositions of the geothermal fluids span a relatively restricted range (0.704783-0.709226). These values are higher than those reported for fresh Kilauea basalts (0.70346-0.70379; Lanphere et al., 1980; White and Hofmann, 1982; Hofmann et al., 1984; Newsome et al., 1986), but fall within the range for average present-day seawater. From 1981 through early-1983, $^{87}\text{Sr}/^{86}\text{Sr}$ ratios decreased systematically. Although data are limited, it appears that $^{87}\text{Sr}/^{86}\text{Sr}$ ratios of the fluids subsequently increased up to 1985 and then slowly decreased through 1989.

DISCUSSION

The major and trace element compositions of the HGP-A fluids show significant abundance variations and temporal correlations. Total dissolved solids and the abundances of Na, Cl, Ca, Sr, Ba, Rb, Cs, B, Li, and Mn increased from 1981, when the generator facility was put into operation, to 1985. After 1985, abundances of these elements remained within 10-15% of the highest abundances. In contrast, Pb and W abundances and Rb/Sr, B/Li, and Na/Ca ratios decreased until 1985. SiO₂ contents and Cl/Br ratios display no clear temporal trends. From 1981 to 1985, correlations between Na and other elements (e.g., Li, B, Mn, Rb, Sr, Cs, Ba), other inter-element correlations (e.g., Sr, Rb, and Co versus Mn), and systematic variations between elemental abundances and several abundance ratios (e.g., Li, B, Na, Ti, Mn, Ge, Br, Ba, B/Li, Na/Ca, Ba/Cs, Rb/Sr) suggest mixing between two geochemically distinct components.

A fluid component with high Rb/Sr, Na/Ca, and B/Li ratios could have been derived from alteration of basalt by seawater, resulting in an anhydrite-amphibole alteration assemblage. A fluid component with low Rb/Sr, Na/Ca, and B/Li ratios could have formed in association with an alteration assemblage dominated by layered silicates. This latter fluid component could represent a hydrothermal component that originated uprift of the HGP-A site on the lower east rift. Such a component could have formed by percolation of meteoric water along fracture and dike swarms trending WNW-ESE. These waters may have originally been driven to depth downrift, and then heated and driven upwards into the more shallow geothermal production area.

Although some inter-ratio correlations suggest mixing between two geochemically distinct reservoirs (e.g., Na/Ca versus Rb/Sr; Fig. 4), the bifurcating trends on plots of other elemental and isotopic ratios (Figs. 5-6) require an additional component. This third component has moderately high ⁸⁷Sr/⁸⁶Sr, low Rb/Sr, and high Ba/Cs. These geochemical characteristics are typical of basalt that has undergone surface weathering, resulting in loss of alkalies (e.g., Feigenson et al., 1983; Chen and Frey, 1985; West et al., in press).

Acknowledgements

We thank G. P. Russ and J. Bazan at LLNL for their generous assistance and access to ICP-MS facilities. Mahalo to Brenda Ikemoto for determining total dissolved solids of the geothermal fluid samples.

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FIGURE CAPTIONS

Figure 1. Map of the Kilauea east rift zone showing the location of the HGP-A well, groundwater wells, and deep geothermal exploration wells (from Thomas, 1989).

Figure 2. Compositions of geothermal fluids from the HGP-A well plotted against the date of sample collection. All samples were collected between 1981 and 1990.

Figure 3. $^{87}\text{Sr}/^{86}\text{Sr}$ versus the date of sample collection for geothermal fluids from the HGP-A well. All samples were collected between 1981 and 1990.

Figure 4. Rb/Sr versus Na/Ca for geothermal fluids from the HGP-A well.

Figure 5. Rb/Sr versus Ba/Cs for geothermal fluids from the HGP-A well.

Figure 6. $^{87}\text{Sr}/^{86}\text{Sr}$ versus Na/Ca for geothermal fluids from the HGP-A well.

Table 1. Summary of geochemical data for fluids collected during 1981-1989 from the HGP-A Geothermal well, East Rift Zone, Kilauea, Hawaii. Concentrations of all elements determined by ICP-MS and given in ppb.

	<u>Mass</u>	<u>Concentrations</u>		<u>Range</u>
		<u>Low</u>	<u>High</u>	
Li	7	0.32	1036	1035.7
Be	9	0.022	0.121	0.099
B	10	96	2771	2675
Ca	44	22414	342836	320422
Ti	49	2.1	76.6	74.5
Cr	52	3.2	20.5	17.3
Mn	55	2.0	373	371
Fe	57	19	1445	1426
Co	59	0.033	0.951	0.918
Cu	65	2.8	86	83.2
Zn	66	1.3	172	170.7
Ga	71	0.48	2.30	1.82
Ge	73	3.5	21.7	18.2
As	75	0.09	9.49	9.40
Br	81	66.8	1473	1406.2
Se	82	0.9	11.2	10.3
Rb	85	8.0	1555	1547
Sr	88	252.3	6466	6213.7
Y	89	0.006	0.049	0.043
Zr	90	0.034	6.81	6.776
Nb	93	0.018	0.039	0.021
Mo	96	0.43	34.3	33.87
Ag	107	0.049	10.89	10.841
Cd	111	0.09	25.0	24.01
Sn	118	0.19	3.64	3.45
Sb	121	0.02	7.17	7.15
Te	125	0.20	5.02	4.82
I	127	6.8	310	303.2
Cs	133	0.01	21.0	21.09
Ba	135	11.1	5447	5436
La	139	0.004	41.44	41.436
Ce	140	0.006	0.194	0.188
Pr	141	0.008	0.082	0.074
Nd	146	0.029	0.218	0.189
Sm	147	0.030	0.335	0.305
Eu	151	0.010	0.480	0.470
Gd	157	0.054	0.398	0.344
Tb	159	0.005	0.027	0.022
Dy	163	0.023	0.094	0.071
Ho	165	0.005	1.640	1.635
Er	166	0.016	0.096	0.080
Tm	169	0.004	0.534	0.530
Yb	171	0.084	0.178	0.094
Hf	178	0.021	0.141	0.120
Ta	181	0.009	0.057	0.048
W	184	0.11	1.36	1.25
Au	197	0.036	0.840	0.804
Hg	202	0.41	13.1	12.7
Tl	205	0.018	3.32	3.30
Pb	206	0.1	79.8	79.7
Th	232	0.011	0.044	0.033
U	238	0.001	0.963	0.962

Table 2. Summary of additional geochemical data for fluids collected during 1981-1989 from the HGP-A Geothermal well, East Rift Zone, Kilauea, Hawaii. Elemental concentrations (in ppm, unless indicated otherwise) determined by ICP and AA.

	<u>Compositions</u>		<u>Range</u>
	<u>Low</u>	<u>High</u>	
TDS ¹	0.2021	35.4234	35.2213
SiO ₂	67	1112	1045
Na	121	7911	7790
Ca	37.1	683.0	645.9
Cl	3290	12780	9490
⁸⁷ Sr/ ⁸⁶ Sr ²	0.704783	0.705114	0.000331

1 TDS = total dissolved solids (in mg-g⁻¹).

2 Determined at Lawrence Livermore National Laboratory.

Table 3. Comparison of geochemical data for fluids from the HGP-A Geothermal well with other data. SiO₂, Na, Ca, and Cl are given in ppm; all other elements are in ppb, unless indicated otherwise.

	HGP-A	Seawater ¹	Basalt ³	Submarine ⁴
SiO ₂	67-1112#	4.3#	233437#	1093-1322#
Na	121-7911#	10800#	16766#	9932 ⁵ #
Ca	37-683#	420#	81476#	625#
Ca*	22-343#	420#		
Cl	3290-12780#	18800#	92	17337 ⁵ #
Li	0.32-1036	180	4600	6427 ⁵ #
Be	0.022-0.121	0.0002	1100	0.1352 ⁵ #
B	96-2771	4440	2500	5405 ⁵ #
Ti	2.1-76.6	1	16220#	
Cr	3.2-20.5	0.3	289#	
Mn	2-373	0.04	1300#	56257 ⁵ =
Fe	19-1445	2	86420#	85446 ⁵ =
Co	0.033-0.951	0.002	45#	
Cu	2.8-86	0.2	136#	2241 ⁵ =
Zn	1.3-172	0.3	105#	6930 ⁵ =
Ga	0.48-2.30	0.03	21#	
Ge	3.5-21.7	0.007	1640	
As	0.09-9.49	1.8	400	
Br	66.8-1473	67#	710	62.3-337#
Se	0.9-11.2	0.1	74	
Rb	8-1555	120	11#	13.4-1160
Sr	252-6466	8000	403#	87-8674
Y	0.006-0.049	0.0013	27.6#	
Zr	0.034-6.81	0.03	179#	
Nb	0.018-0.039	0.01	19#	
Mo	0.43-34.3	10	1020	
Ag	0.049-10.89	0.04	55	
Cd	0.09-25.0	0.07	69	
Sn	0.19-3.64	0.01	6.2#	
Sb	0.02-7.17	0.15	160	
Te	0.20-5.02	-	6.4	
I	6.8-310	60	-	
Cs	0.01-21.0	0.4	130	
Ba	11.1-5447	20	139#	17.2-42.6
La	0.004-41.44	0.003	15.8	232-375
Ce	0.006-0.194	0.001	39#	228-1960
Pr	0.008-0.082	0.0006	5.7#	
Nd	0.029-0.218	0.003	25.2#	70-1148
Sm	0.030-0.335	0.0005	6.2#	8-614
Eu	0.010-0.480	0.0001	2.06#	19-810
Gd	0.054-0.398	0.0007	6.4#	12-270
Tb	0.005-0.027	0.0001	0.96#	
Dy	0.023-0.094	-	5.2#	8.3-162
Ho	0.005-1.640	0.0002	0.99#	
Er	0.016-0.096	0.0008	2.4#	4.4-69
Tm	0.004-0.534	0.0002	0.33#	
Yb	0.084-0.178	0.0008	2.02#	4.6-50
Hf	0.021-0.141	0.007	4.38#	
Ta	0.009-0.057	0.002	1.23#	
W	0.11-1.36	0.1	270	
Au	0.036-0.840	0.004	1.6	
Hg	0.41-13.1	0.005	5.6	
Tl	0.018-3.32	0.01	580	
Pb	0.1-79.8	0.002	2600	0.0135-87.4
Th	0.011-0.044	0.00006	1080	0.00021-0.0077
U	0.001-0.963	3.2	420	0.0007-3.22
⁸⁷ Sr/ ⁸⁶ Sr	0.704783-0.705114	0.709226 ²	0.70347 ⁶	0.703252-0.709109 ⁵

Table 3 (cont.). Comparison of geochemical data for fluids from the HGP-A Geothermal well with other data. SiO₂, Na, Ca, and Cl are given in ppm; all other elements are in ppb, unless indicated otherwise.

- 1 Average seawater (Li, 1982).
 - 2 Average present-day seawater (Veizer, 1989).
 - 3 Basalt BHVO-1, Kilauea, Hawaii (Govindaraju, 1989).
 - 4 Submarine hydrothermal fluids (Edmond et al., 1982; Michard et al., 1984; Chen et al., 1986; Chen, 1987; Michard and Albarede, 1986; Berndt and Seyfried, 1990).
 - 5 Submarine hydrothermal fluids, East Pacific Rise (Piepgras and Wasserburg, 1985; Campbell et al., 1988).
 - 6 Chen et al. (1991).
 - * Determined by ICP-MS.
 - # ppm.
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Figure 1. Map of the Kilauea east rift zone showing the location of the HGP-A well, groundwater wells, and deep geothermal exploration wells (from Thomas, 1989).

Figure 2. Compositions of geothermal fluids from the HGP-A well plotted against the date of sample collection. All samples were collected between 1981 and 1990.

Figure 2 (cont.). Compositions of geothermal fluids from the HGP-A well plotted against the date of sample collection. All samples were collected between 1981 and 1990.

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Figure 2 (cont.). Compositions of geothermal fluids from the HGP-A well plotted against the date of sample collection. All samples were collected between 1981 and 1990.

Figure 3. $^{87}\text{Sr}/^{86}\text{Sr}$ versus the date of sample collection for geothermal fluids from the HGP-A well. All samples were collected between 1981 and 1990.

HGP-A Geothermal Fluids

Figure 4. Rb/Sr versus Na/Ca for geothermal fluids from the HGP-A well.

HGP-A Geothermal Fluids

Figure 5. Rb/Sr versus Ba/Cs for geothermal fluids from the HGP-A well.

HGP-A Geothermal Fluids

Figure 6. $^{87}\text{Sr}/^{86}\text{Sr}$ versus Na/Ca for geothermal fluids from the HGP-A well.

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