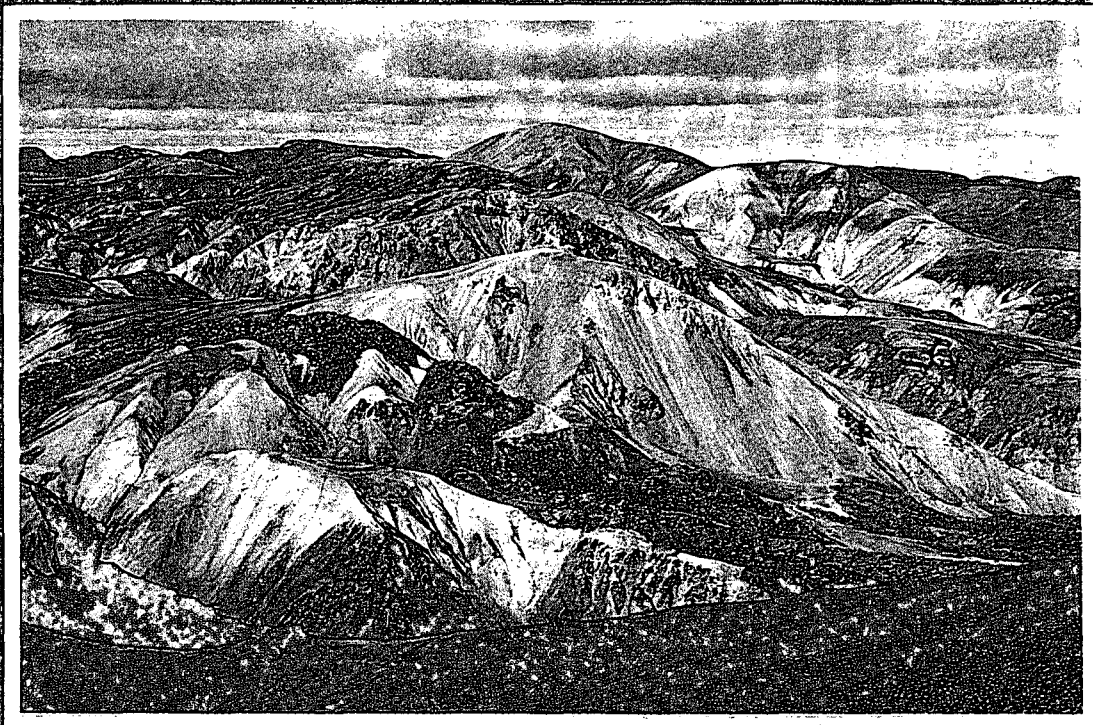


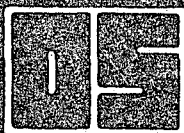
FIFTH INTERNATIONAL SYMPOSIUM ON WATER-ROCK INTERACTION

REYKJAVÍK ICELAND August 8 - 17 1986

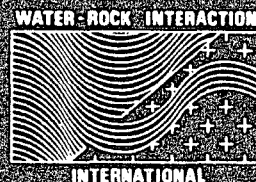
EXTENDED ABSTRACTS



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THE HYDROTHERMAL SYSTEM ASSOCIATED WITH THE KILAUEA EAST RIFT ZONE, HAWAII

Donald M. Thomas
Hawaii Institute of Geophysics, University of Hawaii
Honolulu, Hawaii 96822 U.S.A.

INTRODUCTION

In 1976 a deep research well, named HGP-A, was drilled on the lower southeast flank of Kilauea volcano. The well encountered subsurface temperatures in excess of 350°C and was capable of producing approximately 49 tonnes per hour of steam and brine. A 3 MWe wellhead generator was installed on HGP-A in 1981 and has been in nearly continuous operation for approximately four years. Analysis of the chemistry of the discharge fluids during this period has shown that the hydrothermal system associated with the Kilauea east rift zone (KERZ) is in many respects similar to those found at active seafloor spreading ridges and to the land-based hydrothermal system found on the Reykjanes peninsula in Iceland. Fluid chemistry changes that have occurred during the four-year production period have also yielded substantial insight into the temporal aspects of basalt-seawater interactions that occur in the high temperature hydrothermal system present on Kilauea's southeast flank.

Geologic Setting

Kilauea, located on the island of Hawaii, is a young basaltic shield volcano that has been almost continuously active throughout recorded history. Eruptions and intrusions typically occur in the summit caldera or on the flanks along two well-defined rift zones (Macdonald et al., 1983). The east rift zone is the more active of the latter and extends subaerially for a distance of more than 60 km across the eastern flank of Kilauea and continues as a submarine ridge to the sea floor. Recent modeling (Dzurisin et al., 1984) has suggested that as much as 55% of the total magmatic recharge to Kilauea's summit reservoir is deposited as intrusive material in the KERZ that either cools and forms long tabular dikes (Macdonald et al., 1983; Walker, in press) or is later erupted as partially crystallized, differentiated lavas (Moore, 1983). The surface trace of the rift is marked by both eruptive vents as well as ground cracks associated with faulting and graben formation.

Drilling Results

HGP-A was completed to a total depth of 1966 meters (approximately 1760 m below sea level) and had a bottom hole temperature of 358°C. The chemical composition of the fluids produced by the well during the initial testing indicated much lower than expected salinities; total dissolved solids in the residual brine phase were in the range of 3000 mg/kg and were composed predominantly of sodium chloride and lesser amounts of silica and potassium. The gas concentrations in the steam phase were moderate, having a total concentration of approximately 2500 mg/kg; they were, however, much less concentrated in CO₂ and richer in H₂S than has been typically found in other geothermal systems. A limited number of isotopic analyses conducted on the initial fluids discharged from the well showed: somewhat lighter H/D ratios than local rainfall or seawater and 0-18 ratios heavier than local groundwaters; He-3/He-4 ratios much lighter than atmospheric values but heavier than those at the Kilauea summit; and C-14 activities that were approximately 20% of modern carbon. The initial interpretation of the low salinities found in the well discharge was that the predominant source of fluid to the reservoir penetrated by the well was meteoric recharge from the upper slopes of Kilauea, hence the lighter H/D ratios, and that the fluid residence times in the reservoir, indicated by the C-14 activities, were on the order of eleven thousand years or less. The presence of high concentrations of He-3 was interpreted to indicate that a relatively young intrusion was supplying heat and residual magmatic gas to the geothermal reservoir.

Chloride Ion Concentration In HGP-A Brine

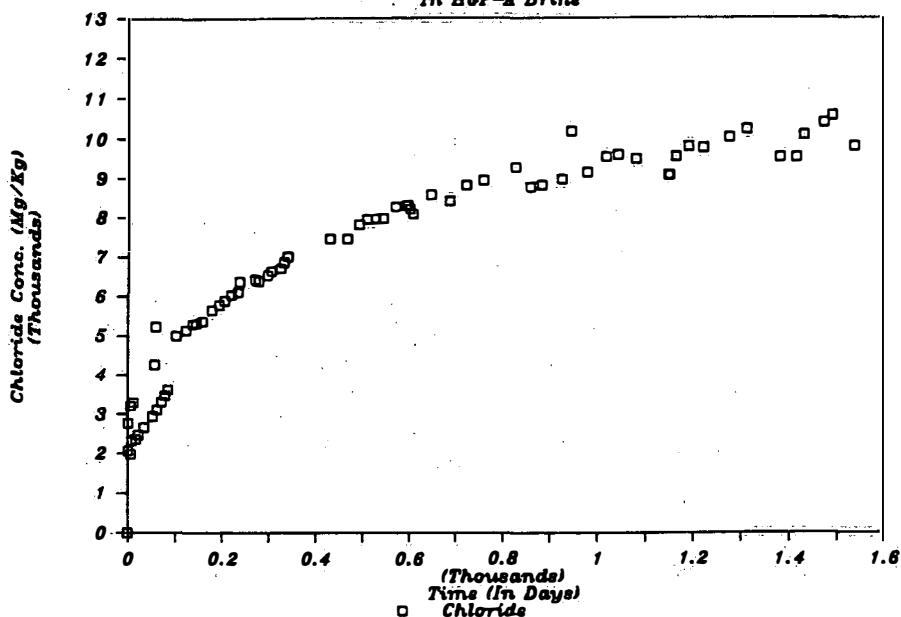


Fig. 1. Changes in chloride concentrations in HGP-A brines.

The chemistry of the production fluids from HGP-A during the last four years has changed markedly from that which was initially found in the relatively undisturbed reservoir. The total dissolved solids concentrations, which increased throughout the early testing interval, have continued to show a progressive enrichment with duration of flow. The chloride ion concentration (Fig. 1) shows a trend of initially rapid enrichment that, after a period of nearly two years, began to stabilize and currently is showing indications of a slight decline. Although other major ion concentrations have shown generally similar trends, their ratios, relative to each other and to chloride have also changed with time. Sodium ion concentrations have most closely tracked chloride and have maintained a ratio with chloride that closely approximates that of seawater. Lithium and potassium ion concentrations, although increasing rapidly with time, have shown declining ratios relative to chloride whereas the calcium and magnesium concentrations have shown increases in both absolute and in relative concentrations with respect to chloride (Fig. 2). The change in dissolved ion chemistry has also been accompanied by a decline in the pH of the liquid phase of the discharge from an initial value of approximately 7.4 to a current value of about 6.5. Although not as well documented as the major ion chemistry, the trace metal ion concentrations, have also shown a trend of increasing concentrations throughout the production interval.

In contrast to the nearly tenfold increase in ion concentrations, the dissolved silica and non-condensable gas concentrations have remained remarkably constant throughout the current production interval. Silica values have remained at approximately 850 mg/kg in the separated brine throughout the more than four years of production and the non-condensable gas concentrations have declined by less than ten percent from their initial concentration of approximately 2400 mg/kg and have maintained nearly constant relative mole fractions.

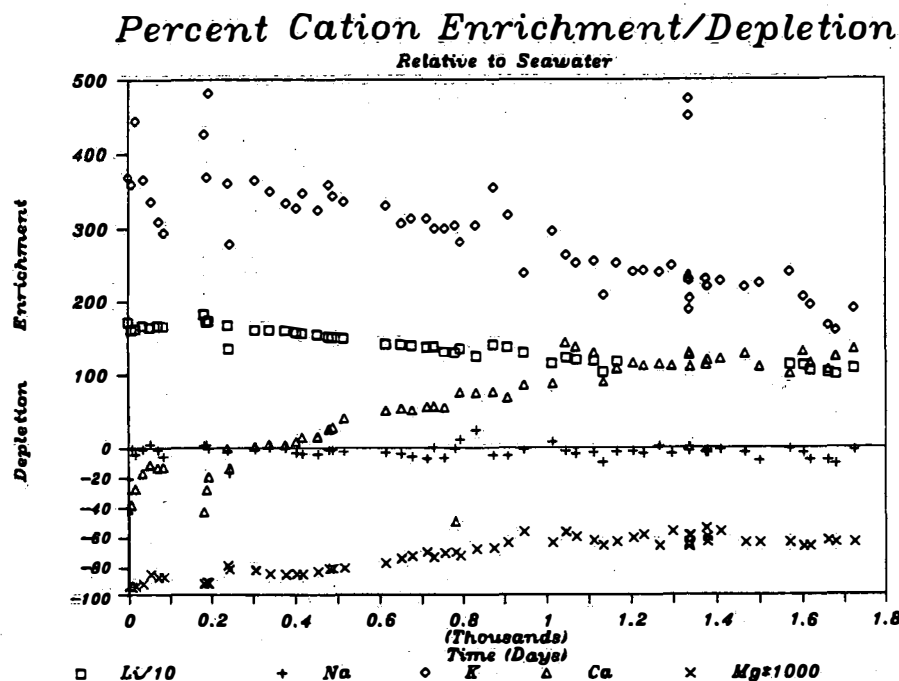


Fig. 2. Percent cation enrichment in HGP-A brine normalized to seawater chloride.

DISCUSSION

Earlier interpretations of the fluid chemistry in the HGP-A well suggested that the primary source of fluids in the geothermal reservoir on the lower east rift zone is meteoric recharge that, because of both the thermal disruption of the Ghyben-Herzberg lens and the permeability structure of the rift zone, is able to displace seawater from the rift faster than it is able to intrude into the hydrothermal system (Thomas, in press). The more recently gathered data indicates that the perturbation imposed by the production of fluids from the geothermal well has resulted in an increase in the rate of seawater recharge to the hydrothermal system. The seawater origin of the current recharge is substantiated by the near coincidence between the geothermal brine Na/Cl ratios and that of seawater. Although the other cation to chloride ratios are substantially different from those in seawater, the patterns of enrichment and depletion are nearly identical to those found in laboratory seawater/basalt experiments and are quite similar to those found in fluids discharged from seafloor hydrothermal systems (Table 1).

The degree of enrichment of the lithium and potassium ions suggest that hydrothermal alteration of the reservoir rocks is proceeding very rapidly in response to the intrusion of seawater into the reservoir; comparison of the Li and K concentrations in the seawater portion of the discharge with their respective concentrations in the Hawaiian tholeiites suggests that the water/rock ratio during the initial period of production was quite high. The decline in the relative enrichment of these ions with duration can be interpreted to indicate that this ratio has increased and that the easily removed lithium and potassium ions present in the reservoir rocks are being depleted and alteration of the calcic minerals has begun. The decline in the pH of the geothermal fluids concurrent with the changing ion concentrations may represent a loss in the capacity of the reservoir rocks to buffer the loss of $MgOH_2$ from the intruding seawater and hence provides some substantiation for this

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Table 1. Major ion chemistry and enrichment factors relative to seawater of HGP-A brine and other geothermal fluids.

Date/Location	Li (ef)	Na (ef)	K (ef)	Ca (ef)	Mg (ef)	Cl
6/18/81	0.34 (17.2)	1100 (0.996)	200 (4.88)	25 (0.59)	0.006 ($10^{-4.2}$)	1986
6/7/82	0.94 (18.3)	3120 (0.990)	525 (4.54)	122.5 (1.016)	0.051 ($10^{-3.87}$)	5667
6/9/83	1.13 (14.8)	4480 (1.01)	660 (4.00)	269 (1.58)	0.14 ($10^{-3.58}$)	8000
6/26/84	1.12 (13.0)	4840 (0.967)	660 (3.56)	443 (2.31)	0.229 ($10^{-3.42}$)	9000
6/13/85	1.12 (11.7)	5400 (0.968)	664 (3.20)	493 (2.31)	0.241 ($10^{-3.45}$)	10035
2/28/86	1.12 (11.9)	5360 (0.984)	587 (2.90)	493 (2.37)	0.234 ($10^{-3.45}$)	9800
Reykjanes	6.6 (35.9)	9560 (0.891)	1380 (3.49)	1580 (3.87)	1.43 ($10^{-2.95}$)	19200
21°N	7.28 (38.0)	11380 (1.02)	977 (2.36)	862 (2.02)	—	20030
Exp'tl	—	10765 (1.00)	1255 (3.15)	2263 (5.49)	6.9 ($10^{-2.27}$)	—

hypothesis. However, comparison of the relative enrichments and depletions in the HGP-A brines with laboratory results for a water/rock ratio of one (Exp'tl, Table 1) suggests that the effective W/R ratio in the HGP-A fluids is still quite low.

An alternative interpretation for the changing degree of enrichment and depletion of the cations is that the decline in relative concentrations of lithium and potassium and the increase in calcium concentrations corresponds to a decrease in geochemical temperature of the intruding seawater. The apparent decline would represent a change in temperature from approximately 305°C to a current temperature of about 235°C. If the latter interpretation is correct, the constancy of the silica concentrations, and apparent temperature of 300°C, in the brine phase would suggest that the cation geothermometer is reflecting an earlier (colder) temperature of the intruding seawater. Continued monitoring of the fluid chemistry will permit us to determine whether the changes in ion chemistry reflect the depletion of wall rock minerals or of reservoir enthalpy.

ACKNOWLEDGEMENTS

The assistance of D. Mills, J. McCullough, R. Taylor, and E. De Carlo in the chemical analysis of the geothermal fluids is gratefully acknowledged. The work reported here has been supported by the State of Hawaii, the Hawaii Electric Light Company and the U.S. Department of Energy. HIG Contrib. No. 1732.

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