

Mineralogical Assessment of Reservoir Fluid Conditions, SOH Geothermal Drill Holes

Submitted by

Martha L. Sykes
Hawaii Institute of Geophysics
2525 Correa Road
Honolulu, HI 96822

Purpose and Significance

The Kilauea East Rift Zone of the Big Island of Hawaii has great potential as a geothermal energy resource comparable to Iceland's. However, many questions remain unanswered about characteristics of the geothermal reservoir. In particular, composition of the geothermal fluids with respect to relative contribution of seawater and meteoric water, flux of water through the system (fluid:rock ratio), locations of and controls on aquifers, and the degree of porosity and permeability reduction by deposition of secondary phases are poorly understood. Production-induced variations in fluid chemistry were observed for HGPA well, but the background range of conditions due to tectonically or magmatically induced variations in seawater:meteoric water, fracture permeability, and downhole temperature are unknown.

The purpose of this proposed research is to provide some preliminary answers to these questions, by the mineralogical, geochemical, and textural assessment of the State of Hawaii (SOH) drill holes 4, 2 and 1, as an aid to reservoir engineering assessment. A detailed knowledge of alteration mineral assemblages, their distribution and chemistry is essential for any future assessments of fluid-rock interactions in these drill holes.

Previous Work

Previous work on these drill holes indicate variable degrees of alteration and mineralization in each. Most work has been completed on SOH-4, which contains an upper unmineralized zone (0-600 m), a mineralized subaerial sequence of a'a and pahoehoe flows plus ash beds (600-1700 m) and an extensively mineralized submarine pillow basalt - hyaloclastite sequence (1700-2000 m). Preliminary x-ray diffraction (XRD) analysis by the proposer indicates groundmass alteration to chlorite + quartz +/- albite through the lower part of the core. Volumetrically significant secondary crystallization includes the zeolites analcime, thomsonite, stilbite and ?laumontite plus quartz, calcite and mixed layer smectites through the upper part of the second zone. Zeolites appear to be absent from the lowest parts of the hole. Anhydrite, albite, adularia(?), and quartz are present through the lower 500 m of SOH-4. Pyrite and chalcopyrite are present in trace amounts through the lower part of the hole. Clay minerals are pervasive in both altered groundmass and as fracture and vug linings. Preliminary XRD analysis indicates the presence of allophane, imogolite, and smectite in the upper part of the core; through the middle and lower zones smectite is dominant, with mixed layer smectite/chlorite and ?chrysotile present in the lowest parts of the core. Hand sample analysis during logging of SOH-1 indicates zeolite mineralization through the 5280 feet level (R. Evans, E. Novak, pers. commun.).

These preliminary results suggest variable permeability controls the location of altered zones, while the alteration mineralogy depends on fluid composition and temperature. The presence of zeolites through the upper 3500 ft of SOH-4 suggests relatively low fluid:rock ratio, while the assemblage quartz + albite + chlorite through the lower parts of the core suggest somewhat higher fluid:rock ratios, perhaps on the order of 10-50, by analogy with seafloor hydrothermal systems (Mottl, 1983). A seawater component to the geothermal fluid is suggested by the presence of anhydrite in SOH-4. The presence of secondary albite both as replacement of plagioclase in basalt groundmass and as a fracture and vug lining can be due to precipitation of sodium from seawater or from leaching of sodium from basalt followed by redeposition in cooler upflow regions. Preliminary energy dispersive analysis of some SOH-4 samples indicated the presence of chlorine-rich phases, suggestive of high salinity fluids.

Proposed research

To make a preliminary assessment of the nature of fluid-rock interactions in SOH-4, -1, and -2, we propose a simple mineralogical and geochemical study of a sample suite from each of the three drill holes; this study will be in conjunction with the petrological study proposed by John Sinton and Tom Hulsebosch. Major techniques used for analysis include X-ray diffraction for mineralogy, electron microprobe analysis of chlorites, and petrographic examination and modal analysis to determine mineralogy and paragenesis of the alteration assemblages. Initial petrography will be based on the Sinton and Hulsebosch sample set; additional samples will be collected from productive zones. Fluid inclusion analysis is potentially a valuable technique in assessing the nature of the geothermal fluid(s); petrographic analysis of thin sections in altered zones will provide an initial indication of the utility of this method.

1. Fluid:rock ratios: These can be determined crudely by analyzing the variation in amount of chlorite plus quartz in the groundmass alteration assemblage (Mottl, 1983a, b; Thompson, 1983), compared to relatively unaltered material such as dike selvages and interiors of dense flows. Relative amounts of chlorite, quartz, and other phases such as albite in the groundmass will be determined by comparison of XRD patterns and by modal analysis of thin sections.

Chemical analysis of core samples is necessary to establish quantitative fluid:rock ratios. Zones of depletion or enrichment in elements such as Mg, Ca, and Na due to interaction of geothermal fluids with the basalts will be determined by XRF analysis of samples, assuming that aluminum is constant (c.f. Mottl, 1983a). By comparing these fluxes with fluid composition (analyzed or assumed) a more quantitative measure of fluid:rock ratio can be obtained. XRF analyses will be obtained from the companion petrological study proposed by Sinton and Hulsebosch.

2. Fluid composition: Assuming that the geothermal fluids are in equilibrium with their alteration assemblages, the composition of the secondary minerals should reflect fluid composition. Assumption of equilibrium appears valid for the analogous Icelandic geothermal systems (Arnórsson et al., 1983). For example, variations in the Mg/Fe content of hydrothermal chlorites has been correlated with variation in fluid composition as well as fluid-rock ratios (Thompson, 1983). The cation composition of feldspars and zeolites will also be sensitive to the alkali content of the fluids. Mineral compositions will be determined by electron microprobe analysis of phases in polished thin sections, or by energy dispersive analysis of finer-grained phases with the SEM.

A more direct method of assessing fluid composition for SOH samples is by analysis of fluid inclusions in secondary quartz grains. Quartz crystals are abundant as vug and fracture fillings and linings in some zones of the core; some of these crystals appear to have large fluid inclusions suitable for analysis.

3. Temporal variations: Paragenesis of alteration and secondary minerals will be most easily determined by careful petrographic analysis of thin sections of core material. Special attention will be paid to replacement textures and sequence of crystallization. Finer-grained samples will be studied with SEM.

4. Reservoir permeability: The true utility of mineralogically based studies of these geothermal systems comes by combining these data with those for reservoir fluid compositions and other *in situ* drill hole measurements. For example, discrepancies between core-based determinations of high permeability zones with those from well logging could indicate fracture sealing by secondary deposition from the geothermal fluids. Determination of the sequence of mineralization in fractures and the fluid-rock interactions resulting in deposition of minerals will delineate possible future changes in reservoir permeabilities.

More detailed studies of fluid-rock equilibria such as that of Ragnarsdottir et al. (1984) for an Icelandic geothermal system rely on a combination of mineralogical data and fluid chemistry. Although such a study is beyond the present scope of this proposal, the data collected will be essential for a detailed geochemical study of these geothermal systems.

References

- Arnórsson, S., E. Gunnlaugsson, and H. Svavarsson, 1983, The chemistry of geothermal waters in Iceland. II. Mineral equilibria and independent variables controlling water compositions. *Geochim. Cosmochim. Acta* 47, 547-566.

- Mottl, M.J., 1983a, Hydrothermal processes at seafloor spreading centers: application of basalt-seawater experimental results, in *Hydrothermal Processes at Sea-floor Spreading Centers*, eds. P.A. Rona, K. Bostrom, L. Laubie and K.L. Smith, Jr., Plenum Press, NY, pp. 199-224.
- Mottl, M.J., 1983b, Metabasalts, axial hot springs, and the structure of hydrothermal systems at mid-ocean ridges. *Geol. Soc. Amer. Bull.* 94, 161-180.
- Ragnarsdottir, K.V., J.V. Walther and S. Arnorsson, 1984, Description and interpretation of the composition of fluid and alteration mineralogy in the geothermal system, at Svartsengi, Iceland. *Geochim. Cosmochim. Acta* 48, 1535-1553.
- Thompson, G., 1983, Basalt-seawater interaction, in *Hydrothermal Processes at Sea-floor Spreading Centers*, eds. P.A. Rona, K. Bostrom, L. Laubie and K.L. Smith, Jr., Plenum Press, NY, pp. 225-278

ESSENTIAL BUDGET

Note: If the on-going work on samples from SOH-4, -2, and -1 is completed, unexpended funds can be used to work on future core material.

Sample preparation:

1. Doubly polished thin sections for fluid inclusion work: 15 @ \$20 each	\$ 300
2. Polished thin sections for petrography: 100 @ \$15	<u>1,500</u>
Total sample preparation	<u>\$1,800</u>

Analysis

3. X-ray diffraction: 240 samples @ \$100/12 (overnight runs)	2,400
4. Electron microprobe: 100 samples/200 hrs @ \$15/hr	3,000
5. SEM analysis: 40 hours at \$55/hr	<u>2,200</u>
Total analysis	<u>\$7,600</u>

Travel: three two-day trips to the Big Island for sample collection:
each \$90 airfare + \$50 per diem + \$50 rental car

\$ 570

Salary for M.L. Sykes

6 months 50% time @ \$4,858/mo	14,574
Fringe benefits @ 37.5%	<u>5,465</u>
Total salary and fringe	<u>\$20,039</u>

Subtotal

\$30,009

Overhead

10% of MTDC for State funds	<u>3,001</u>
-----------------------------	--------------

Total

\$33,010