DOE/ET/28392-17

FINAL REPORT

**Hydrothermal Alteration at the Roosevelt
Hot Springs Thermal Area, Utah**

by

W. T. Parry, N. L. Bryant, R. E. Dedolph, J. M. Ballantyne

G. H. Ballantyne, D. T. Rohrs, and J. L. Mason

Work performed under Contract No.

EG-78-C-07-1701

Department of Geology and Geophysics

University of Utah
Salt Lake City, Utah (USA)

November 1978

Prepared for
DEPARTMENT OF ENERGY
Division of Geothermal Energy

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

NOTICE

This report was prepared to document work sponsored by the United States Government. Neither the United States nor its agent, the United States Department of Energy, nor any Federal employees, nor any of their contractors, subcontractors or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

NOTICE

Reference to a company or product name does not imply approval or recommendation of the product by the University of Utah or the U.S. Department of Energy to the exclusion of others that may be suitable.

Final Report

Hydrothermal Alteration at the Roosevelt
Hot Springs Thermal Area, Utah

by

W. T. Parry, N. L. Bryant, R. E. Dedolph, J. M. Ballantyne,
G. H. Ballantyne, D. T. Rohrs, and J. L. Mason

November 1978

Abstract

Hot spring deposits in the Roosevelt thermal area consist of opaline sinter, and siliceous-sinter-cemented alluvium. Alluvium, granite to granodiorite plutonic rocks, and amphibolite facies gneiss have been altered by acid-sulfate water to alunite and opal at the surface, and to kaolinite, alunite, montmorillonite, and muscovite to a depth of 60m. Marcasite and pyrite occur below the water table at about 30m. Deeper alteration sampled to a depth of 2.26 km consists of muscovite, chlorite, calcite, K-feldspar, albite, and epidote with pyrite and sparse chalcopyrite.

Thermal water is dilute (ionic strength 0.1 to 0.2) sodium chloride brine. Surface water contains 10 times as much calcium and 100 times as much magnesium as the deep water. Sulfate varies from 48 to 200 mg/l. Present-day spring temperature is 25°C but in 1950 the spring temperature was 85°C. Computed Na-K-Ca temperature is 241°C for the present-day spring, 274°C for a well and 283°C for the 1957 spring. Quartz saturation temperatures are 170°C for the present-day spring, 283°C for the well, and 213°C for the 1957 spring.

A plausible model for development of the near-surface alteration consists of hydrothermal fluid which convectively rises along major fractures. Water cools by conduction and steam separation, and hydrogen ion is produced by oxidation of hydrogen sulfide. The low pH water percolates from the surface downward and reacts with rocks to produce alunite, kaolinite, montmorillonite, and muscovite as hydrogen is consumed.

Introduction

The Roosevelt Hot Springs thermal area is located within the Basin-and-Range province 21 km northeast of Milford, Beaver County, Utah, on the western flank of the Mineral Mountain Range. Hot spring deposits and hydrothermal alteration occur within alluvium from the Mineral Mountains, high grade metamorphic rocks of undetermined age, and a Tertiary granite to granodiorite pluton. Hydrothermal activity consists of a small water-seep with a temperature of 25°C, but opal deposits and alteration attest the vigor of past activity. The spring discharge was 38 liters per minute at 88°C in 1908, 4 liters per minute at 85°C in 1950, "small" at 55°C in 1957, and in 1966 the spring was completely dry (Mundorff, 1970). Surface and deep thermal waters are dilute (ionic strength = .1) sodium chloride brines with chemical similarities to New Zealand geothermal fluids. Commercial power production capability of the area is currently under evaluation.

Our investigation of hydrothermal alteration at the Roosevelt Hot Springs Thermal Area has included detailed surface mapping; chemical analysis and mineralogical study of surface outcrop, three shallow cores, and three deep wells; determination of fluid chemistry; and theoretical modeling of hot water - rock interaction.

Hot Spring Deposits and Surface Alteration

Spring deposits and alteration exposed in outcrop are shown in Figure 1; chemical compositions of outcrop samples are shown in Table 1, and computed modal mineralogical compositions are shown in Table 2.

Figure 1 Geologic map of the Roosevelt Hot Springs Thermal Area, Utah. Mapping by R. E. Dedolph and W. T. Parry, 1976, and adapted from Petersen (1975) and Evans (1977). Circled numbers refer to the outcrop samples of Table 1 and Table 2.

Table 1. Chemical analyses of rocks from the Roosevelt
Hot Springs Thermal Area, Utah*

	R1	R3	R4	R5	R6	R7	R9	R13	R14	R15	P16	R20	R21	R22	R24a	R24b	R25
SiO ₂	77.8	90.1	82.0	75.8	75.8	86.8	95.8	71.8	56.4	59.7	72.9	71.3	63.5	71.7	62.9	62.3	72.0
Al ₂ O ₃	8.8	4.9	6.5	10.5	11.1	5.0	2.8	9.0	15.4	13.6	9.7	8.5	13.2	12.4	19.3	6.8	11.5
TiO ₂	.57	.08	.14	.64	.61	.37	.00	.84	.37	.37	.21	.18	.27	1.5	.21	.58	.47
Fe ₂ O ₃ **	3.4	1.1	1.7	3.6	4.8	2.0	.86	.85	.77	1.3	.95	1.3	1.3	6.3	2.0	5.7	4.9
MgO	.43	.30	.52	.93	.00	.74	.10	1.1	.00	.00	.04	.11	.00	2.6	.93	.00	.64
CaO	1.1	.47	3.0	1.4	.36	.53	.11	6.4	.20	.03	.22	2.2	.02	.74	.12	.95	1.1
Na ₂ O	3.3	1.3	1.9	3.6	2.1	1.4	.10	.66	.34	.00	.33	.44	.45	1.3	2.5	.57	4.0
K ₂ O	4.3	1.7	4.2	3.4	4.8	2.9	.09	4.3	5.2	4.9	6.1	3.1	5.3	3.2	7.1	2.8	5.3
SO ₃	.32	.07	1.3	.26	.47	.32	.16	5.2	21.4	20.1	9.6	12.9	16.0	.17	4.9	20.3	.13

*x-ray emission analyses using the method of Norrish and Hutton (1969)

recalculated to 100% on an ignition dry basis

**Total Fe as Fe₂O₃

Table 2. Modal mineralogical compositions in weight percent of
rocks from the Roosevelt Hot Springs Thermal Area, Utah*

	R1	R3	R4	R5	R6	R7	R9	R13	R14	R15	R16	R20	R21	R22	R24a	R24b	R25
quartz+opal	46	74	58	41	42	69	94	56	56	60	62	71	61	35	29	60	38
k-feldspar	22	10	21	17	33	13	.1	17			16	24	2	3	52	3	26
plagioclase	24	12	14	32	17	10	2	5			.3		2	11			18
biotite	3	2	3	6		5	.7				.3			17			3
alunite	.7	.2	.3	.6	1	.7	.5	12	41	38	19		33		12	19	.3
sulfur										3	1	7	2			12	
kaolinite														7			3
montmorillonite														23			6
hematite			1	2	5	1	.7	.9	.8	1	.9	1	1	2	2	4	4
sphene	2	.3	.5	2	1	1	.2	3	.8	.2	.6	.7	.1	2	.5	2	1
rutile	3	.7			.2					.3			.3		.03		

*Mineralogical compositions determined by a combination of x-ray diffraction,
petrographic examination, and least squares fit to chemical analyses.

Siliceous sinter is the dominant hot spring deposit. Thin bedded, varicolored, opaline sinter occurs in the Opal Mound area, Figure 1. Smaller areas of sinter crop out elsewhere in the mapped area. White, opaque, opaline sinter, chalcedonic sinter, cellular sinter, microbanded, colloform, and knobby sinters are common in the Opal Mound area. Analysis R3 in Table 1 and Table 2 is typical of the sinter deposits. Vertically laminated and banded opal occurs within old spring vents exposed on the opal mound.

Sinter cemented alluvium surrounds the spring vents and constitutes a transition between altered alluvium and spring deposits. Mineral and rock fragments derived from the Mineral Mountains have been cemented by opal and chalcedony. Analyses R1 and R4 through R9 in Table 1 and Table 2 are representative compositions of sinter cemented alluvium.

Altered and cemented alluvium is the dominant surface alteration type in the Roosevelt Thermal area. Mineral and rock fragments derived from granitic rocks, gneiss, and volcanic rocks of the Mineral Mountain Range have been cemented by varicolored opal and chalcedony. The feldspars, biotite, hornblende and volcanic glass have been altered by acid-sulfate spring water to alunite and opal. Hematite stains the opal and fills small intergranular pores. Cubic pseudomorphs of hematite after pyrite also occur within opal cement. Analyses R10 through R24b in Table 1 and Table 2 are representative of altered alluvium. Native sulfur occurs with opaline sinter and in intergranular spaces in cemented alluvium as very fine to coarse euhedral to anhedral crystals. Microcrystalline sulfur is intergrown with alunite in altered alluvium.

Alluvium which is not visibly altered or cemented is widespread in

the hot spring area and consists of mineral and rock fragments of granitic rock, gneiss, and volcanic rocks, from clay through coarse sand and gravel size to sporadic boulders up to one meter in diameter. Analysis R25 in Table 1 and Table 2 is an example of unaltered alluvium composition.

Restricted lithologies include an altered, bedded volcanic ash which occurs in a sulfur prospect pit in Hot Springs Wash near sample site 24, and near DDH 1B. The outcrop near DDH 1B contains glass and alunite and an analysis of this material is presented as analysis R13 in Table 1 and Table 2. Altered, biotite-rich rock crops out near the salt spring at sample site 22. Kaolinite and montmorillonite occur with biotite quartz, orthoclase and plagioclase. Analysis R22 in Table 1 represents the composition of this altered rock.

The distribution of altered rocks and spring deposits is apparently fault controlled. Faults inferred from the alteration include a northeast striking set and a northwest set. The most conspicuous fault is the northeast striking Opal Mound fault which, with less prominent parallel striking faults, has localized the sinter and cemented alluvium of the opal mound. Other faults are inferred from location and orientation of spring deposits and altered rocks.

Shallow Subsurface Alteration

Three shallow holes have been drilled from which core was recovered for alteration studies: DDH 1A, DDH 1B, DDH 1976-1. Lithologic and alteration logs of these three drill holes are shown in Figure 2.

Each of the three holes penetrated altered rocks near the Opal Mound fault, where quartz monzonite of Tertiary age, metamorphic rocks of

Figure 2 Geologic cross-section parallel to the Opal Mound Fault of Figure 1, looking northwest. Mineral abundance data for diamond-core holes is computed from a linear, least-squares fit to bulk rock chemical composition determined by x-ray emission analyses.

undetermined age and Quaternary alluvium are hosts for hydrothermal alteration.

Altered and cemented alluvium occurs to 35m in DDH 1A. Very fine grained alunite and opal replace all but quartz grains in alluvium from the granite. Opal lines and fills fractures and intergranular pores. Traces of realgar and cinnabar and up to 5% native sulfur occur in opal-rich zones. Kaolinite first appears at 18m, montmorillonite at 20m, and K-mica at 32m. Jarosite fills intergranular pores and fractures from 24.4m to 32m, and traces of barite occur at 20.4m. Pyrite and marcasite overgrowths on pyrite occur from 32m downward. No sulfate minerals are present below 32m. Altered and brecciated gneiss occurs from 35m to the bottom of the hole at 66m. Moderately to intensely brecciated gneiss contains varying proportions of bleached, sericitized biotite, K-feldspar, plagioclase, pyrite, marcasite, kaolinite, K-mica, and montmorillonite. Hydrothermal K-feldspar partially replaces a few plagioclase crystals and fills fractures.

In diamond drill hole 1B, no core or cuttings were recovered from the surface to 40.5m. Core consists of altered and cemented alluvium from 40.5m to 64m. Angular and rounded fragments of quartz, K-feldspar, plagioclase, biotite, granite, and gneiss from silt to gravel size are embedded in a clay matrix. Plagioclase and biotite are altered to clay, in patches and veinlets. Vein and intergranular K-feldspar is prominent at 47.2m and 56.4m. Clay minerals are kaolinite, K-mica, montmorillonite and interstratified montmorillonite-mica. Fault gouge consisting of very fine grained clay, quartz, K-feldspar, and biotite occurs at 64m to 65.5m. From 65.5m to the bottom of the hole at 70.4m, altered gneiss consists of

plagioclase, quartz, and biotite, with clay developed in patches and along fractures, and occasional large patches of K-feldspar. Interstratified clay, kaolinite, and K-mica occur to 69.2m where K-mica becomes the only detected clay mineral.

Diamond drill hole 1976-1 encountered altered and cemented granitic alluvium from 3m to 19.8m. Detrital fragments of quartz and feldspar are cemented by opal and chalcedony. The feldspar has been altered to opal, alunite, jarosite, and clay. Biotite is altered to vermiculite.

Porous, cellular sinter with alunite lining the cells occurs near 3.7m. Intensely altered quartz monzonite occurs from 19.8m to 32m. Vermiculite, clay, opal and chalcedony occur as fracture fillings, patches, and replacement of feldspars. The interval 32m to 35.7m is fault gouge and breccia consisting of quartz in a clay matrix with veinlet and disseminated pyrite. Moderately altered quartz monzonite occurs from 35.7m to the total depth of 61m with veinlets of green muscovite, clay, and pyrite. Patches of clay and a few scattered patches of calcite replace feldspars and biotite. Biotite is also replaced by green muscovite. A narrow zone of fine grained secondary quartz and K-feldspar occurs at 49.4m. Numerous small veinlets of K-feldspar-quartz intergrowths persist to 60m. General alteration intensity changes from moderately altered at 35.7m to weakly altered at 60m. Numerous shear and deformed zones occur from 19.8m to 60m. Clay minerals in DDH 1976-1 are alunite and vermiculite from 3.7m to 9.1m; kaolinite and muscovite from 9.1m to 19.8m; kaolinite, muscovite, and interstratified muscovite-montmorillonite from 19.8m to 32m; montmorillonite, muscovite, and chlorite from 32m to 38.1m; and muscovite with calcite from 38.1m to 61m.

Deep Subsurface Alteration

Hydrothermal alteration characteristics have been determined from cuttings from three deep test wells: Thermal Power Company well Utah State 14-2, drilled in plutonic rocks to a depth of 1866m; Thermal Power Company well Utah State 72-16 drilled in plutonic rocks to a depth of 382m, and Getty Oil Company well Utah State 52-21 drilled in amphibolite facies metamorphic rocks to a depth of 2256m.

Thermal Power Company well Utah State 14-2 is located 1.6 km east of the Opal Mound Fault (Figure 1). The hole was drilled in alluvium to 76.2m and in igneous intrusive rocks from 76.2m to 1866m. The major rock type is a medium grained biotite hornblende monzonite, which has been intruded by granite to andesite dikes.

Thermal Power Company well Utah State 72-16 is located 500m east of the Opal Mound on Figure 1. The hole was drilled in alluvium and opal cemented alluvium to 152m and in intrusive igneous rocks from 152m to 382m. The predominant igneous rock is hornblende biotite granodiorite which is cut by diorite, dacite and latite dikes. Biotite hornblende quartz monzonite occurs in the lower 30m of the well.

Getty Oil Company well 52-21 is located 2 km south of the Opal Mound and is not shown in Figure 1. The well was drilled in alluvium to 183m and amphibolite facies metamorphic rocks from 183m to 2256m. All lithologies are weakly altered to chlorite + sericite + clay with occasional traces of calcite above 762m and calcite + epidote below 762m. Zones of increased alteration intensity occur in the interval 584.6m to 701m within and adjacent to a dacite dike, and from 1829m to the bottom of the hole.

Hydrothermal alteration has affected all rocks in well 14-2, but original rock textures are generally preserved. Zones of more intense alteration occur at 274m to 305m, 488m to 581m and 869m to 899m in well 14-2. Alteration product minerals in the well are white to light green sericite and calcite, which replace plagioclase, hornblende, and biotite and occurs as a vein filling along with quartz, calcite, sericite, and K-feldspar below 700m; epidote which occasionally replaces plagioclase and biotite; K-feldspar which replaces plagioclase and occurs as vein fillings; montmorillonite which was identified by x-ray diffraction in samples from 300m to 500m and interstratified K-mica-montmorillonite which occurs sporadically to 700m where chlorite and K-mica become the only clay minerals. Anhydrite and barite occur sporadically in small amounts below 1524m. Pyrite replaces magnetite, occurs as disseminated grains in plagioclase or as vein fillings. Chalcopyrite was tentatively identified in the cuttings. Limonite and limonite-calcite veins are common above 700m. A magnetite-K-feldspar-chlorite-pyrite vein was noted in core at 800m.

Microprobe-determined chlorite compositions show distinct differences due to host mineral type. Tetrahedral Si in chlorite increases according to host mineral types in the order: biotite, plagioclase, hornblende. Octahedral Mg increases in the order: plagioclase, hornblende, biotite. Compositions vary with depth but no systematic trend was recognized. Chlorite specimens from 701m to 1859m are structural type IIB. No systematic trend in structural polymorph was found. Sericite replaces plagioclase and rarely biotite. No host mineral effect on sericite composition is evident. The sericites are phengitic with Si to Al ratios

greater than 3 to 1. Both Si and F/Mg increase with depth.

Water Chemistry

Chemical analyses of surface waters are summarized in Table 3.

While there is some variability, the sodium chloride-rich nature of these waters is preserved in all analyses. Ionic strength generally varies from 0.11 to 0.2. Sulfate concentrations vary from 48 to 200 mg/l and total dissolved solids approximate 6000 mg/l. Surface waters (from the seep; analysis 1) differ from the deep waters (analysis 2,) and the hot springs (analysis 3). Surface Mg^{2+} is greater by a factor of 100, and surface Ca^{2+} is greater by a factor of 10 than the deep waters.

The highest Na-K-Ca temperature in the state of Utah (according to the analysis of Mundorff, 1970, and calculations of Swanberg, 1974), occurs at Roosevelt Hot Springs. Analysis of a cool seep (Table 9) indicates a Na-K-Ca temperature of 241°C.

In his discussion of thermal waters associated with Tertiary and Quaternary volcanism, White (1957) described waters that are variously enriched with sodium chloride, H^+ , sulfate, and bicarbonate. Within White's definitions, Roosevelt Hot Springs water could be defined as a sodium chloride water grading into an acid sulfate water. The sulfate measurements of 54-200 ppm (at Roosevelt) are lower than those at Norris Basin, Yellowstone Park (454 ppm) or Frying Pan Lake, New Zealand (262 ppm) which have been defined as acid-sulfate, chloride waters. Both Na and Cl contents of waters from Roosevelt are considerably higher than for sodium chloride waters described by White (Steamboat Springs, Washoe County, Nevada; Morgan Springs, Tehama County, California; Norris Basin, Yellowstone Park, Wyoming; Well 4, Wairakei, New Zealand). White envisions

Table 3. Major constituents in mg/l in selected water from the Roosevelt Hot Springs Thermal Area, Utah

	(1)	(2)	(3)
Na	1840	2072	2500
Ca	122	31	22
K	274	403	488
SiO ₂	173	639	313
Mg	25	.26	0
Cl	3210	3532	4240
SO ₄	120	48	73
HCO ₃	298	25	156
Al		1.86	.04
Fe		.016	
Total Dissolved Solids	6063	6752	7792
Temp.	25°C	92°C	55°C
pH	6.5	5.0	7.9
Na-K-Ca Temp.	241°C	274°C	283°C
SiO ₂ Temp.	170°C	283°C	213°C

(1) Roosevelt Seep. University of Utah, June, 1975.

(2) Thermal Power Company Well 72-16, University of Utah, Jan., 1977, surface leakage.

(3) Roosevelt Hot Springs, U.S. Geol. Survey, Sept., 1957, Mundorff (1970).

these waters having formed by a process which includes: 1) the rising from a magma chamber at a depth, of supercritical, high density gases (CO_2 , H_2S , alkali halides, SiO_2 , etc.); 2) condensation of this phase into a sodium chloride water which heats meteoric water by conduction; 3) the ascension of meteoric water which cools and becomes more acidic as boiling occurs; and 4) the oxidation of H_2S above the water table by atmospheric oxygen. This is not an unreasonable process for the Roosevelt Hot Springs convective hydrothermal system.

Age of the Hydrothermal Activity

Brown (1977a, 1977b) has attempted two independent estimates of the duration of hot spring activity at Roosevelt. The first estimate is based on obsidian hydration rind thickness (Brown 1977a) and a calculated hydration rate at 10°C of $3.5 \mu\text{m}^2/10^3 \text{ yrs.}$ The time required for development of the hydration rim on one obsidian sample in silicified alluvium is 220,000 years, which must be regarded as a maximum estimate because the effective hydration temperature probably exceeded 10°C for at least part of the time. The second estimate of duration of hot spring activity is based on measurements of remnant magnetism in opal from the opal mound. These measurements (Brown, 1977b) result in an estimate of 70,000 years for deposition of about 7 meters of opal, all of it during the Bruhnes epoch, i.e. during the last 690,000 years. Systematic changes in magnetic declination and inclination in 20 cm of opal core can be correlated with the Biwa II (295,000 yrs.), Biwa I (181,000 yrs.), Black (111,000 yrs.), Mungo (30,000 yrs.) or Laschamp (12,000 yrs.) providing a minimum estimate of 12,000 years for Roosevelt Hot Springs activity. Young

volcanism began 0.8 m.y. ago with eruption of rhyolite from two vents 4 km east of the hot springs. At least ten rhyolite domes and small flows were produced in the period 0.6 to 0.5 m.y. ago along the crest and western flank of the Mineral Mountains. Hydrothermal activity could have been initiated with each of these events.

Alteration Geochemistry

The activity diagrams in Figure 3 represent the major alteration product minerals observed at Roosevelt Hot Springs. Even though plagioclase is a major reactant mineral, there are no sodium product minerals except for minor sodium montmorillonite and possibly natrojarosite. Biotite is consistently altered to vermiculite and green muscovite. Even though thermodynamic data for vermiculite can be estimated, lack of reliable Fe^{+3} and Fe^{+2} data for minerals and fluids at Roosevelt preclude the drawing of activity diagrams including vermiculite.

Figure 3 indicates the following: 1) A solution at 100°C with an $a_{\text{Mg}^{2+}}$ high enough for a sizeable Mg-montmorillonite field, restricted to a_{SiO_2} between quartz and opal saturation, can produce opal with alunite, Mg-montmorillonite and kaolinite. 2) At the assumed ion activities, muscovite can form only in a solution undersaturated with respect to quartz. The muscovite field can be intersected at quartz saturation or opal saturation at 100°C if $a_{\text{Mg}^{2+}}$ is decreased and $a_{\text{K}^{+}}$ is increased. 3) Calcite is incompatible with alunite at all temperatures.

Geothermal fluid compositions are shown in the activity diagrams of Figure 3b, 3c, 3d, 3e. The plotted water compositions are calculated activities at 100°C as shown in Table 4. These diagrams suggest that the

Figure 3. Activity diagrams for some minerals which occur in altered rocks of the Roosevelt Hot Springs thermal area.

A. $\text{pH} - \log a(\text{H}_4\text{SiO}_4)$ with $\log a(\text{K}^+) = -2.10$, $\log a(\text{Mg}^{++}) = -3.44$, $\log a(\text{SO}_4) = -3.10$ at 100°C .

B. $\log a(\text{K}^+)/a(\text{H}^+) - \log a^2(\text{H}^+) a(\text{SO}_4)$ with $\log a(\text{H}_4\text{SiO}_4) = -3.08$ (quartz saturation) at 100°C .

C. $\log a(\text{K}^+)/a(\text{H}^+) - \log a^2(\text{H}^+) a(\text{SO}_4)$ with $\log a(\text{H}_4\text{SiO}_4) = -2.2$ (amorphous silica saturation) at 100°C .

D. $\log a(\text{Mg}^{++})/a^2(\text{H}^+) - \log a(\text{K}^+)/a(\text{H}^+)$ with $\log a(\text{H}_4\text{SiO}_4) = -3.08$ (quartz saturation) at 100°C .

E. $\log a(\text{Mg}^{++})/a^2(\text{H}^+) - \log a(\text{K}^+)/a(\text{H}^+)$ with $\log a(\text{H}_4\text{SiO}_4) = 2.2$ (amorphous silica saturation) at 100°C .

Thermodynamic data for construction of the diagrams is from Helgeson (1969) and Hemley, et al., (1969).

Figure 3

Table 4. Molalities (m), activity coefficients (γ) and activities (a) of solution species in Roosevelt Hot Springs thermal waters at 100°C

Species	Roosevelt Seep			Thermal Power Co. 72-16 Surface Leakage		
	log m	log γ	log a	log m	log γ	log a
Ca ⁺⁺	-2.59	-.48	-3.07	-3.11	-.48	-3.60
Mg ⁺⁺	-3.01	-.46	-3.47	-4.97	-.46	-5.43
Na ⁺	-1.10	-.13	-1.22	-1.04	-.13	-1.17
K ⁺	-2.15	-.14	-2.29	-1.99	-.14	-2.12
Cl ⁻	-1.04	-.14	-1.18	-1.00	-.14	-1.14
SO ₄ ⁼	-3.03	-.50	-3.53	-3.41	-.50	-3.92
HCO ₃ ⁻	-2.37	-.12	-2.49	-3.38	-.12	-3.50
H ⁺	-6.40	-.10	-6.5	-4.90	-.10	-5.00
Log Activity Ratios						
log Ca/H ²		9.93			6.40	
log Mg/H ²		9.53			4.57	
log Na/H		5.28			3.83	
log K/H		4.21			2.88	
log H ² SO ₄		-16.53			-13.92	

observed alteration mineral assemblage could result from pH gradients in the geothermal system. Muscovite and kaolinite can be formed in solutions undersaturated to saturated with quartz, a condition not observed in surface water in the area. Water compositions plot near the stability field for Mg-montmorillonite. Waters are supersaturated with respect to quartz at 100°C which precludes equilibrium with muscovite or kaolinite. Equilibrium with Mg-chlorite requires a higher pH than is measured in Roosevelt waters, in fact, the Mg-chlorite occurs at depths where water-calcite-CO₂ equilibria would indicate a pH as low as 5.7. Minerals observed in the alteration assemblage and waters analyzed do not represent an equilibrium assemblage at the existing temperatures and depths.

The alteration can be interpreted in terms of a model proposed for Steamboat Springs, Nevada by Schoen and others (1974) in which H₂S in hydrothermal fluid is oxidized at the surface to sulfate which lowers the pH in the upper portion of an active hot spring system. Hydrogen ion and sulfate are carried downward by descending groundwater producing an alteration assemblage superimposed upon that produced by the ascending fluid.

At the Roosevelt Hot Springs, hydrothermal fluid in equilibrium with K-feldspar, muscovite, Mg-chlorite, calcite, and quartz at 260°C and a depth of 1 km convectively rises along the Opal Mound fault and related fractures. Water cools by conduction and steam separation, quartz and opal precipitate and, at the surface, H₂S oxidizes to sulfate decreasing the pH. The low pH, high sulfate waters then percolate downward and react to produce alunite, kaolinite, and muscovite in turn as hydrogen ion is consumed. Alteration products are formed by both upward moving and

downward moving fluids producing the observed mineral assemblages.

A theoretical model of the hydrolysis of microcline by water similar to surface waters at Roosevelt has been computed using the numerical techniques of Helgeson (1968). Reactant minerals present at Roosevelt, but not considered in the model are plagioclase, biotite, and hornblende. The results of the model calculations are illustrated in Figure 4. Quartz saturation was assumed throughout and a starting pH of 3.5 was used to ensure encountering alunite. Alunite saturation was reached first (Figure 4) followed by kaolinite saturation. Alunite then dissolved as kaolinite precipitated. When alunite was consumed, the solution composition traversed the field of kaolinite as kaolinite continued to precipitate. Muscovite saturation was then encountered and kaolinite dissolved as muscovite precipitated. When all kaolinite was consumed, the reaction path crossed the muscovite field and overall equilibrium was reached with muscovite, K-feldspar and solution. A summary of initial and final solution compositions and moles of minerals produced and destroyed in the model is given in Table 5.

Discussion

Alluvium, plutonic igneous rocks from granite to granodiorite, granite to andesite dikes, and amphibolite facies gneiss have been weakly to strongly altered in the Roosevelt Hot Springs Thermal area. Alteration is intense in surface and near surface rocks near the Opal Mound fault where acid-sulfate waters were probably present. Alteration is less intense in deeper wells and wells more remote from the Opal Mound fault. Alteration intensity in deep wells is correlated with fractured zones and dikes

Figure 4 Molalities of solution species and moles of minerals produced or consumed per kilogram of water during a hypothetical reaction of microcline with solution similar to Roosevelt thermal water at 100°C.

Table 5 . Initial and final solution compositions and moles of minerals produced and destroyed in a hypothetical reaction of microcline and acid-sulfate water at 100°C.

	log molality	
	initial	final
H^+	-3.54	-6.67
Al^{+3}	-6.89	-15.29
$Al(OH)_4^-$	-10.05	-5.89
K^+	-1.97	-1.95
KSO_4^-	-3.86	-3.80
HSO_4^-	-3.68	-6.78
$SO_4^{=}$	-2.68	-2.65
$H_3SiO_4^-$	-8.33	-5.19
H_4SiO_4	-3.06	-3.06
OH^-	-8.50	-5.36
	log moles	
	produced	destroyed
microcline	--	-3.12
quartz	-2.82	--
kaolinite	-3.60	-3.60
muscovite	-3.59	--
alunite	-4.15	-4.15

although all dikes are not altered.

The low overall abundance of alteration minerals in Roosevelt deep wells compared to systems such as Wairakei and Ohaki-Broadlands in New Zealand (Steiner, 1968, Browne and Ellis, 1970) and Reykjanes, Iceland (Tomasson et al., 1972) may be due to differences in host rocks. At Roosevelt the major rock types are medium grained, crystalline plutonic and metamorphic varieties, while the systems noted above occur in fine grained, dominantly pyroclastic, volcanic material with higher porosity and chemical reactivity than crystalline intrusive rock. At Ohaki-Broadlands welded tuffs and ignimbrites with low porosity exhibit little alteration despite high temperatures.

Alteration products of primary minerals in the Roosevelt system are similar to those found in other geothermal systems. At Ohaki-Broadlands hornblende and biotite are replaced by chlorite, illite, calcite, quartz or pyrite (Browne and Ellis, 1970) and at Wairakei ferromagnesian minerals are altered to chlorite, micaceous clays, quartz, calcite, epidote, apatite and pyrite (Steiner, 1968). At Steamboat Springs, hornblende is altered to mixed illite-montmorillonite and Fe-chlorite. Biotite is first bleached and then replaced by chlorite (Schoen and White, 1965). Original biotite and hornblende are not reported from Reykjanes or from the Salton Sea.

A range of plagioclase alteration products is reported from different geothermal systems. Browne and Ellis (1970) report that andesine at Ohaki-Broadlands is replaced by adularia, albite, calcite, illite, wairakite, epidote and quartz. Plagioclase at Wairakei has been converted to a variety of hydrothermal minerals, including montmorillonite, micaceous clays, calcite, wairakite, albite, K-feldspar, quartz and epidote (Steiner,

1968). At Steamboat Springs, plagioclase is replaced by illite-montmorillonite, calcite, albite, and at shallow depths by K-feldspar (Schoen and White, 1965). Specific descriptions of plagioclase alteration products are not reported for Reykjanes or the Salton Sea, but albite and epidote occur in plagioclase at Reykjanes (Tomasson et al., 1972). In the Roosevelt system, wairakite has not been recognized in plagioclase, and chlorite and hematite are common alteration products, in addition to those reported from other systems.

Zeolites have not been identified in the Roosevelt system. However, since zeolites most commonly fill fractures and cavities at other systems, their apparent absence at Roosevelt could be due to sampling procedure. Much of the vein filling material has probably been lost from the cuttings.

Secondary K-feldspar which replaces plagioclase at Roosevelt and also occurs as a vein filling, is assumed to be adularia because of its paragenesis. The morphological characteristics which commonly distinguish adularia were not noted in plagioclase replacements, though some of the vein K-feldspar exhibits variable extinction.

Epidote, a minor constituent in the Roosevelt System, is a common constituent at depth in other systems.

Anhydrite is a very minor constituent in the deeper portion of Thermal Power Company well 14-2, and is also a common, if minor, constituent at Reykjanes and at the Salton Sea (Tomasson et al., 1972; Muffler and White, 1969). Anhydrite is not reported from New Zealand geothermal fields.

A common feature of the deep wells 14-2, 72-16, and 52-21 is low total sulfide content, generally much less than 1%. However, limonite is abundant in the upper part of the drillholes and may reflect greater

original sulfide content than that downhole.

The problem of distinguishing alteration due to older geothermal events from alteration related to the modern geothermal system has not been resolved. Careful examination of cross cutting relationships in deep core and radiometric age measurements on alteration minerals may assist in resolving the problem.

References

- Armstrong, R. L., 1970, Geochronology of Tertiary igneous rocks, eastern Basin and Range Province, western Utah, eastern Nevada, and vicinity, U.S.A., *Geochim. Cosmochim. Acta.* v. 34, p. 203-232.
- Brown, F. H., 1977(a), Geothermal Research, Roosevelt Hot Springs KGRA, Quarterly Progress Report November 1976 - January 31, 1977, Contract EY-76-S-07-1601, ERDA (now DOE), p. 11.
- Brown, F. H., 1977(b), Attempt at paleomagnetic dating of opal, Roosevelt Hot Springs KGRA: Technical Report Volume 77-1, ERDA (now DOE) contract EY-76-S-07-1601, 13 p.
- Browne, P. R. L., and Ellis, A. J., 1970, The Ohaki-Broadlands hydrothermal area, New Zealand: Mineralogy and related geochemistry: *Am. Jour. Sci.*, v. 269, p. 97-131.
- Cathles, L. M., 1977, An analysis of the cooling of intrusives by ground water convection which includes boiling: *Econ. Geol.*, v. 72, p. 804-826.
- Earll, F. N., 1957, Geology of the central Mineral Range, Beaver County, Utah: Ph.D. thesis, University of Utah, 112 p.
- Evans, S. H. Jr., 1977, Geologic Map of the Central and Northern Mineral Mountains, Utah: Department of Geology and Geophysics, Univ. of Utah.
- Evans, S. H. Jr., and Nash, W. P., 1978, Quaternary rhyolite from the Mineral Mountains, Utah, U.S.A.: in preparation.
- Helgeson, H. C., 1968, Evaluation of irreversible reactions in geochemical processes involving minerals and aqueous solutions - I. Thermodynamic relations: *Geochim. et Cosmochim. Acta.*, v. 32, p. 853-877.
- Helgeson, H. C., 1969, Thermodynamics of hydrothermal systems at elevated temperatures and pressures: *Am. Jour. Sci.*, v. 267, p. 729-804.
- Hemley, J. J., Hostetler, P. B., Gude, A. J., and Mountjoy, W. T. 1969, Some stability relations of alunite: *Econ. Geol.*, v. 64, p. 599-612.
- Liese, H. D., 1957, Geology of the northern Mineral Range, Millard and Beaver Counties, Utah: M.S. thesis, University of Utah, 88 p.
- Lipman, P. W., Rowley, P. D., Mehnert, H., Evans, S. H. Jr., Nash, W. P., Brown, F. H., 1978, Pleistocene rhyolite of the Mineral Mountains, Utah: Geothermal and archeological significance: *Jour. Res. U.S. Geol. Survey*, v. 6, p. 133-147.

- Muffler, L. J. P., and White, D. E., 1969, Active metamorphism of Upper Cenozoic sediments in the Salton Sea geothermal field and the Salton Trough, Southeastern California: *Geol. Soc. America Bull.*, v. 80, p. 157-182.
- Mundorff, J. C., 1970, Major thermal springs of Utah: *Utah Geol. and Mineral Survey Water Resources Bull.* 13, 60 p.
- Norrish, K., and Hutton, J. T., 1969, An accurate x-ray spectrographic method for the analysis of a wide range of geological samples: *Geochim. et Cosmochim. Acta.*, v. 33, p. 431-453.
- Petersen, C. A., 1975, Geology and geothermal potential of the Roosevelt Hot Springs area, Beaver County, Utah: M.S. thesis, University of Utah, 50 p.
- Schoen, R., and White, D. E., 1965, Hydrothermal alteration in GS-3 and GS-4 drillholes, Main Terrace, Steamboat Springs, Nevada: *Econ. Geology*, v. 60, no. 7, p. 1411-1421.
- Schoen, R., White, D. E., and Hemley, J. J., 1974, Argillization by descending acid at Steamboat Springs, Nevada: *Clays and Clay Minerals*, v. 22, p. 1-22.
- Sigvaldason, G. E., 1963, Epidote and related minerals in two deep geothermal drillholes, Reykjavik and Hvergerdi, Iceland: *U.S. Geol. Surv. Prof. Paper* 450-E, p. 77-79.
- Sigvaldason, G. E., and White, D. E., 1962, Hydrothermal alteration in drillholes GS-5 and GS-7 Steamboat Springs, Nevada: *U.S. Geol. Surv. Prof. Paper* 450-D, p. 113-117.
- Steiner, A., 1968, Clay minerals in hydrothermally altered rocks at Wairakei, New Zealand: *Clays and Clay Minerals*, v. 16, p. 193-213.
- Swanberg, C. A., 1974, Application of the Na-K-Ca geothermometer to thermal areas of Utah and the Imperial Valley, California: *Geothermics*, v. 3, p. 53-59.
- Tomasson, J., and Kristmannsdottir, H., 1972, High temperature alteration minerals and thermal brines, Reykjanes, Iceland: *Contr. Mineral. and Petrol.*, v. 36, p. 123-134.
- Truesdell, A. H., and Jones, B. F., 1974, WATEQF, a computer program for calculating chemical equilibria of natural waters: *U.S. Geol. Surv. Jour. Res.*, v. 2, p. 233-248.
- Ward, S. H., Parry, W. T., Nash, W. P., Cook, K. L., Smith, R. B., Whelan, J. A., Brown, F. H., Bowman, J. R., and Chapman, D. S., 1978, A Summary of the Geology, Geochemistry and Geophysics of the Roosevelt Hot Springs Thermal Area, Utah: *Geophysics*, in press.

White, D. E., 1957, Thermal waters of volcanic origin: Geol. Soc. America
Bull., v. 68, p. 1637-1658.

Distribution List

Dr. James K. Applegate
Department of Geology
Boise State University
Boise, ID 83725

Mr. Sam Arentz, Jr., President
Steam Corporation of America
1720 Beneficial Life Tower
Salt Lake City, UT 84111

Dr. David J. Atkinson
Hydrothermal Energy Corp.
2519 Horseshoe Canyon Drive
Los Angeles, CA 90046

Dr. Carl F. Austin
c/o Geothermal Technology
Code 2661, NWC
China Lake, CA 93555

Mr. Lawrence Axtell
Geothermal Services, Inc.
10072 Willow Creek Rd.
San Diego, CA 92131

Mr. Larry Ball
DOE
Division of Geothermal Energy
3rd Floor, MS 3122C
20 Massachusetts Ave., N.W.
Washington, DC 20545

Mr. Ronald Barr
Earth Power Corporation
P.O. Box 1566
Tulsa, OK 74101

Dr. Rudolf A. Black
DOE
Dir. of Div. of Geothermal Energy
3rd Floor, MS 3122C
20 Massachusetts Ave., N.W.
Washington, DC 20545

Dr. David D. Blackwell
Southern Methodist University
Department of Geological Sciences
Dallas, TX 75275

Dr. Gunnar Bodvarsson
Oregon State University
School of Oceanography
1377 N.W. Alta Vista Dr.
Corvallis, OR 97330

Mr. C. M. Bonar
Director, Geothermal Projects
Atlantic Richfield Co.
P.O. Box 1829
Dallas, TX 75221

Roger L. Bowers
Hunt Energy Corp.
2500 1st Natl Bank Bldg.
Dallas, TX 75202

Mr. William D. Brumbaugh
Geophysics Bldg., Room 12
Interpretation Group
Conoco
Ponca City, OK 74601

Mr. Glen Campbell
Geothermal Supervisor
Gulf Min. Resource Company
1720 South Bell Aire St.
Denver, CO 80222

Tom Cassel
Fels Center of Govt.
Univ. of Pennsylvania
39th & Walnut Streets
Philadelphia, PA 19104

Dr. Bob Christiansen
U.S. Geological Survey
345 Middlefield Road
Menlo Park, CA 94205

Eugene V. Ciancanelli
Consulting Geologist
12352 Escala Drive
San Diego, CA 92128

Dr. Jim Combs
Geothermal Services, Inc.
10072 Willow Creek Rd.
San Diego, CA 92131

Mr. F. Dale Corman, President
O'Brien Resources, Inc.
49 Toussin Avenue
Kentfield, CA 94904

Dr. R. Corwin
Dept. Eng. Geoscience
University of California @ Berkeley
Berkeley, CA 94720

Mr. Ritchie Coryell
Program Manager
National Science Foundation
1800 G Street, N.W.
Washington, DC 20050

Dr. Gary Crosby
Phillips Petroleum Company
71-C PRC
Bartlesville, OK 74003

Mr. W. L. D'Olier
Geothermal Operations
Thermal Power Co.
601 California Street
San Francisco, CA 94108

Mrs. Katie Dixon
3781 Lois Lane
Salt Lake City, UT 84117

Mr. William Dolan
Chief Geophysicist
Amax Exploration Inc.
4704 Harlan Street
Denver, CO 80212

John E. Dooley
R. F. Smith Corp.
552 E. 3785 S.
Salt Lake City, UT 84106

Robert C. Edmiston
Anadarko Production Co.
P.O. Box 1330
Houston, TX 77001

Mr. Samuel M. Eisenstat, President
Geothermal Exploration Co., Inc.
400 Park Ave.
New York City, NY 10022

Dr. Val A. Finlayson
Research Engineer
Utah Power and Light Company
1407 West North Temple
Salt Lake City, UT 84110

Mr. Milton Fisher
295 Madison Avenue
New York City, NY 10017

Mr. Ron Forrest, Geologist
Phillips Petroleum Co.
P.O. Box 858
Milford, UT 84751

Ken Fournier
Union Oil
Union Research Center
Box 76
Brea, CA 92621

Dr. Frank Frischknecht
Box 25046, Denver Federal Center
U.S. Geological Survey
Denver, CO 80225

Mr. Gary Galyardt, Geologist
U.S. Geological Survey
MS 602
Box 25046, Federal Center
Denver, CO 80225

Ms. N. Sylvia Goeltz
UV Industries, Inc.
19th Floor, University Club Bldg.
Salt Lake City, UT 84111

Dr. N. E. Goldstein
Lawrence Berkeley Laboratory
Building 90
University of California, Berkeley
Berkeley, CA 94720

Mr. Steven M. Goldstein
The Mitre Corporation
Metrek Division
1820 Dolley Madison Blvd.
McLean, VA 22101

Mr. Bob Greider, V. P. Exploration
Intercontinental Energy Co.
P.O. Box 17529
Denver, CO 80217

Mr. J. H. Hafenbrack
Exxon Co. USA
P.O. Box 120
Denver, CO 80201

Mr. Dee C. Hansen
Utah State Engineer
442 State Capitol
Salt Lake City, UT 84114

Dr. Norman Harthill
Executive Vice President
Group Seven, Inc.
9250 W. 5th Ave.
Lakewood, CO 80226

Dan E. Haymond
P.O. Box 239
Salt Lake City, UT 84110

Mr. Jack Von Hoene
Davon, Inc.
250 North 100 West
Milford, UT 84751

George Hopkins
Geotronics Corp.
10317 McKalla Place
Austin, TX 78758

Mr. Gerald W. Hutterer, Sr. Geologist
Intercontinental Energy Corporation
7503 Marin Dr., Suite 1-C
Englewood, CO 80110

Mr. Laurence P. James
2525 South Dayton Way #1406
Denver, CO 80231

Dr. George R. Jiracek
Department of Geology
University of New Mexico
Albuquerque, NM 87131

Mr. Richard L. Jodry
P.O. Box 941
Richardson, TX 75080

Dr. Paul Kasameyer
Lawrence Livermore Lab, L-224
P.O. Box 808
Livermore, CA 94550

Dr. George Keller
Professor and Head
Department of Geophysics
Colorado School of Mines
Golden, CO 80401

Mr. James B. Koenig
Geothermex
901 Mendocino Avenue
Berkeley, CA 94704

Dr. Mark Landisman
Professor of Geophysics
University of Texas, Dallas
Box 688
Richardson, TX 75080

A. W. Laughlin
Group Leader
Geothermal Programs
Geological Applications Group G-9
Los Alamos Scientific Laboratory
P.O. Box 1663
Los Alamos, NM 87545

Mr. Guy W. Leach, Geologist
Oil Development Company of Texas
Box 12053, American Natl Bank Bldg.
Amarillo, TX 79101

Mr. Dick Lenzer
Phillips Petroleum Company
P.O. Box 239
Salt Lake City, UT 84110

Earth Sciences Division Library
Building 90
University of California
Lawrence Berkeley Laboratory
1 Cyclotron Road
Berkeley, CA 94720

Mr. Skip Matlick
Republic Geothermal
P.O. Box 3388
Santa Fe Springs, CA 90670

James O. McClellan, President
Geothermal Electric Systems Corp.
5278 Pinemont Drive, Suite A-150
Salt Lake City, UT 84107

Dr. Robert B. McEuen
Woodward Clyde Consultants
Three Embarcadero Center, Suite 700
San Francisco, CA 94111

Mr. Don C. McMillan
Utah Geological & Mineral Survey
606 Blackhawk Way, Research Park
Salt Lake City, UT 84108

Dr. Tsvi Meidav
Consultant
40 Brookside Ave.
Berkeley, CA 94705

Mr. Frank G. Metcalfe, Pres.
Geothermal Power Corporation
1127 Grant Ave., Suite 6
P.O. Box 1186
Novato, CA 94947

Dr. Martin Molloy
U.S. DOE
1333 Broadway
Oakland, CA 94612

Dr. Frank Morrison
Professor of Geophysics Eng.
University of California
Hearst Mining Building
Berkeley, CA 94720

Dr. L. J. Patrick Muffler
U.S. Geological Survey
345 Middlefield Road
Menlo Park, CA 94205

Mr. Clayton Nichols
DOE
Division of Geothermal Energy
Idaho Operations Office
550 Second Street
Idaho Falls, ID 83401

Mr. Carel Otte
President of Geothermal Division
Union Oil Company
P.O. Box 7600
Los Angeles, CA 90051

Dr. Wayne Peeples
Dept. of Geological Sciences
Southern Methodist University
Dallas, TX 75221

Mr. C. R. Possell
General Ener-Tech, Inc.
4842 Viane Way
San Diego, CA 92110

Dr. Alan O. Ramo
Sunoco Energy Development Co.
12700 Park Central Pl.
Suite 1500, Box 9
Dallas, TX 75251

Dr. Robert W. Rex, President
Republic Geothermal, Inc.
11823 E. Slauson Ave., Suite 1
Santa Fe Springs, CA 90670

Ms. Barbara Ritzma
Science & Engineering Department
Marriott Library
159 MLI, CAMPUS

Dr. Jack Salisbury
DOE
Division of Geothermal Energy
3rd Floor, MS 3122C
20 Massachusetts Avenue, N.W.
Washington, DC 20545

Dr. Konosuke Sato
Metal Mining Agency of Japan
Tokiwa Bldg.
1-24-14 Toranomom
Minato-Ku, Tokyo
JAPAN

Dr. John V. A. Sharp
Hydrosearch, Inc.
333 Flint Street
Reno, NV 89501

Mr. Wayne Shaw
Getty Oil Company
P.O. Box 5237
Bakersfield, CA 93308

Mr. Gregory L. Simay
City of Burbank - Public Service Dep
164 West Magnolia Blvd.
Burbank, CA 91503

Mr. W. P. Sims
DeGolyer and MacNaughton
One Energy Square
Dallas, TX 75206

Donald W. Smellie
Consulting Geophysicist
1015 - 837 W. Hastings St.
Vancouver V6C 1C4 CANADA

Dr. H. W. Smith
Department of Electrical Engineering
University of Texas, Austin
Austin, TX 78712

Marty Steyer
Nat'l Geothermal Info Resource
Lawrence Berkeley Lab, 50A-0143A
Univ. of California
Berkeley, CA 94720

Mr. Paul V. Storm
California Energy Company, Inc.
Wells Fargo Bldg., Suite 300
P.O. Box 3909
Santa Rosa, CA 95402

Dr. Chandler Swanberg
New Mexico State University
P.O. Box 4408
University Park Dr.
Las Cruces, NM 88003

Dr. Charles M. Swift, Jr.
Chevron Oil Co.-Minerals Staff
P.O. Box 3722
San Francisco, CA 94105

Dr. Bernard Tillement
Aquitaine Co. of Canada
2000 Aquataine
540 5th Avenue, S.W.
Calgary, Alberta
Canada 2TP 0M4

David D. Tillson
Washington Public Power Supply System
P.O. Box 968
Richland, WA 99352

Dr. Ronald Toms
DOE
Division of Geothermal Energy
3rd Floor, MS 3122C
20 Massachusetts Avenue, N.W.
Washington, DC 20545

Dr. John Tsiaperas
Shell Oil Company
Box 831
Houston, TX 77001

Dr. A. F. Veneruso
Geothermal Technology Division 5736
Sandia Laboratories
Albuquerque, NM 87115

Dan Vice
555 Park Lane
Billings, MT 59102

Dr. James R. Wait
Rx7, Room 242, RB1
U.S. Dept. of Commerce
National Oceanic & Atmospheric Admin
Environmental Research Labs
Boulder, CO 80302

Mr. D. Roger Wall, Geologist
Geothermal Resources Division
Aminoil USA, Inc.
1250 Coddington Center
Santa Rosa, CA 95401

Dr. Paul Walton, President
American Geological Enterprises, Inc
1102 Walker Bank Bldg.
Salt Lake City, UT 84111

Ed Witterholt
City Services Oil Co.
Energy Research Lab
Box 50408
Tulsa, OK 74150

Mr. William B. Wray, Jr.
VanCott, Bagley, Cornwall & McCarthy
141 East 1st South
Salt Lake City, UT 84111

Dr. Paul C. Yuen
University of Hawaii @ Manoa
2540 Dole Street, Holmes 240
Honolulu, HI 96822

Dr. S. H. Yungul
Chevron Resources Co.
P.O. Box 3722
San Francisco, CA 94119

Dr. Elliot J. Zais
Elliot Zais & Associates
7915 N.W. Siskin Dr.
Corvallis, OR 97330