AREA
UT
Beaver
Roos
PE/GPC

FEB 17 1981

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UNITED STATES
DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY
Conservation Division, MS-92
345 Middlefield Road
Menlo Park, CA 94025

UNIVERSITY OF UTAH
RESEARCH INSTITUTE
EARTH SCIENCE LAB.

FEB 13 1981

Memorandum

To: Interested Parties

From: Acting Deputy Conservation Manager, Geothermal

Subject: Plan of Exploration, Geothermal Power Corporation, Roosevelt Hot Springs KGRA, Federal Lease U-14990, Beaver County, Utah
Ref: 2403-01 U-14990 (POO for EA 175-81)

Geothermal Power Corporation has submitted a Plan of Exploration to construct up to three drilling pads, to drill three deep exploratory wells, and conduct short-term testing of the wells. Please refer to the enclosed map for proposed drill site locations.

An Environmental Assessment (EA #175-81) will be prepared by the Office of the Deputy Conservation Manager for Geothermal for the proposed action.

You are invited to participate in a field inspection of the proposed site, weather permitting, to be led by Ken Bull, Salt Lake City District Geothermal Office, USGS. Participants are asked to meet at the Hong Kong Cafe, Main St., Milford, Utah at 9:00 a.m., on Wednesday, March 4, 1981.

We urge you to send in written commentary and will appreciate hearing from you even if you are of the opinion that the existing regulations, lease terms, and Geothermal Resource Operational Orders provide adequate environmental protection.

All comments concerning the proposed action should be received no later than March 18, 1981, by:

Deputy Conservation Manager, Geothermal
U.S. Geological Survey, Conservation Division
345 Middlefield Road, MS-92
Menlo Park, CA 94025
ATTN: Richard Hoops
Tel: (415) 323-8111, ext. 2848
FTS: 467-2848

All comments will be given serious consideration in the preparation of the Environmental Assessment and any subsequent conditions of approval.

The Deputy Conservation Manager for Geothermal will not send a draft Environmental Assessment to Interested Parties for review. Certain parties, however, such as the surface managing agency, the lessee, GEAP, and the U.S. Fish and Wildlife Service will receive a copy of the completed EA.

Copies of the Environmental Assessment, and the complete Plan of Exploration are available for inspection during normal business hours at the Office of the Deputy Conservation Manager for Geothermal and the Office of the District Geothermal Supervisor in Salt Lake City, Utah. Copies are available upon request.

William F. Isherwood

Enclosure

INTERESTED PARTIES EA #175-81

Geothermal Power Corporation
Plan of Exploration

U-14990
Roosevelt KGRA

* * * * *

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United States Forest Service - USDA
Intermountain Region
ATTN: Regional Mining Engineer
ATTN: Bill Johnson
324 Twenty-fifth Street
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Cedar City, Utah 84720

Bureau of Land Management
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154 N. Main Street
P.O. Box 208
Cedar City, Utah 84720

U.S. Department of Agriculture
ATTN: Floyd Bartlett
Beaver, Utah 84713

Fishlake National Forest
Intermountain Region
ATTN: Ralph Cisco
170 North Main Street
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U. S. Forest Service, USDA
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Industrial Commission of Utah
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Water Resources Division
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INTERESTED PARTIES for EA #175-81

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Mr. Clyde E. Kuhn
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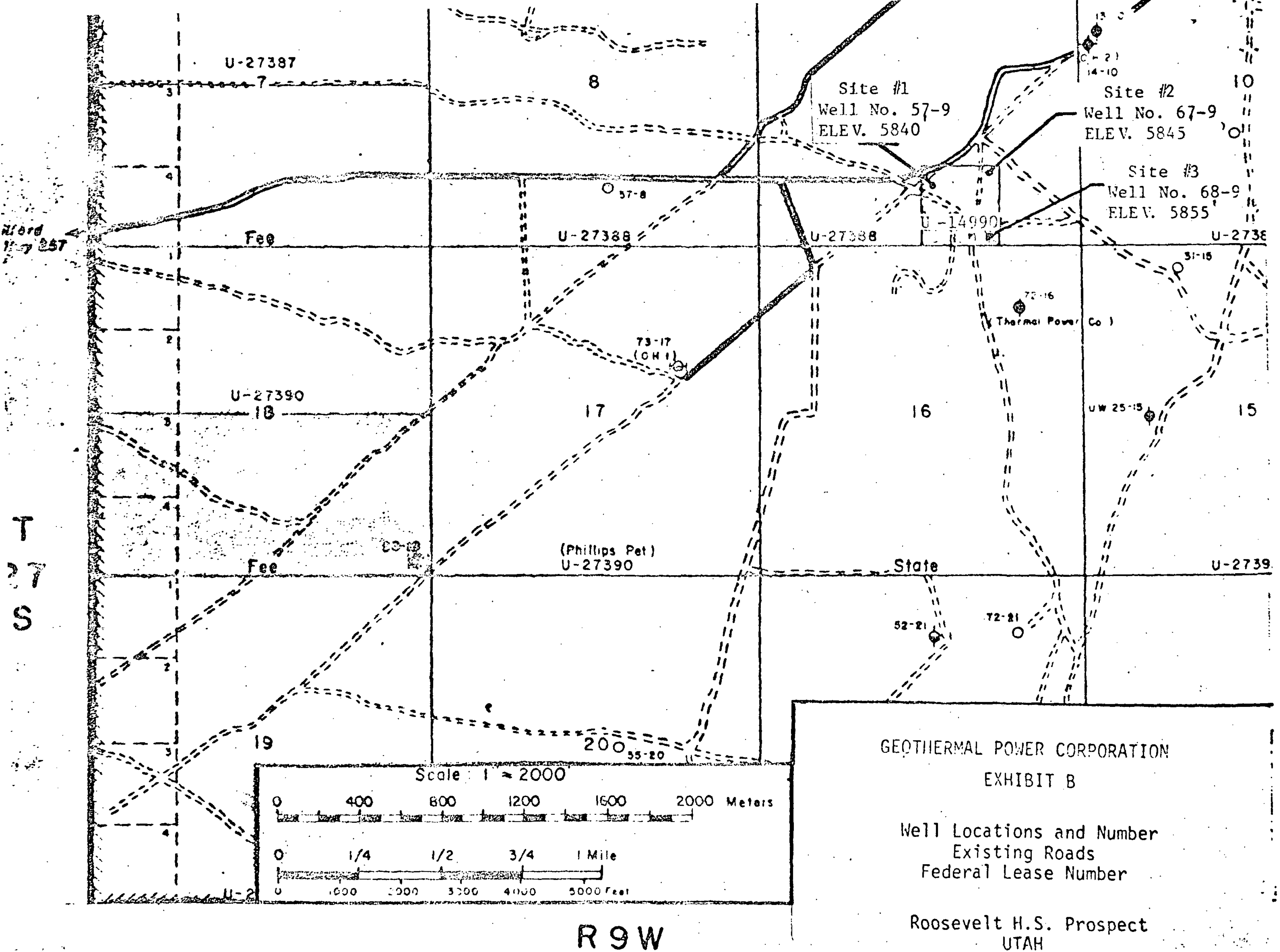


GEOTHERMAL POWER CORPORATION

EXHIBIT B

Well Locations and Number
Existing Roads
Federal Lease Number

Roosevelt H.S. Prospect
UTAH

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
Conservation Division, MS-92
345 Middlefield Road
Menlo Park, CA 94025

MAR 23 1981

Memorandum

To: Interested Parties

From: Acting Deputy Conservation Manager, Geothermal

Subject: Unit Plan of Operation for Development, Injection, Utilization, and Production, Phillips Petroleum Company and Utah Power and Light Company, Roosevelt Hot Springs Unit, Federal Leases U-27386, U-27388, U-27389, and U-27392, Beaver County, Utah
Ref: 2403-01 RHSU U-27386 (POO for EA #163-81)

Phillips Petroleum Company and Utah Power and Light Company have submitted Plans of Operation for Development, Injection, Utilization, and Production proposing the drilling of two (2) additional production wells; injection of produced geothermal fluids; operation and monitoring of the Roosevelt Hot Springs geothermal field; and the construction of steam and water pipelines, access roads and other surface facilities necessary for the operation of a proposed 20 MW (net) power plant within the Roosevelt Hot Springs Unit. Please refer to the enclosed map to the locate the proposed drill sites, access roads, pipelines, and power plant locations.

An Environmental Assessment (EA #163-81) will be prepared by the Office of the Deputy Conservation Manager for Geothermal (DCM, Geothermal) for the proposed operations other than drilling. To expedite the drilling program, the Plan of Development will be treated as a separate Environmental Assessment (EA #177-81). Details of this EA will be forwarded shortly in a separate interested parties letter. An additional EA will be prepared by the Cedar City District BLM office for the proposed electric transmission line to the proposed power plant.

A meeting was held on March 5, 1981 in Beaver, Utah to determine if a public field inspection is necessary for this proposed plan. Attending the meeting were representatives of the U.S. Geological Survey, the Bureau of Land Management, and the Beaver County Planning Commission. The attendees concurred that no field inspection will be scheduled since numerous field inspections have been held in the immediate vicinity of the proposed plant location. However, you are invited to visit the site at your own convenience.

We urge you to send written commentary and will appreciate hearing from you even if you are of the opinion that the existing regulations, lease terms, and operational orders provide adequate environmental protection.

All comments concerning the proposed actions should be received no later than April 13, 1981 by:

DCM, Geothermal
U.S. Geological Survey
Conservation Division
345 Middlefield Road, MS-92
Menlo Park, CA 94025
Attn: Richard Hoops
(415) 323-8111, ext. 2848
FTS: 467-2848

All comments will be given serious consideration in the preparation of the Environmental Assessment and any subsequent condition of approval.

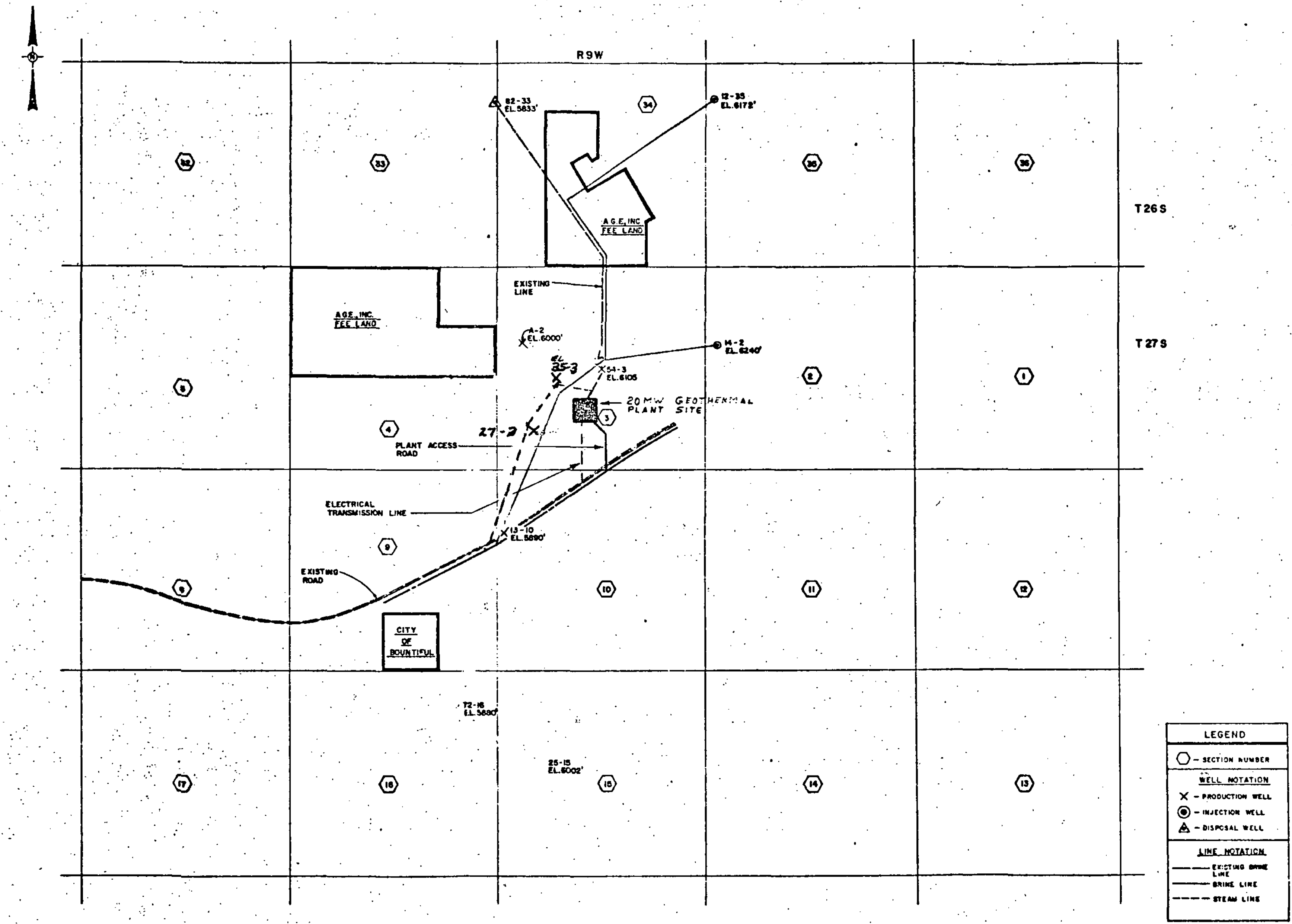
The Deputy Conservation Manager for Geothermal will not send a draft Environmental Assessment to interested parties for review. Certain parties, however, such as the surface managing agency, the lessee, GEAP, and the U.S. Fish and Wildlife Service will receive a copy of the completed EA.

Copies of the Environmental Assessment, and the complete Plan of Operation are available for inspection during normal business hours at the Office of the Deputy Conservation Manager for Geothermal, the Office of the District Geothermal Supervisor in Salt Lake City, and at the Cedar City District BLM Office. Copies are available upon request.

William Isherwood
William F. Isherwood

Enclosure

cc: DGS, Salt Lake City, UT



SITE MAP

0 2000 4000
SCALE IN FEET

CONCEPTUAL DESIGN FOR
COST ESTIMATE

SES 2/80
ETH 2/80

SITE MAP

PHILLIPS PETROLEUM CO
20MW GEOTHERMAL PRO
BEAVER COUNTY, UTA

MORRISON
KNUDSEN

P.E.1008
FIGURE

INTERESTED PARTIES EA #163-81

Phillips Petroleum Company
Plan of Utilization and Production

U-27386, U-27388, U-27389, U-27392
Roosevelt Hot Springs Unit

* * * * *

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United States Forest Service - USDA
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Fishlake National Forest
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INTERESTED PARTIES for EA #163-81

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Utah Oil, Gas & Mining Division
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Earth Science Laboratory
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HISTORICAL SYNOPSIS OF THE ROOSEVELT HOT SPRINGS GEOTHERMAL FIELD, UTAH

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The discovery and development of the Roosevelt Hot Springs Thermal area has involved many individuals, companies, institutions, and organizations. A search of literature reveals that a limited number of investigations were performed at the Roosevelt Hot Springs site prior to 1970.

In the late 1880's and early 1900's, the area was known as McKeans Hot Springs. In 1902, it was developed into a hot springs resort with operation continuing into the 1920's. The site of Roosevelt Hot Springs is now dry, emitting only some water vapor and gasses as active fumaroles.

W. T. Lee published the first scientific information about the hot springs in 1908. He reported sodium sulfate chloride water flowing from the largest spring at a rate of 10 gallons per minute (gpm) with a temperature of 190°F. In November, 1950, the Roosevelt Hot Springs were described by the U.S. Geological Survey. They reported the water as a sodium chloride type flowing at a rate of 1 gpm at 185°F. The dissolved mineral content was 7,040 parts per million (ppm), of which 405 ppm was silica. In

September, 1957, the U. S. Geological Survey again classified the hot springs water as sodium chloride water containing 7,800 ppm of total dissolved solids. The flow rate was small with a temperature of 131^{o}F. In May, 1966, the hot spring was "dry", with indications that it had been dry for possibly two years (Mundorff, 1970).

During the 1960's, exploration gave an indication of the importance of the Roosevelt Hot Springs area as a potential geothermal energy resource. In December, 1967, Mr. A. L. McDonald and Dr. E. Davie jointly drilled an 80' hole in the Roosevelt Hot Springs area (T26S, R9W, Sec. 16). It was eventually plugged because it encountered boiling hot water at shallow depths. A second drill hole, located about 300' to the east of the first hole, reached a depth of 165' before encountering hot water flashing to steam. This hole was temporarily abandoned until April, 1968, when it was deepened to about 270'. At this depth, the 270^{o}F water flashed into steam. The well flowed out of control for approximately two months. It is this well that is generally described as the "discovery well" for the Roosevelt Hot Springs Thermal Area (Personal

A.L.
Observations by Mr. McDonald).

In December, 1970, the U.S. Congress passed the Geothermal Steam Act. In 1971, the U.S. Geological Survey created the eight-section KGRA (Known Geothermal Resource Area) at Roosevelt Hot Springs. In 1972, Phillips Petroleum Company initiated their geothermal exploration program in the area. Competition between Phillips and other companies resulted in the expansion of the KGRA to 36.5 sections in January, 1974. At the lease sale in July, 1974, Phillips was the successful bidder on nine of the 12 tracts (18, 871 acres); Getty Oil Company acquired one tract of 1,920 acres; Union Oil Company leased one tract of 1,600 acres; and Mr. A. L. McDonald acquired one tract of 40 acres. After the leases were issued in October, 1974, Phillips' exploration activities shifted to deep test drilling.

The deep test program began in February, 1975. During that year, six deep tests and two stratigraphic tests were drilled. In late April, 1975, Phillips' second deep test (#3-1) was drilled and this well is considered to be their discovery well.

In April, 1976, Phillips Petroleum Company gained the approval of the United states government to unitize the Roosevelt Hot Springs reservoir, thus allowing the field to be developed in the most efficient and economical manner. This unit (Figure 1) was the first to be approved in the United States. During 1976, Phillips also sought to better understand the geothermal system by performing flow tests and conducting a number of geophysical and geochemical surveys.

During 1977, Phillips drilled three stratigraphic test holes to obtain additional information on the dimensions of the reservoir. In October, 1977, their longest flow test and reinjection operation began, lasting 236 days. The main objective of this test was to determine the capacity of the geothermal reservoir.

Early in 1978, Phillips completed several stratigraphic test holes in the Roosevelt Hot Springs thermal area. Additional information on the geometry of the reservoir was gathered.

In 1979, Phillips' main interest was to obtain still more information by conducting another major flow - reinjection test. Their goal is the eventual development of the field. Under the regulations of the Roosevelt hot Springs Unit, Phillips plans further development, culminating in the generation of electrical power by using the geothermal energy -- possibly as early as 1983.

The Case History of the Roosevelt Hot Springs Thermal Area, Utah, would not be complete without documentation of all party accomplishments. The Historical Synopsis highlights only the key events pertaining to this field. Activities of Phillips Petroleum Company were emphasized because that company has proven since 1972 to be the most active operator influencing the geothermal development of this field. The passing of the Geothermal Steam Act in 1970 by the U.S. government resulted in a veritable "explosion" of information from surveys performed at Roosevelt Hot Springs thermal area.

The amount of information released to the public domain indicates this to be one of the most extensively researched geothermal fields in the United States. Numerous energy-seeking industries have performed exploratory activities. The academic community, particularly the University of

Utah Department of Geology and Geophysic, has completed a vast collection of reports on this geothermal field.

One approach to list all these accomplishments at Roosevelt Hot Springs was to organize the information into two separate tables: Table A is a chronologic listing of the known history and developments by all parties except Phillips Petroleum Company. Table B is a complete listing of the historical development at Roosevelt Hot Springs thermal area by Phillips Petroleum Company.

cont. on following page

~~Many other individuals, companies, institutions, and organizations have contributed to the large data base available for the Roosevelt geothermal area, but these are too numerous to mention in this report.~~

As of February 1979, 11 geothermal test wells had been drilled within the Unit. Six of the wells are considered capable of producing fluid in commercial quantities: Phillips #3-1, #54-3, #13-10, and #25-15; Amax-Thermal Power-O'Brien (ATO) #14-2 and #72-16. Phillips well #12-35 is productive but presently not commercial. Four wells have not encountered the geothermal reservoir: #9-1 and #82-33; Getty Oil Co. #52-21; and ATO #24-36.

In addition to the deep tests, eight observation holes ranging in depth from 1760 to 2317 feet have been drilled in the area, of which seven are within the unit.

In May 1980, Phillips Petroleum Co and Utah Power and Light Co. announced a 90-day negotiation period focused on intentions to reach an agreement for the commercial electrical development of the Roosevelt Hot Springs Unit. If a contract agreement is reached, initial construction of the first of three power plants would likely begin in late 1980. The first plant, a 20 megawatt, would be completed by early 1983. This would be followed by two additional 50 megawatt plants also located at the geothermal site. They are projected for completion in 1985 and 1986. At this time, commercial output of this geothermal field is set at 120 megawatts of electrical power, sufficient for the needs of about 120,000 people. This would rank the Roosevelt Hot Springs Unit thermal area in the top three in the United States for generating electrical power from a geothermal reservoir system.

TABLE A

EARLY HISTORY AND DEVELOPMENT OF THE ROOSEVELT HOT SPRINGS THERMAL AREA BY ALL PARTIES (EXCLUDING PHILLIPS PETROLEUM COMPANY)

Late	1880's	The Roosevelt Hot Springs site, then known as McKeans.
Early	1900's	Hot Springs, was turned into a hot spring resort, or spa. (Petersen, 1975)
	1908	The first recorded Scientific information on Roosevelt Hot Springs was reported by Lee. He identified the water type as a sodium sulfate-chloride the largest spring flowing 10 gpm at 190°F. (Lee, 1908)
November	1950	The hot spring site was examined by the U.S. Geological Survey. The water was classified as a sodium

		chloride type and had a flow of 1 gpm at 185°F (Mundorff, 1970).
	1957	The U.S. Geological Survey re-examined the hot spring and classified it as sodium chloride type. The springs had a small flow at a temperature of 131°F (Mundorff, 1970).
May	1966	The U.S.G.S. visited the hot spring and it was "dry". It appeared to have been dry for possibly two years (Mundorff, 1970).
During	1960's	Mr. A.L. McDonald obtained a mineral lease from the state of Utah on Sec. 16, T27N, R9W, and staked claims on adjacent federal land to extract and mine opal.

December	1967	Mr. A.L. McDonald, (A UNION PACIFIC ENGINEER + RESIDENT OF MILFORD) and Dr. E. Davie, a Milford physician, joined together to drill an 80' hole in Mr. McDonald's main opal pit and encountered boiling water.
December	1967	Mr. A.L. McDonald and Dr. E Davie jointly drilled a second hole in the same area to a depth of 165'. The hole was plugged and abandoned after encountering hot water which flashed to steam.
April	1968	Dr. E. Davie re-entered the second hole and drilled to a of about 270'. Hot water (270°F) in the well flashed to steam and it took nearly two months to plug and abandon the well.
May	1968	Mr. A.L. McDonald applied to drill six geothermal wells

		on his mining claims.
May 5	1969	Mr. A.L. McDonald applied for the geothermal rights and other minerals (potassium) on his mining claims. This application led the U.S. government to eventually designate Sections 3, 4, 9, 10, 15, and 16 in T27S, R9W, and Sections 34 and 35 in T26S, R9W, as first KGRA.
October	1970	Mr. McDonald's application rejected.
December 26	1970	"Steam Act" went into effect.
June 26	1971	Mr. McDonald plans for 120 acres (40 acres applicable to federal land).
	1971	The Roosevelt area was designated as "KGRA." (Known Geothermal Resource Area)
January	1972	Dr. E. Davie organized Ther-

		mal Power Company of Utah.
Summer	1972	Carol Peterson, University of Utah, initiated geologic mapping project of the Roosevelt Hot Springs thermal area as Master's thesis and supported project by UG&MS Report completed in Fall, 1975 (Vol. 2, No. 2).
Mid	1973	Dr. E Davie and Jack Von Hoene join together to form the DAVON Company.
Summer	1973	Thermal Power Company drilled a number of temperature gradient holes in the Roosevelt Hot Springs KGRA.
		Getty Oil Co. was high bidder on a 3 sq. mi. federal tract in southern part of Roosevelt Hot Springs KGRA.

		Mr. A.L. McDonald exercised his grandfather's rights on a 40 acres tract of federal land near the center of the Roosevelt Hot Springs KGRA.
Mid	1974	University of Utah Department of Geology and Geophysics began detailed geological, geophysical, and geochemical studies of the Roosevelt Hot Springs thermal area. These studies continue at the present time. Funding has been by grants from National Science Foundation (NSF), Energy Research development Administration (ERDA), Department of Energy/Division of Geothermal Energy (DOE/DGE).
June	1976	Electrical Survey by Sen-

		turion Science.
July	1976	Geotronics performed electrical survey for Getty Oil Co.
September	1976	Thermal Power Co. spudded Utah State #14-2.
October	1976	Thermal Power Co. spudded Utah State #72-16.
June - Aug.	1977	Geothermal Power Corp. drilled 15 temperature gradient holes in the Roosevelt area.
June	1977	Getty Oil Co. submitted a plan of operations to drill up to eight ± 7500' deep geothermal wells.
July	1977	City of Bountiful purchases MR. A.L. McDonald's 40-acre tract. (FOR $125,000).
November	1977	Thermal Power Co. spudded Utah State #24-36.

February	1978	Getty Oil Co. spudded R.H.S.U. #52-21.
April	1978	Getty Oil Co. ran a second electrical survey.
July	1978	Geothermal Power Corp. spudded Observation Hole GPC #15.
August 29	1978	Colorado School of Mines performed electrical and seismic surveys.
November	1978	Thermogenics spudded Observation Hole #5, located about 2 miles south of Roosevelt Hot Springs Unit's southern boundary line.
December	1978	Thermogenics spudded Observation Hole #9, about 3 miles south of the southern R.H.S.U. boundary.
Late	1978	Earth Science

		Lab/University of Utah Research Institute initiated their research and reports.
Jan. - Feb.	1979	Beaver County Commission attended hearings at State Capitol for Power Development Interest at R.H.S.U.
March	1979	McCulloch Geothermal Inc. spudded deep test, Acord #1-26, about 1.7 miles west of R.H.S.U.'s western boundary.
April 30 -	1979	Thermal Power Co. flow tested Utah State #14-2. FOR PERIOD OF FIVE DAYS.

TABLE B

HISTORY OF DEVELOPMENT
ROOSEVELT HOT SPRINGS THERMAL AREA, UTAH
BY PHILLIPS PETROLEUM COMPANY

Late	1972	Literature Survey and Field Reconnaissance
February	1973	Reconnaissance Geochemical Survey
March	1973	Gravity Survey
May	1973	Geochemical Survey (Continuing)
June	1973	Bipole-Dipole Survey
June	1973	Groundnoise Survey
July	1973	Temperature Gradient Survey (Continuing)
October	1973	Magnetotelluric Survey
July 30	1974	Competitive Lease Sale (± 18,871 acres; cost $798,860)
October	1974	Leases Issued

December	1974	Reflection Seismic Survey
February	1975	Spudded Observation Hole #2
March	1975	Spudded Observation Hole #1
March	1975	Spudded Roosevelt KGRA #9-1
April	1975	Ground Level Magnetic Survey
April	1975	Discovery well #3-1
May	1975	Magnetotelluric Survey
June	1975	Petrologic Studies
July	1975	Spudded Roosevelt KGRA #54-3
August	1975	Spudded Roosevelt KGRA #12-35
October	1975	Spudded Roosevelt KGRA #13-10
November	1975	Spudded Roosevelt KGRA #82-33

December 29	1975	Submitted proposed plan of operations to drill 16 deep test wells on federal leases at Roosevelt KGRA
January	1976	Water Observation System
February	1976	Magnetotelluric Survey
February	1976	Most Significant Flow Test (#54-3)
March	1976	Isotopic Studies
April	1976	Unit Approved (Unitization of Roosevelt KGRA)
April	1976	Water Application Hearing
April	1976	Flow Tested #13-10
May	1976	Helium Survey
August	1976	Spudded Roosevelt Hot Springs Unit #25-15
October	1976	Microearthquake and Groundnoise Surveys
October	1976	Spontaneous Potential Survey

October 22	1976	Submitted proposed plan to drill 6 deep test wells on federal leases at Roosevelt Hot Springs Unit
November	1976	High Resolution Seismic Survey
December	1976	Landsat Imagery Study
February	1977	Spudded Observation Hole #4
March	1977	Spudded Observation Hole #5
April	1977	Spudded Observation Hole #3
August	1977	Five Air quality Monitoring Stations set up; also, Phillips' upgrading of baseline water survey
August	1977	Initiated construction of 1.4 mile reinjection pipeline

October	1977	Start one-year environmental baseline study of Phillips by Woodward-Clyde Consultants with support from the Environmental Monitoring and Support Laboratory at Las Vegas of the Environmental Protection Agency and the University of Utah.
October	1977	Flow Test - Reinjection Operation (Flowed from #54-3, reinjectioned into #82-33. Test lasted 236 days.)
October	1977	Phillips granted permission to Hydrothermal Power Co. and Jet Propulsion Laboratory for the construction and active operation of a 1 megawatt unit at Phillips Pad Site #54-3

November	1977	Reseeding program of all Phillips pad sites except #54-3 and #82-33
July	1978	Spudded Observation Hole #8
September	1978	Spudded Observation Hole #7
October	1978	Three-day operation (October 13, 14, 15) for removal of calcite scale by workover rig on well #54-3
June	1979	Initiated the second long-term Flow - Reinjection Test. A damaged lower massive valve aborted the test.
August	1979	Flow Test - Reinjection operation (flowed from #54-3, reinjected into #82-33). Test lasted 88 days.
November	1979	Phillips Petroleum Company, Thermal Power, Amax, O'Brien agreed to develop the Roosevelt Hot Springs geothermal reservoir.
May	1980	Phillips Petroleum Co. and Utah Power and Light Co. agreed to a 90-day negotiation period to seek a contract agreement for commercial development of the Roosevelt Hot Springs Unit thermal area.

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Fluid-mineral equilibria in a hydrothermal system, Roosevelt Hot Springs, Utah

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Abstract—The availability of fluids and drill cuttings from the active hydrothermal system at Roosevelt Hot Springs allows a quantitative comparison between the observed and predicted alteration mineralogy, calculated from fluid-mineral equilibria relationships. Comparison of all wells and springs in the thermal area indicates a common reservoir source, and geothermometer calculations predict its temperature to be higher (288°C ± 10°) than the maximum measured temperature of 268°C.

The composition of the deep reservoir fluid was estimated from surface well samples, allowing for steam loss, gas release, mineral precipitation and ground-water mixing in the well bore. This deep fluid is sodium chloride in character, with approximately 9700 ppm dissolved solids, a pH of 6.0, and gas partial pressures of O_2 ranging from 10^{-32} to 10^{-35} atm, CO_2 of 11 atm, H_2S of 0.020 atm and CH_4 of 0.001 atm.

Comparison of the alteration mineralogy from producing and nonproducing wells allowed delineation of an alteration pattern characteristic of the reservoir rock. Theoretical alteration mineral assemblages in equilibrium with the deep reservoir fluid, between 150° and 300°C, in the system Na_2O-K_2O-CaO-MgO-FeO-Fe_2O_3-Al_2O_3-H_4SiO_4-H_2O-H_2S-CO_2-HCl, were calculated. Minerals theoretically in equilibrium with the calculated reservoir fluid at >240°C include sericite, K-feldspar, quartz, chalcedony, hematite, magnetite and pyrite. This assemblage corresponds with observed higher-temperature (>210°C) alteration assemblage in the deeper parts of the producing wells. The presence of montmorillonite and mixed-layer clays with the above assemblage observed at temperatures <210°C corresponds with minerals predicted to be in equilibrium with the fluid below 240°C.

Alteration minerals present in the reservoir rock that do not exhibit equilibrium with respect to the reservoir fluid include epidote, anhydrite, calcite and chlorite. These may be products of an earlier hydrothermal event, or processes such as boiling and mixing, or a result of errors in the equilibrium calculations as a result of inadequate thermochemical data.

INTRODUCTION

ACTIVE geothermal systems provide a unique glimpse at the chemical and physical processes that take place during hydrothermal alteration and the influence that variations in temperature, pressure and chemical composition of thermal fluid have on the formation of alteration minerals. Detailed studies of the relationship between fluid chemistry and alteration mineralogy in geothermal systems are, however, lacking. In part, this represents the unavailability of complete fluid analyses and of detailed petrologic studies for most geothermal systems.

Extensive exploration in recent years at Roosevelt Hot Springs has made the necessary data available to study these processes. Seven wells, up to approximately 2000 m in depth, currently tap thermal fluids (Fig. 1). Chemical analyses of fluids and petrographic analyses of drill cuttings from several of these wells have been described (Ballantyne and Parry, 1978; Ballantyne, G., 1978; Nielson *et al.*, 1978; Parry, 1978; Rohrs and Parry, 1978; Glenn and Hulen, 1979; Bamford *et al.*, 1980; Glenn *et al.*, 1981). In most cases, however, these studies have focused on the individual wells rather than on the reservoir as a whole.

In this paper alteration mineralogy from the producing and nonproducing wells is compared and an alteration pattern characteristic of the reservoir rock is defined. The composition of the deep reservoir fluid is calculated from analyses of liquid and steam samples from production well 14-2. Corrections are made for the effects of ground-water mixing, mineral precipitation, steam loss and gas release on the pH, gas partial pressures and element concentrations of the original reservoir fluid. Finally, mineral equilibria in the deep reservoir fluid are quantitatively evaluated at temperatures ranging from 150° to 300°C and compared to the alteration mineralogy of the reservoir rock.

GEOLOGY AND HYDROTHERMAL ALTERATION

Roosevelt Hot Springs thermal area, located in west-central Utah, covers approximately 32 sq km on the western margin of the Mineral Mountains (Fig. 1). The thermal reservoir occurs within fractured Precambrian gneisses and Tertiary granitic rocks of the Mineral Mountains pluton (Nielson *et al.*, 1978; Sibbett and Nielson, 1980). At least ten rhyolite domes occur along the crest of the Mineral Mountains, representing igneous activity between 0.5 and 0.8 million years ago. A deep-seated magma body related to this young rhyolitic volcanism is a possible heat source for the present geothermal system (Smith and Shaw, 1975).

The western boundary of the geothermal system is defined by the northeast-trending Opal Mound fault (Fig. 1). Wells drilled east of this fault, except 52-21 and 24-36, produce commercial quantities of fluid, whereas the two wells drilled west of the fault (9-1 and 82-33) do not (Fig. 1) (Forrest, 1980).

Drill cuttings are available for study from four geother-

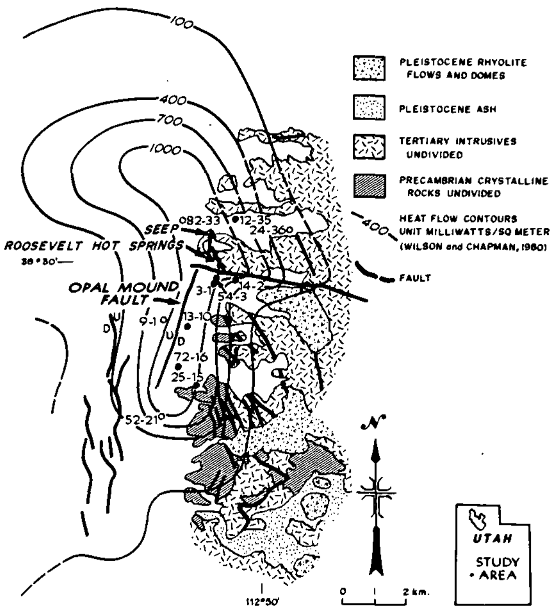


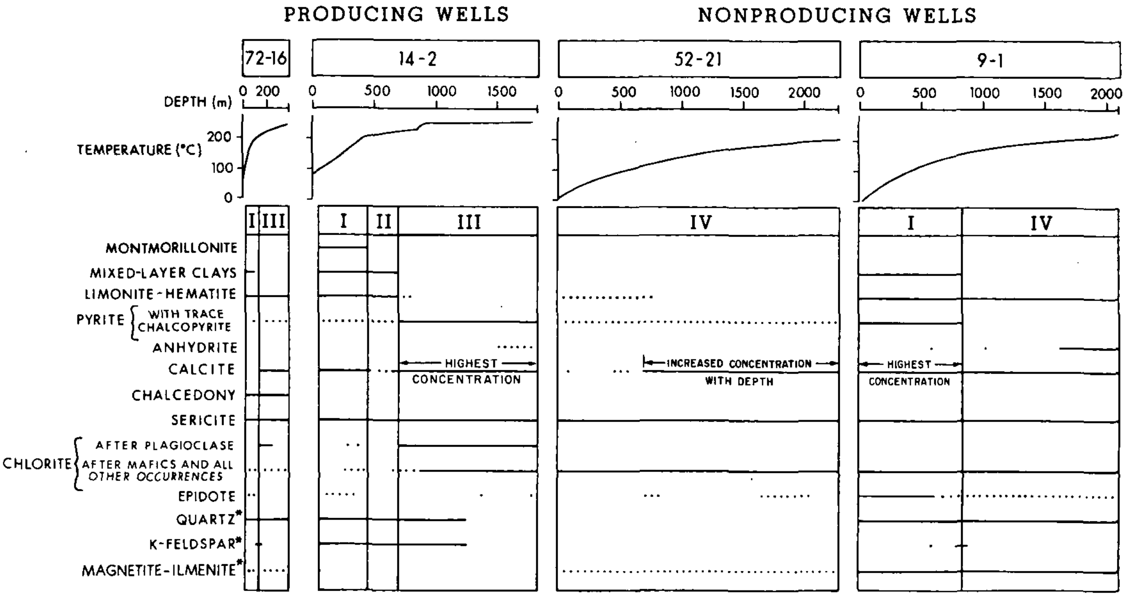
FIG. 1. Generalized geologic map of the Roosevelt Hot Springs thermal area, taken from Nielson and Moore (1979). Closed circles represent geothermal production wells and open circles represent nonproducing wells, as defined by Forrest (1980). Triangles indicate areas of surface seepage. The heat flow contours are taken from Wilson and Chapman (1980).

mal exploration wells, including the producing wells 72-16 and 14-2, and the nonproducing wells 52-21 and 9-1. Mineralogic descriptions of the cuttings from these wells are taken from the work of Ballantyne and Parry (1978), Ballantyne, G. (1978), Nielson *et al.* (1978), Parry (1978), Rohrs and Parry (1978), Glenn and Hulen (1979) and Glenn *et al.* (1981). Petrographic studies of alteration mineralogy of these drill cuttings were limited by the small chip size which prohibited the accurate determination of paragenetic relationships.

Lithologies found in producing wells 72-16 and 14-2, and nonproducing wells 52-21 and 9-1, consist of arkosic alluvium overlying interfingering gneisses and granitic rocks. Alteration in these wells occurs mainly along faults and fractures that mark past and present fluid channels and appears to be largely independent of rock type.

Three alteration assemblages are recognized at depth in producing wells 72-16 and 14-2 (Fig. 2). These include an upper assemblage (I) characterized by the occurrence of montmorillonite, mixed-layer clays and epidote, a transition assemblage (II) present only in well 14-2, and a lower assemblage (III) that in contrast to the upper zones contains minor anhydrite and greater abundances of chlorite after plagioclase, pyrite and calcite. Despite these differences both zones contain chlorite after mafic minerals, limonite-hematite, quartz, sericite and traces of chalcopyrite. Chalcedony is present in both zones of well 72-16 but absent from well 14-2. K-feldspar is common in rocks of the reservoir and is described as an alteration phase in both 72-16 and 14-2. It is very difficult, however, to distinguish hydrothermal K-feldspar from perthitic, anti-perthitic and micrographic K-feldspar in gneisses and granitic rocks when examining only cuttings (Nielson *et al.*, 1978), and therefore it is considered as a questionable alteration product. Magnetite-ilmenite, although present as primary phases in wells 14-2 and 72-16, are also described as alteration products in 72-16.

Although these zones occur at considerably different depths in wells 72-16 and 14-2, their measured temperatures are very similar (Fig. 2). The highest measured temperatures for assemblage I in wells 72-16 and 14-2 are 196° and 210°C, respectively. The lower-most assemblage



*ALSO PRESENT AS A PRIMARY PHASE AT ALL DEPTHS

FIG. 2. Alteration mineralogy and temperature log data for wells 72-16, 14-2, 52-21 and 9-1, Roosevelt Hot Springs thermal area. Mineralogic and temperature-log data taken from Ballantyne and Parry (1978), Ballantyne, G. (1978), Nielson *et al.* (1978), Parry (1978), Rohrs and Parry (1978), Glenn and Hulen (1979) and Glenn *et al.* (1981). When more than one temperature log was available, the log that recorded the highest overall temperatures was used. A solid line indicates minor abundances; a dotted line indicates trace abundances.

(III) corresponds to temperatures ranging from 196°C to the bottom-hole temperature of 243°C in well 72-16 and from 224°C to the bottom-hole temperature of 268°C in well 14-2.

The alteration assemblage in nonproducing well 52-21 (assemblage IV) is markedly different from assemblages observed in the producing wells and includes sericite, chlorite (after mafic minerals), calcite and traces of hematite, pyrite, chalcopyrite, epidote and magnetite-ilmenite. The abundances of these alteration minerals are similar throughout the well with the exception of calcite and epidote which increase in concentration with depth, and hematite which only occurs above 762 m. Quartz and K-feldspar are present throughout the well, although not considered alteration products. The maximum measured temperature in well 52-21 is 204°C.

Alteration mineral assemblages in well 9-1 (although a nonproducing well) exhibit characteristics comparable to both nonproducing well 52-21 and the two producing wells 14-2 and 72-16. The upper mineral assemblage (I) in well 9-1 occurs above a major fault zone at 844 m and contains mixed-layer clays and epidote. This assemblage resembles the lower-temperature assemblages found in the producing wells (assemblages I and II). On the other hand, below 844 m in well 9-1, the lower alteration assemblage is characterized by the absence of chlorite after plagioclase and is most similar to the alteration assemblage observed in nonproducing well 52-21 (assemblage IV). An exception to this similarity, however, is the presence of trace amounts of anhydrite in assemblage IV of well 9-1. Measured temperatures in the upper zone of 9-1 (assemblage I) are less than 160°C, whereas in the lower portion of the well (assemblage IV) they range from 160°C to the bottom hole temperature of 224°C.

The apparent similarity between alteration minerals present in the upper portion of well 9-1 and the upper alteration assemblages found in the production wells suggests that at one time there was an influx of thermal fluid into the rocks above 844 m in well 9-1. Although well 9-1 is presently devoid of free-flowing thermal fluid, Glenn *et al.* (1981) have recognized a zone above the major fault at 844 m that is more fractured and altered than rock encountered in deeper portions of the well.

Several hydrothermal events have altered the rocks in the Roosevelt Hot Springs thermal area. Consequently, it is difficult to separate alteration assemblages produced by the present geothermal event from those of earlier events (i.e., Tertiary alteration associated with Cu-Pb-Zn mineralization (Bamford *et al.*, 1980)). Nevertheless the mineralogic relationships described for wells 72-16, 14-2, 52-21 and 9-1 suggest that alteration assemblages characteristic of the producing wells are related to the present thermal event. This argument is supported by the similarity in the zoning sequences found within the two producing wells, 14-2 and 72-16, and the differences between alteration assemblages found in producing and nonproducing wells.

FLUID CHEMISTRY

Chemical analyses of fluids from wells and springs in the Roosevelt Hot Springs area (Table 1) indicate that four types of water are present: 1) deep circulating thermal fluid tapped by producing wells 14-2, 54-3, and 72-16; 2) hot water from nonproducing wells 9-1 and 52-21; 3) recent discharge from the Roosevelt seep; and 4) water from the now dry Roosevelt Hot Spring. Fluid from wells that do not produce has a composition clearly different from production well fluid. The temperature and concentration of Na, K, F, Cl and total dissolved solids are lower in fluid discharged from nonproductive wells, whereas Ca, Mg, Fe, SO_4 and HCO_3 are more concentrated. Spring water from the Roosevelt seep is similar to nonproducing well fluid, exhibiting greater concentrations of Ca, Mg and HCO_3 than producing well fluid. The total dissolved solids content of fluid discharged from the seep, however, is in the same range as that measured for production wells. Fluid from the now dry Roosevelt Hot Spring is similar to producing well fluid but has higher Mg and lower Si concentrations.

Comparison of the compositions of the Roosevelt fluids, however, suggests they are derived from a common reservoir source and that variations in composition are due largely to ground-water mixing. Local ground water is enriched in Ca, Mg, Fe, SO_4 and HCO_3 and depleted in Na, K, F and Cl relative to the thermal fluid (Mower and Cordova, 1974). This compares well with enrichments and depletions in nonproducing well fluids relative to production well fluid to indicate that nonproducing well fluid is mixed with local ground water.

The extent of ground-water mixing with thermal fluid in the Roosevelt geothermal system tends to increase with distance from well 54-3 (Fig. 3). The minimum mixing percents for fluid from wells 14-2, 72-16, 9-1 and 52-21 average 7, 12, 17 and 21%, respectively, whereas the maximum amounts of ground-water mixing with fluids discharged from the Roosevelt seep and hot spring average 25 and 11%, respectively. These relationships suggest that well 54-3 and other nearby producing wells have the most direct access to the reservoir. Contouring of heat flow data from the Roosevelt thermal area (Fig. 1) produces a similar pattern, with the highest heat flow corresponding to areas of least mixing.

An enthalpy-chloride diagram (Fig. 4) (Truesdell and Fournier, 1976; Fournier, 1979) is used to calculate the percentage of ground-water mixing. This diagram employs the bottom-hole temperatures and fluid chloride concentrations listed in Table 1 and calculated percentages of steam loss listed in Table 2. Fluid from well 54-3 (sample 5) is taken as the well fluid having the lowest percentage of ground water because it exhibits the highest enthalpy and chloride concentrations in relation to the other wells. For the purposes of these calculations, 54-3(5) is designated as zero-percent mixed. This assumption allows minimum percentages of ground-water mixing to be calculated for other well fluids using Fig. 4 (Fournier, 1979). Estimation of the percent mixing for surface seepages is complicated, however, by uncertainties in their cooling history. Assuming that surface seepages cooled entirely by steam loss to 100°C, the maximum percentages of ground water in fluids discharged from the Roosevelt seep and hot spring are calculated using Fig. 4 (Fournier, 1979).

Fluids from producing wells have undergone single-stage liquid-vapor separation in the well bore. The fraction of isoenthalpic steam separation, X_g, can

Table 1. Chemistry of Thermal Water[1]

Sample No	1[9,10]	2[9,11]	3	4	5[9,12]	6	7	8	9	10	11	12	13
Well: Utah State	14-2	14-2	14-2	14-2	54-3	72-16	72-16	52-21	9-1	Hot Spring	Hot Spring	Seep	Seep
Reference[2]	1	1	2	2	3	2	2	4	5	6	6	7	7
Collection Date	5/78	?/78	11/77	11/77	11/79	4/77	4/77	11/78	10/75	11/50	9/57	5/73	8/75
Na	2070	2340	2150	2200	2320	1800	2000	1900	1780	2080	2500	2400	1800
K	384	419	390	410	461	380	400	216	440	472	488	378	280
Ca	11	6.8	9.2	6.9	8	12.4	12.20	107	69.1	19	22	113	107
Mg	0.28	<0.24	0.6	0.08	<2	0.29	0.29	4.0	1.0	3.3	0	17	23.6
Fe	0.13	<0.02			0.03			6.3	0.370				
Al	0.31	<0.28			<0.5			<0.1			0.04		
Si			229	383	263	238	244	65	178	189	146	36	50
Sr	1.44	1.28			1.2	1.36	1.20						
Ba	0.24	<0.24			<0.5								
As	3.2	3.6	3.0	2.2	4.3								
Li	25	28			25.3	15.0	16.0				0.27		17
Be	0.004	<0.004			0.005								
B	23	25	29	28	29.9	26.4	27.2	27.0	28.2		38	37	29
Ce	<0.20	<0.20			0.27								
F			5.2	4.8	6.8	5.2	5.3	3.6		7.1	7.5	5.2	3.3
Cl			3650	3650	3860	3110	3260	2880	2860	3810	4240	3800	3200
HCO_3					232	181	181	615.0	485	158	156	536	300
SO_4			78	60	72	33	32	85	120	65	73	142	70
NO_3							1.3	<0.2	1.9	11	tr.	tr.	
T.D.S.[3]			>6614*	>6745*	7504	6074	6444	5677	5715*	7040	7800	7506	5948
pH (collection T)			5.9	6.2		7.83	7.53	6.8	7.3		7.9	8.2	6.43
T (collection)			14	9						85	55	17	28
T (bottom hole)[4]	268	268	268	268	>260[5]	243	243	204	225[6]				
Total depth (m)[5]	1862	1862	1862	1862	878	382	382	2289	2098				
Geothermometers													
T (Na-K-Ca)(-Mg)[7]	284	291	286	293	297	289	288	209*	278	283*	284	181*	141*
T (quartz cond)[8]			276	302	263	254	256	156	228	234	212	123	141
T (quartz adiab)[8]			244	268	234	227	229	149	207	211	194	121	136

[1] For well locations, see Figure 1. Element concentrations are reported in mg/l and temperatures in °C. A blank indicates data not determined or information not available, and tr indicates trace amounts measured.

[2] References: 1 = Bamford et al. (1980), 2 = Thermal Power Co. (1978), 3 = This report, 4 = Getty Oil Co. (1978), 5 = S. D. Johnson (*personal communication*, 1980), 6 = Mundorff (1970), 7 = Lenzer et al. (1976).

[3] Total dissolved solids. Starred values were calculated in this study by summing ion concentrations (Hem, 1970).

[4] Glenn and Hulen (1979).

[5] Koenig and Gardiner (1977).

[6] Geothermal Resources Council Bulletin, 1979, P. O. Box 98, Davis California, Vol. 8, No. 8, p. 6.

[7] Calculated using the methods of Fournier and Truesdell (1973, 1974). The starred values are magnesium corrected (Fournier and Potter, 1979).

[8] Calculated using the methods of Fournier (1977).

[9] Elements analyzed for but present at concentrations less than ICPQ limits of quantitative detection (Bamford et al., 1980) include Mn, Cu, Pb, Zn, P, Ti, V, Cr, Co, Ni, Mo, Cd, Ag, Au, Sb, Bi, U, Te, Sn, W, Zr, La, and Th.

[10] Sample supplied by J. R. Bowman, Univ. of Utah. Silica was not preserved in this sample and therefore is not reported.

[11] Sample supplied by A. H. Truesdell, U.S.G.S. Silica was not preserved in this sample and therefore is not reported.

[12] Chemical analyses on this sample were completed on fluid filtered to 0.45μ in the field as follows: fluoride, chloride, and total dissolved solids were determined employing specific ion electrode, silver nitrate titration, and gravimetric methods, respectively; sulfate was determined gravimetrically on samples treated with 1% acid in the field; all other elements were determined by Inductively Coupled Plasma Quantometer on fluid diluted with 20% nitric acid in the field.

be calculated from the relation

$$X_g = (h_{f,Ti} - h_{f,Tc})/(h_{g,Tc} - h_{f,Tc}) \qquad (1)$$

where h_g and h_f are the enthalpies of saturated steam and saturated liquid, respectively, at both the initial temperature, *Ti*, of the deep reservoir fluid and final temperature, *Tc*, of the fluid at the collection site. Steam-loss fractions calculated for fluid samples from wells 14-2, 72-16 and 54-3 are listed in Table 2. Truesdell (Thermal Power Co., 1978) has calculated the presence of less than 1.5% steam in the Roosevelt reservoir, indicating that the fluid is very near liquid-vapor equilibrium. Therefore, it was not necessary to correct for excess or insufficient enthalpy in the reservoir fluid in these steam-loss calculations.

Interpretation of geothermometer calculations allows prediction of the deep reservoir fluid temperature to be 288°C ± 10°, compared to the maximum measured temperature of 268°C (Table 1). Calculated cation-geothermometer temperatures for producing well fluids, as listed in Table 1, range from 284° to 297°C. Cation-geothermometer temperatures, however, may be unreliable if uncorrected for the occurrence of calcite scaling (Fournier and Truesdell, 1973) in Roosevelt production wells. Sulfate-water isotopic geothermometer temperatures for samples from two Roosevelt production wells predict reservoir temperatures of 278° and 280°C (Nehring and Mariner, 1979). In addition, a minimum tem-

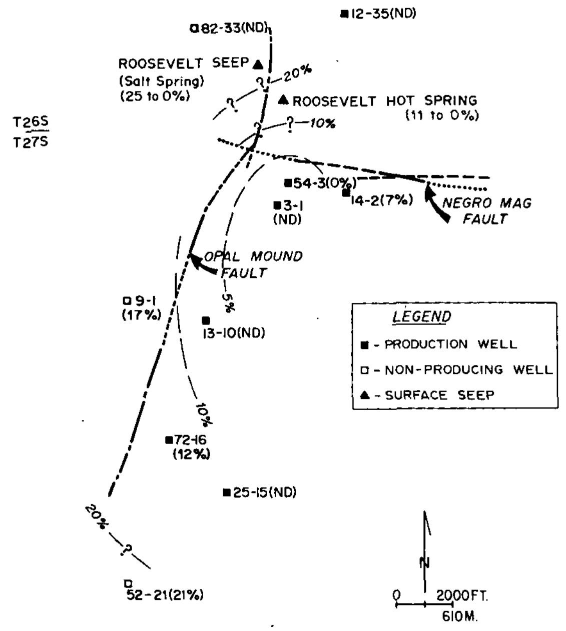


FIG. 3. Average percentage mixing of nonthermal ground water with the thermal reservoir fluid, Roosevelt Hot Springs thermal area. The percentage of mixing is included in parentheses after the well number. ND indicates not done. Refer to Fig. 1 for the location of this area.

perature for the reservoir fluid of 284° is estimated from the point of intersection of lines A and B on the enthalpy-chloride diagram (Fig. 4) (see Fournier, 1979).

CALCULATION OF DEEP RESERVOIR FLUID CHEMISTRY

The composition of the deep reservoir fluid was estimated from calculations that account for the effects of ground-water mixing, steam loss, gas release and mineral precipitation in the well bore on the pH, gas partial pressures and element concentrations of the original reservoir fluid. Fluid samples from well 14-2 are used for these calculations because they are the only samples for which all the necessary data, including gas analyses (A. H. Truesdell, unpublished data, 1979), are available. In the absence of required data from other production wells, 14-2 well fluid was considered adequate to represent the reservoir fluid composition because, as concluded in the previous section, production well fluids all have similar compositions and are probably derived from a common source. These 14-2 samples, in particular (3) and (4), are reliable in that they were chemically preserved and filtered at the sample site. Also, chemical and isotopic data indicate that the steam and liquid have undergone nearly complete separations (Thermal Power Co., 1978).

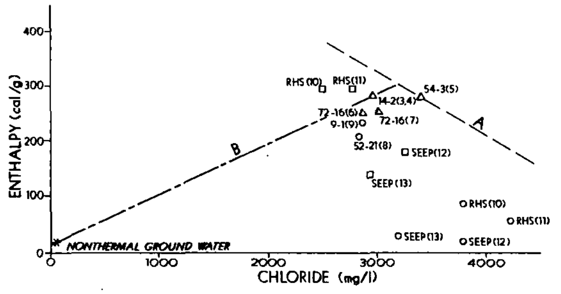


FIG. 4. Enthalpy-chloride diagram, Roosevelt Hot Springs thermal area. Data and sample numbers on this figure are taken from Tables 1 and 2. The local nonthermal ground water composition is taken from Mower and Cordova (1974). Triangles represent producing well fluid compositions corrected for steam loss, squares represent nonproducing well and surface seep samples assuming conductive cooling. Curves "A" and "B" are the upper bounding boiling and mixing curves, respectively. "RHS" denotes Roosevelt Hot Spring. This diagram was constructed employing the methods described by Fournier (1979).

The composition of 14-2 well fluid used in the reservoir fluid calculations (Table 3) represents the average of analyses 14-2(1) through 14-2(4). The average analysis corrected for concentration by 18% steam loss is also given in Table 3. Because the HCO_3 content of these samples was not measured, the HCO_3 concentration present in the least mixed fluid 54-3(5), corrected for 12% steam loss, is used.

An average fluid analysis corrected for both con-

Table 2. Fraction of Steam Separated from Flashed Well Fluids

Well	Sample No.[1]	Collection Pressure[2] (atm)	Collection Temperature[3] (°C)	Reservoir Enthalpy (cal/g)	Reservoir Temperature[4] (°C)	Steam Fraction
14-2	1,2,3,4	12.83[5]	192	277[5]	265	0.18
54-3	5	23.61[6]	222	277[7]	265	0.11
72-16	6,7	20.38[5]	214	250[5]	242	0.07

[1] See table 1.

[2] At the separator. These are absolute values excepting for 54-3 (see footnote 6).

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

[4] Determined from the reservoir enthalpy assuming liquid-vapor equilibrium (Keenan et al., 1969).

[5] Thermal Power Co. (1978).

[6] Written communication (S. D. Johnson, 1980). This is a gauge pressure rather than absolute, therefore the calculated steam fraction is a minimum value.

[7] Data is lacking on the reservoir enthalpy at the base of well 54-3, therefore the enthalpy is assumed equivalent to that of the nearby producing well 14-2.

Table 3. Composition of Reservoir Fluids from Well 14-2

Element	Average analysis	Average analysis corrected for	
		steam loss	steam loss gas loss scaling
Na (mg/l)	2190	1800	1800
K	401	329	329
Ca	8	7	12
Mg	0.32	0.26	0.26
Fe	<0.08	<0.06	<0.06
Al	<0.30	<0.24	<0.24
Si	341	280	280
Cl	3650	2990	2990
C	206	206	1790
S	69	57	138
T.D.S.[a]	6680		9707
Geothermometers			
T(Na-K-Ca)[b]°C			277
T(SiO_2 cond.)[c]°C			269

[a] T.D.S. represents total dissolved solids calculated by the method of Hem (1970). In accord with Hem's treatment of HCO_3^-, H_2CO_3 is converted by a gravimetric factor (H_2CO_3 (mg/l) x 0.4837 = CO_3 (mg/l)) which assumes half of the H_2CO_3 is volitilized as CO_2. This value is used in the summation.

[b] Calculated using the methods of Fournier and Truesdell (1973, 1974).

[c] Calculated using the methods of Fournier (1977).

centration by 18% steam loss and dilution through 7% mixing was also determined. Both of these fluids were considered because it is not known whether mixing occurred in the well bore or reservoir. Mineral-fluid equilibrium calculations on both these calculated fluids produced very similar results. Therefore, the fluid corrected only for steam loss is discussed in this paper.

Because well 14-2 is cased to 551 m (Glenn and Hulen, 1979), sampled waters are assumed to represent a composite of fluids derived from 551 m to at least 1830 m, the total depth of the well. Well log temperatures in this depth interval vary from 210° to 268°C (Glenn and Hulen, 1979). The only significant hot-water entry occurs at 869-881 m (Bamford *et al.*, 1980), where the recorded well log temperature is 250°C.

Methodology for equilibrium calculations

The distribution of element concentrations among aqueous species is calculated using a modification of the computer program PATH (Helgeson *et al.*, 1970; Knight, 1976). The sources of thermochemical data for aqueous species considered in these calculations are Helgeson (1969), supplemented by data from Kharaka and Barnes (1973), Bladh (1978) and Rimstidt (1979). Thermochemical equilibrium constants for minerals and gases are calculated using data reported by Helgeson *et al.* (1978).

In these calculations, the standard state for H_2O and intercrystalline standard state for solids are consistent with unit activity of the pure component at any pressure and temperature. The intracrystalline standard state for minerals calls for all activity coefficients of atoms on the lattice sites of solid solutions to approach unity as the mole fractions of the atoms on the sites approach those in the thermodynamic components of the solid at any pressure and temperature. The standard state for aqueous species, other than H_2O, is one of unit activity in a hypothetical one molal solution referenced to infinite dilution at any pressure and temperature. For gases the standard state is one of unit fugacity of the hypothetical ideal gas at one bar and any temperature.

Component activities accounting for nonstoichiometry of sericite and chlorite in rock samples from well 14-2 are calculated from electron microprobe analyses reported by Ballantyne, J. (1978, 1980) and are shown in Fig. 5. The specific expressions for calculating the activities of the components, listed in Table 4, are derived from the general equations relating site occupancy in a mineral to the activity of the thermodynamic component as presented by Helgeson *et al.* (1978, Equations (46) through (52)), and from preferential site occupancies as de-

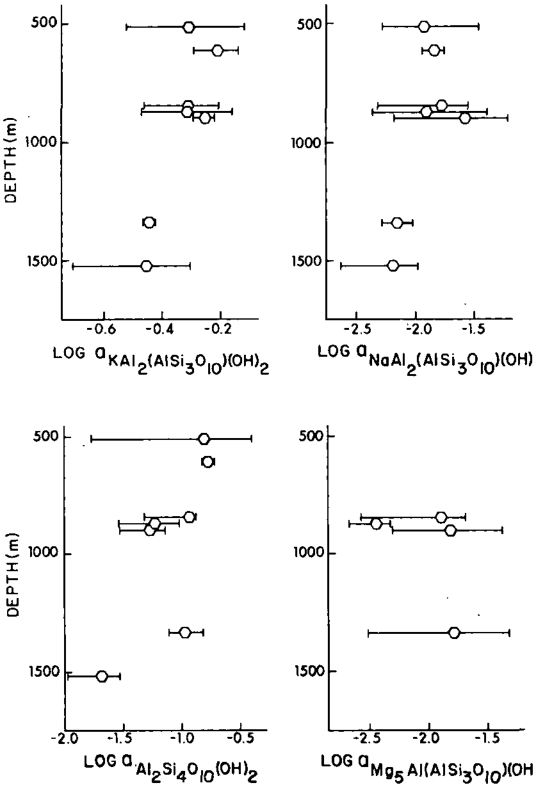


FIG. 5. Variation with depth of the activities of the $KAl_2(AlSi_3O_{10})(OH)_2$, $NaAl_2(AlSi_3O_{10})(OH)_2$ and $Al_2Si_4O_{10}(OH)_2$ components in sericite, and the $Mg_5Al(AlSi_3O_{10})(OH)_8$ component in chlorite from well 14-2. These activities are calculated using electron microprobe analyses of these minerals taken from Ballantyne, J. (1978, 1980). Hexagons indicate the average value for that depth and the bars represent the range in values. Refer to the text for the method of calculation.

Table 4. Specific Equations for Calculating Component Activities

Component	Activity [a]
$KAl_2(AlSi_3O_{10})(OH)_2$	$(X_{K^+,A})\,(X_{Al^{+3},M(2)})^2\,(X_{Al^{+3},T1o})\,(X_{Si^{+4},T1m})\,(X_{Si^{+4},T2})^2\,(X_{OH^-})^2$ [b,c]
$Al_2Si_4O_{10}(OH)_2$	$(X_{V,A})\,(X_{Al^{+3},M(2)})^2\,(X_{Al^{+3},T1o})\,(X_{Si^{+4},T1m})\,(X_{Si^{+4},T2})^2\,(X_{OH^-})^2$ [b,c]
$NaAl_2(AlSi_3O_{10})(OH)_2$	$(X_{Na^+,A})\,(X_{Al^{+3},M(2)})^2\,(X_{Al^{+3},T1o})\,(X_{Si^{+4},T1m})\,(X_{Si^{+4},T2})^2\,(X_{OH^-})^2$ [b,c]
$Mg_5Al(AlSi_3O_{10})(OH)_8$	$(X_{Mg^{+2},M})^5\,(X_{Al^{+3},M})\,(X_{Al^{+3},T})\,(X_{Si^{+4},T})^3\,(X_{OH^-})^8$ [b]

[a] $a_i = k_i \prod_s \prod_j X_{j,s}^{\nu_{s,j,i}}$ (equation (46) from Helgeson et al. (1978)), where: a_i is the activity of the ith component; k_i is the proportionality constant (defined by equation (48) from Helgeson et al. (1978)) relating the intracrystalline and intercrystalline standard states; $x_{j,s}$ is the mole fraction of the jth species on the sth site; and $\nu_{s,j,i}$ is the stoichiometric number of sth energetically equivalent sites occupied by the jth species in one mole of the ith component.

[b] These equations are consistent with random mixing and equal interactions of atoms on energetically equivalent sites.

[c] These equations are consistent with ordered standard state site distributions, equations and data reported by Helgeson et al. (1978) for muscovite, paragonite and pyrophyllite.

fined by Helgeson and Aagaard (1981). The thermodynamic components of the mineral sericite correspond to the chemical formulax units of $Al_2Si_4O_{10}(OH)_2$, $KAl_2(AlSi_3O_{10})(OH)_2$ and $NaAl_2(AlSi_3O_{10})(OH)_2$. For chlorite the activity of the component $Mg_5Al(AlSi_2O_{10})(OH)_8$ is calculated.

Gas pressures

Calculated partial pressures of O_2, CO_2, H_2S and CH_4 dissolved in the reservoir fluid are shown in Fig. 6. The partial pressures of CO_2, H_2S and CH_4 are calculated using the Henry's law relation

$$f = K_T X \tag{2}$$

where f is the fugacity of the gas (at the temperatures and pressures considered in this study the fugacity is essentially equivalent to the partial pressure of a gas in atmospheres), K_T is the Henry's law constant at temperature T (Table 5), and X is the mole fraction of the gas in the reservoir fluid. Mole fractions of these gases in the reservoir fluid are calculated from concentrations measured in the steam sample. The gas content of the steam fraction collected at the same time as liquid samples (1) through (4) from well 14-2 was provided by A. H. Truesdell (unpublished data, 1979). It is assumed for these calculations that CO_2, H_2S and CH_4 separate completely into the steam fraction. This is supported by the work of Drummond (1981, Fig. 4.5) in which he calculates that with 18% steam loss as the result of isoenthalpic boiling of a 250°C (3 m NaCl) fluid, less than 1% of these gases will remain in the liquid phase. This is further supported by a study of gas concentrations in geothermal discharges from the Wairakei system (Ellis, 1962) which has temperatures, pressures and fluid composition similar to those of Roosevelt Hot Springs.

The oxygen partial pressure (P_{O_2}) of the reservoir fluid is approximated using both hematite-magnetite and methane-carbon dioxide equilibria, given by equations (3) and (4), respectively,

$$6Fe_2O_3 = 4Fe_3O_4 + O_{2(g)} \tag{3}$$

$$CH_{4(g)} + 2O_{2(g)} = CO_{2(g)} + 2H_2O \tag{4}$$

and from the relationship between temperature and P_{O_2} determined by D'Amore and Panichi (1980) (equation 5).

$$\log P_{O_2} = 8.20 - (23643/T(°K)) \tag{5}$$

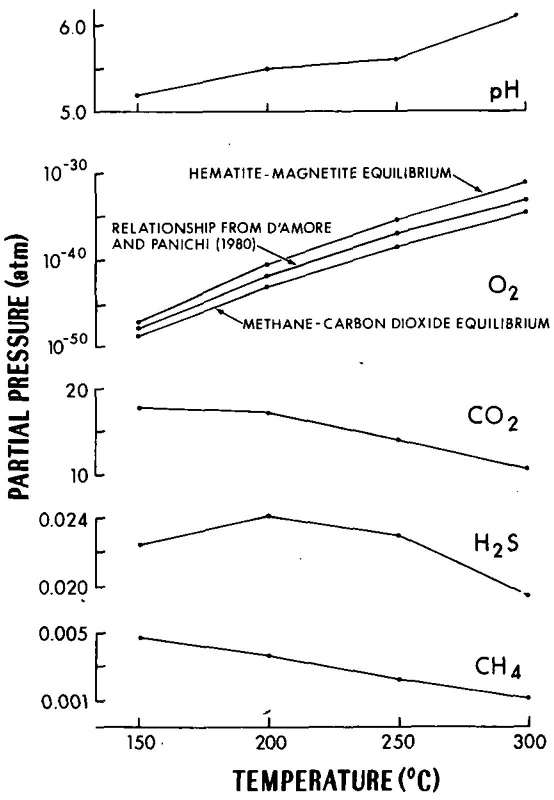


FIG. 6. The variation with temperature of pH and partial pressures of O_2, CO_2, H_2S and CH_4 in the reservoir fluid. See text for methods of calculation.

Table 5. Henry's Law Constants

Gas	K_T (atm/mole fraction)				Source[2]
	150°C	200°C	250°C	300°C	
CO_2[1]	6750	6500	5380	4100	1
H_2S	1860	2000	1900	1620	2
H_2	78387	49459	27813	13939	3
CH_4	87952	70000	44000	22093	3

[1] For 0.1 moles/l NaCl solution.

[2] References: 1 = Ellis and Golding (1963); 2 = Kozintseva (1964) after Ellis and Mahon (1977, p. 132); 3 = Naumov et al. (1974).

At 288°C, the P_{O_2} ranging from 10^{-32} to 10^{-35} atm, P_{CO_2} of 11 atm, P_{H_2S} of 0.020 atm, and P_{CH_4} of 0.001 atm in the Roosevelt reservoir fluid are similar in magnitude to calculated gas pressures in other high-temperature geothermal reservoirs such as Wairakei and Broadlands (Ellis, 1979; D'Amore and Panichi, 1980).

Ion concentrations corrected for gas losses and scaling

The concentrations of calcium, carbon and sulfur will decrease in the fluid by 5, 1753 and 119 mg/l, respectively, as a result of CO_2, CH_4 and H_2S gas release and calcite precipitation accompanying steam separation. The amounts of carbon and sulfur lost to the steam fraction are calculated from the concentrations of CO_2, CH_4 and H_2S released from the flashed fluid. The amounts of calcium and carbon removed from the reservoir through calcite precipitation are calculated from the change in calcite solubility as a result of boiling. The composition of the reservoir fluid corrected for these losses is given in Table 3.

As the reservoir fluid boils and thereby cools from the reported bottom-hole temperature of 265°C to the collection temperature of 192°C, the solubility of calcite decreases by 1.31×10^{-4} moles/l. This solubility decrease is largely a result of the CO_2 pressure decrease in response to the removal of CO_2 from the fluid by the gas phase. The solubility change of calcite can be determined using equation (6) (adapted from Segnit *et al.*, 1962) which gives moles of Ca^{++} in a kilogram of fluid, $m_{Ca^{++}}$, in equilibrium with calcite.

$$m^3_{Ca^{++}} = 13.9 K_1 K_c X_{CO_2}/K_2 \tag{6}$$

$$K_1 = a_{H^+} a_{HCO_3^-}/a_{H_2CO_3} \tag{7}$$

$$K_2 = a_{H^+} a_{CO_3^=}/a_{HCO_3^-} \tag{8}$$

$$K_c = a_{Ca^{++}} a_{CO_3^=}/a_{CaCO_{3(s)}} \tag{9}$$

K_j = equilibrium constant for the j^{th} reaction

X_{CO_2} = mole fraction of CO_2 gas in the reservoir fluid

a_i = activity of the i^{th} species in solution

The variation in the mole fraction of CO_2 in the reservoir fluid as a result of boiling is determined using the fraction of CO_2 removed with each percentage of steam separated from the flashed 260°C reservoir fluid of the Wairakei geothermal system as reported by Ellis (1962, Fig. 3).

For the estimation of calcium and carbon loss due to calcite scaling, it is assumed the reservoir fluid is in equilibrium with calcite and that the fluid remains in equilibrium with calcite as it boils. The occurrence of calcite at depth in well 14-2 supports this assumption of equilibrium. Filtering of the sample upon collection corrects for removal of calcite precipitate that has not adhered to the piping.

Hydrogen ion concentration

The reservoir fluid pH is determined by the method of hydrogen ion mass balance (Truesdell and Singers, 1974; Bischoff and Dickson, 1975) (Fig. 6). This method of estimating pH is based on the assumption that the mass balance of hydrogen in a fluid is independent of temperature and that the hydrogen mass balance of the fluid corrected for gas separation equals that of the deep reservoir fluid. The method of hydrogen mass balance is used in this study because it is independent of mineral equilibrium relationships which the final calculated reservoir fluid will ultimately be used to predict.

The hydrogen mass balance for the fluid corrected for CO_2 and H_2S loss is 0.340 moles/l. This corresponds to a pH of 6.0 at 288°C (Fig. 6) and is similar to pH values calculated for other high-temperature geothermal fluids. For example, New Zealand geothermal fluids having temperatures of 220°C exhibit a range in calculated reservoir pH from 5.9 to 7.1 (Ellis, 1979), and Icelandic geothermal fluids with temperatures of 195° to 220°C range in pH from 5.0 to 8.3 (Arnorsson *et al.*, 1978; Ellis, 1979).

Effect of changing temperature

The effects of temperature change on the pH, gas partial pressures and distribution of aqueous species were determined at 150°, 200°, 250° and 300°C for fixed concentrations of elements in solution (Fig. 6). These calculations suggest that decreasing temperature produces a decrease in the fluid pH and P_{O_2}, an increase in P_{CO_2} and P_{CH_4}, and no consistent variation in P_{H_2S}.

DISCUSSION OF FLUID-MINERAL EQUILIBRIA

The equilibrium relationship between the alteration mineralogy and the deep reservoir fluid of the Roosevelt Hot Springs thermal system is quantitatively evaluated at temperatures ranging from 150° to 300°C. Species distribution calculations are used to calculate mineral equilibria in the deep reservoir fluid at 150°, 200°, 250° and 300°C. The results of these calculations are displayed on a plot of chemical affinity of each mineral in solution against temperature in Fig. 7.

The chemical affinity, A_j, (Helgeson, 1979) indicates the equilibrium condition of the mineral in the fluid and is calculated using equation 10,

$$A_j = RT \ln (K_j/Q_j) \qquad (10)$$

where K_j and Q_j represent the equilibrium constant and activity product for the j^{th} reaction, T is the temperature in °K and R is the gas constant. A positive value indicates the mineral is undersaturated with respect to the fluid. The chemical affinity is zero for mineral-fluid equilibrium and negative for supersaturation. Phases that satisfy equilibrium or supersaturated conditions are shown in the lower portion of Fig. 7, with undersaturated conditions represented on the upper portion of the diagram.

Minerals included on the chemical affinity *versus* temperature diagram are those described as alteration minerals in the Roosevelt system. Thermochemical data for montmorillonite and mixed-layer clays are not supplied in the data compilation by Helgeson *et al.* (1978), nor are compositional data available to calculate component activities. Data for (Ca-) montmorillonite and illite equilibrium taken from Helgeson (1969) are, therefore, used to calculate the equilibrium trends of these minerals. Although these data are not entirely consistent with the Helgeson *et al.* (1978) data base, they will at least provide a reasonable approximation of the actual equilibrium conditions.

Microprobe analyses were available for chlorite and sericite from well 14-2 (Ballantyne, J., 1978, 1980), allowing calculation of the component activities to account for solid solution in these minerals. Using these calculated activities, the chemical affinity of the component in solution was calculated for the $KAl_2(AlSi_3O_{10})(OH)_2$ component of sericite and the $Mg_5Al(AlSi_3O_{10})(OH)_8$ component of chlorite. These component affinities are represented on Fig. 7 by the dashed lines. For comparison, the chemical affinities of the pure end members muscovite and clinochlore are also shown in Fig. 7.

The activities of the $KAl_2(AlSi_3O_{10})(OH)_2$ component of sericite used to calculate the range in chemical affinities of this component are shown in Fig. 5. The activity of the $KAl_2(AlSi_3O_{10})(OH)_2$ component of sericite tends to decrease with increased depth (Fig. 5). A similar trend is noted for the activities of the other two components of sericite (Fig. 5), $NaAl_2(AlSi_3O_{10})(OH)_2$ and $Al_2Si_4O_{10}(OH)_2$. The distribution of available compositional data with depth allows for a grouping of samples into those above 896 m and those below 1341 m in well 14-2. The average activity of $KAl_2(AlSi_3O_{10})(OH)_2$ is 0.51 for the upper group and 0.36 for the lower. Measured well temperatures for these two groups is 210° to 250°C for the upper group and 255°C for the lower group (Fig. 2). The calculated equilibration temperature ($A_j = 0$) of the $KAl_2(AlSi_3O_{10})(OH)_2$ component with the reservoir fluid for the upper group is 246°C and for the lower group is 254°C (Fig. 7). This suggests that solid solution in sericite is temperature dependent and that calculation of component activities to correct for its effects on fluid-mineral equilibrium calculations is appropriate.

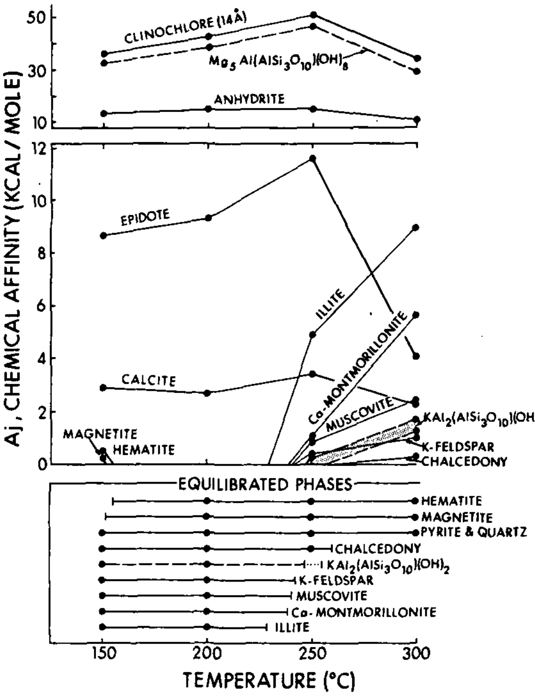


FIG. 7. Chemical affinities of minerals with respect to the Roosevelt reservoir fluid from 150° to 300°C. See text for discussion.

The activity of the $Mg_5Al(AlSi_3O_{10})(OH)_8$ component of chlorite does not appear to vary consistently within the depth range for which microprobe analyses are available (Fig. 5). Therefore, the average activity of 0.013 for all depths is used to calculate the chemical affinity of this component in solution. Chlorites in the reservoir rock contain nearly equal atomic proportions of Fe and Mg (Ballantyne, J., 1978). Thermochemical data for the Fe component of chlorite, however, are not available and therefore only the Mg component is discussed.

Comparison of mineral equilibria in the calculated reservoir fluid (Fig. 7) with alteration mineral assemblages described in producing wells (Fig. 2) indicates that the majority of these minerals could have been produced through interaction of the reservoir rocks with the present thermal fluid. Phases such as hematite, magnetite, pyrite and quartz are saturated with respect to the fluid at nearly all temperatures. These minerals are present in the production wells at all depths, except hematite which is absent from the deeper high-temperature alteration assemblage III in well 14-2.

A select group of phases including chalcedony, the $KAl_2(AlSi_3O_{10})(OH)_2$ component of sericite, K-feldspar, (Ca-) montmorillonite and illite exhibit a crossover from undersaturated to saturated conditions in the temperature range from 229° to 260°C. Typically those phases that exhibit a crossover between 240° and 260°C occur in both the low (I and II) and high (III) temperature alteration zones of the producing wells. These phases include sericite, K-feldspar and chalcedony. A second group of minerals that equilibrate below 240°C is present only in the lower-temperature alteration zones (I and II) of the production wells and includes the clay minerals montmorillonite and illite.

Finally, there is a group of phases present as alteration minerals in production wells 72-16 and 14-2 that is undersaturated with respect to the reservoir fluid at all temperatures, suggesting that these minerals could be the result of a past thermal event. This group includes chlorite, calcite, epidote and anhydrite. Anhydrite and epidote are present in only trace amounts in producing wells, whereas chlorite and calcite are more abundant. All four of these minerals, however, are also present in the nonproducing wells, therefore their presence in the production wells could be the result of a past thermal event.

The abundance of calcite in the upper alteration zone (I) of wells 14-2 and 9-1, in contrast to the near absence of calcite in the upper 700 m of nonproducing well 52-21, however, suggests that calcite in assemblage I is a product of the present thermal event. Because calcite equilibrium is strongly dependent on those chemical characteristics of the reservoir fluid most difficult to quantify, pH, P_{CO_2} and total carbon, it is possible that the error in calculating these fluid components could indeed allow for calcite equilibrium with the fluid. On the other hand, the presence of calcite in the upper 400 m of the reservoir rock can be explained by boiling of the fluid at these shallower depths. According to data from Mahon *et al.* (1980, Fig. 1), the present Roosevelt Hot Springs reservoir fluid, with 0.64 wt % CO_2, will be very close to, if not at, its hydrostatic boiling point in the upper portions of the reservoir (less than 400 m). Boiling of this fluid in the formation rocks can precipitate calcite, a condition analogous to steam loss in well bores in the Roosevelt Hot Springs geothermal system that produces a calcite scale.

Chlorite after plagioclase is present in both wells 72-16 and 14-2 but is lacking from nonproducing well 52-21 and found only rarely and in trace quantities in nonproducing well 9-1. Chlorite after mafics, however, is present in all wells. This suggests that chlorite after plagioclase is a product of the present thermal event, despite the apparent nonequilibrium of chlorite with the reservoir fluid. The lack of thermochemical data for the Fe component of chlorite, however, does not allow a complete evaluation of chlorite equilibrium relationships with the known reservoir fluid. Bird and Norton (1981) in evaluating fluid-mineral equilibria in the Salton Sea geothermal system found a similar situation of nonequilibrium of the thermal fluid with chlorite which appeared related to the present thermal event.

These fluid-mineral equilibrium calculations do not take into account the effects of mineral precipitation on the composition of the fluid as it travels along its flow path in the cooling process. The possibility of mixing with nonthermal ground waters, which is undoubtedly occurring at the margins of the system, or the mineralogic consequences of boiling are also not considered in detail. It is realized, however, that in the Roosevelt thermal system the effects of these processes could be significant.

This study suggests, however, that the observed sequence of a lower to upper mineral assemblage in the production wells can be produced by the present reservoir fluid as it cools from approximately 300°C during its migration to the surface. The mineral equilibrium calculations suggest fluid temperatures of 240° to 260°C in rocks containing the lower mineral assemblage, and temperatures ranging from approximately 229° to 240°C in rocks of the upper mineral assemblage. These predicted temperatures agree within 40°C with the maximum measured temperatures of 210°C in the upper production well alteration assemblage I and 268°C in the lower production well assemblage III (Fig. 2). The highest temperature of 260°C predicted for fluid-mineral equilibrium in mineral assemblage III is remarkably close to geothermometer temperatures for the fluid. For example, geothermometer temperatures estimated from the elemental composition of the surface sample, sulfate-water isotopes and enthalpy-chloride relationships give a temperature of 288°C ± 10°. Also, the Na-K-Ca geothermometer temperature determined from the calculated composition of the deep reservoir fluid is 277°C (Table 3).

CONCLUSION

In the Roosevelt Hot Springs geothermal system, the interaction of the country rock with the present high-temperature thermal fluid will result in a complex series of dissolution and deposition reactions as the fluid and rock attempt to equilibrate. The extent to which the thermal fluid is in equilibrium with the country rock is estimated by comparing actual alteration assemblages with predicted fluid alteration products.

The composition of the high-temperature fluid at depth is estimated from well samples. The effects of nonthermal ground-water mixing, mineral precipitation in the well bore, steam loss and gas release on these surface samples are considered. The predicted composition of the deep fluid is similar in composition to fluids found in other high-temperature geothermal systems, such as Wairakei and Broadlands (Ellis, 1979).

Comparing predicted alteration mineral assemblages for the calculated reservoir fluid, in the temperature range from 150° to 300°C, with alteration assemblages described in drill cuttings of geothermal production wells indicates that several alteration minerals are equilibrated with the reservoir fluid. These include hematite, magnetite, pyrite and quartz which are saturated with respect to the fluid at all temperatures, and chalcedony, sericite, K-feldspar, (Ca-) montmorillonite and illite which are saturated in the fluid at temperatures less than 260° to 229°C. The calculated equilibration temperatures of the last group of minerals predicts to within 40°C the transition zone observed between shallow (lower temperature) and deep (higher temperature) alteration zones. Furthermore, the variation in temperatures of equilibration of the $KAl_2(AlSi_3O_{10})(OH)_2$ component of sericite with the reservoir fluid with depth in well 14-2 is in agreement with observed temperatures in the well. This indicates that sericite solid solution is temperature dependent and that it is necessary to correct for its effects in equilibrium calculations.

Phases that do not exhibit equilibrium with respect to the reservoir fluid, such as epidote, anhydrite, chlorite and calcite, could be remnants of an earlier event. Disequilibrium of the reservoir fluid with chlorite, however, may be the result of inadequate thermochemical data, as the presence of chlorite after plagioclase as a characteristic alteration product in production wells suggests it is a product of the present thermal event. Calcite, on the other hand, could be a product of another process inherent to geothermal activity, such as boiling.

It is suggested, therefore, that the geothermal reservoir fluid at Roosevelt Hot Springs has probably not changed character significantly in the recent past. This is supported by the similarity between the observed alteration mineralogy and fluid-mineral equilibrium calculated for the reservoir fluid and the agreement between predicted equilibration temperatures and observed temperatures.

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REFERENCES

Arnorsson S., Gronvold K. and Sigurdsson S. (1978) Aquifer chemistry of four high-temperature geothermal systems in Iceland. *Geochim. Cosmochim. Acta* **42**, 523–536.

Ballantyne G. H. (1978) Hydrothermal alteration at the Roosevelt Hot Springs thermal area, Utah: Characterization of rock types and alteration in Getty Oil Company Well Utah State 52-21. Univ. of Utah Dept. of Geology and Geophysics Topical Rep. No. 78-1701.a.1.1.4, DOE/DGE contract No. EG-78-C-07-1701, 23 p.

Ballantyne J. M. (1978) Hydrothermal alteration at the Roosevelt Hot Springs thermal area, Utah: modal mineralogy, and geochemistry of sericite, chlorite, and feldspar from altered rocks, Thermal Power Company well Utah State 14-2. Univ. of Utah Dept. of Geology and Geophysics Rep. No. 78-1701.a.1.15, DOE/DGE contract No. EG-78-C-07-1701, 36 p.

Ballantyne J. M. (1980) Geochemistry of sericite and chlorite in well 14-2 Roosevelt Hot Springs geothermal system and in mineralized hydrothermal systems. Univ. of Utah Dept. Geology and Geophysics Rep. No. 79-1701.a.1.6, DOE/DGE contract No. DE-AC07-78ET/28392, 92 p.

Ballantyne J. M. and Parry W. T. (1978) Hydrothermal alteration at the Roosevelt Hot Springs thermal area, Utah: Petrographic characterization of the alteration at 2 kilometers depth. Univ. of Utah Dept. of Geology and Geophysics Tech. Rep. No. 78-1701.a.1.1, DOE/DGE contract No. EG-78-C-07-1701, 23 p.

Bamford R. W., Christensen O. D. and Capuano R. M. (1980) Multielement geochemistry of solid materials in geothermal systems and its applications Part I: The hot-water system at the Roosevelt Hot Springs KGRA, Utah: Univ. of Utah Res. Inst. Earth Sci. Lab. Division Rep. No. 30, DOE/DGE contract No. DE-AC03-79ET-27002, 168 p.

Bird D. K. and Norton D. L. (1981) Theoretical prediction of phase relations among aqueous solutions and minerals in the Salton Sea geothermal system. *Geochim. Cosmochim. Acta.* **45**, 1479–1493.

Bishoff J. L. and Dickson F. W. (1975) Seawater-basalt interaction at 200°C and 500 bars: Implication for origin of seafloor heavy-metal deposits and regulation of seawater chemistry. *Earth Planet. Sci. Lett.* **25**, 383–397.

Bladh K. W. (1978) The weathering of sulfide-bearing rocks associated with porphyry-type copper deposits. Ph.D. dissertation, Univ. of Arizona, 98 p.

D'Amore F. and Panichi C. (1980) Evaluation of deep temperatures of hydrothermal systems by a new gas geothermometer. *Geochim. Cosmochim. Acta* **44**, 549–556.

Drummond S. E. Jr. (1981) Boiling and mixing of hydrothermal fluids: chemical effects on mineral precipitation. Ph.D. dissertation, Pennsylvania State Univ., 380 p.

Ellis A. J. (1962) Interpretation of gas analysis from the Wairakei hydrothermal area. *New Zealand J. Sci.* **5**, 434–452.

Ellis A. J. (1979) Explored geothermal systems. In *Geochemistry of Hydrothermal Ore deposits* (ed. H. L. Barnes). John Wiley and Sons, 632–683.

Ellis A. J. and Golding R. M. (1963) The solubility of carbon dioxide above 100°C in water and in sodium chloride solutions. *Amer. J. Sci.* **261**, 47–60.

Ellis A. J. and Mahon W. A. J. (1977) *Chemistry and Geothermal Systems.* Academic Press, 392 p.

Forrest R. J. (1980) Historical synopsis of the Roosevelt Hot Springs geothermal field, Utah. In *Geothermal Systems in Central Utah* (ed. D. L. Nielson), Guidebook to Field Trip No. 7. Geothermal Resources Council Annual Meeting, 18–24.

Fournier R. O. (1977) Chemical geothermometers and mixing models for geothermal systems. *Proc. International Atomic Energy Agency Advisory Group on the Application of Nuclear Techniques to Geothermal Studies,* Pisa, 1975, Geothermics, Spec. Issue 5, 41–50.

Fournier R. O. (1979) Geochemical and hydrologic considerations and the use of enthalpy-chloride diagrams in the prediction of underground conditions in hot-spring systems. *J. Volcanol. Geothermal Res.* **5,** 1-16.

Fournier R. O. and Truesdell A. H. (1973) An empirical Na-K-Ca geothermometer for natural waters. *Geochim. Cosmochim. Acta* **37,** 1255-1275.

Fournier R. O. and Truesdell A. H. (1974) Geochemical indicators of subsurface temperature - part 2: estimation of temperature and fraction of hot water mixed with cold water. *J. Res. U.S. Geol. Surv.* **2,** 263-270.

Fournier R. O. and Potter R. W., II (1979) A magnesium correction to the Na-K-Ca geothermometer. *Geochim. Cosmochim. Acta* **43,** 1543-1550.

Getty Oil Co. (1978) Data for Roosevelt Hot Springs KGRA, Utah. Univ of Utah Res. Inst. Earth Sci. Lab. Division, August 10-11, 1978, open-file release.

Glenn W. E. and Hulen J. B. (1979) Interpretation of well log data from four drill holes at Roosevelt Hot Springs, KGRA. Univ. of Utah Res. Inst. Earth Sci. Lab. Division Rep. No. 28, DOE/DGE contract No. EG-78-C-07-1701, 74 p.

Glenn W. E., Hulen J. B. and Nielson D. L. (1981) A comprehensive study of LASL C/T-2 Roosevelt Hot Springs KGRA, Utah and applications to geothermal well logging. Los Alamos Scientific Lab. Rep. LA-8686-MS, 175 p.

Helgeson H. C. (1969) Thermodynamics of hydrothermal systems at elevated temperatures and pressures. *Amer. J. Sci.* **267,** 729-804.

Helgeson H. C. (1979) Mass transfer among minerals in hydrothermal solutions. In *Geochemistry of Hydrothermal Ore Deposits,* 2nd Edition (ed. H. L. Barnes), 568-610.

Helgeson H. C., Brown T. H., Nigrini A. and Jones T. A. (1970) Calculation of mass transfer in geochemical processes involving aqueous solutions. *Geochim. Cosmochim. Acta* **34,** 569-592.

Helgeson H. C., Delany J. M., Nesbitt H. W. and Bird D. K. (1978) Summary and critique of the thermodynamic properties of rock-forming minerals. *Amer. J. Sci.* **278-A,** 1-229.

Helgeson H. C. and Aagaard P. (1981) Thermodynamic and kinetic constraints on reaction rates among minerals and aqueous solutions. I. Theoretical considerations: *Amer. J. Sci.* (in press).

Hem J. D. (1970) Study and interpretation of the chemical characteristics of natural waters, 2nd ed. U.S. Geol. Sur. Water-Supply Paper 1473, 363 p.

Keenan J. H., Keyes F. G., Hill P. G. and Moore J. G. (1969) *Steam Tables, Thermodynamic Properties of Water including Vapor, Liquid, and Solid Phases (SI Units).* John Wiley and Sons, 156 p.

Kharaka Y. K. and Barnes I. (1973) SOLMNEQ: Solution mineral equilibrium computations. U. S. Dept. Commerce, Natl. Tech. Inf. Service Rep. No. PB-215 899, 82 p.

Knight J. (1976) A thermochemical study of alunite and copper-arsenic sulfosalt deposits. M. S. thesis, Univ. of Arizona, 142 p.

Koenig J. B. and Gardner M. C. (1977) Geothermal potential of the lands leased by Geothermal Power Corporation in the Northern Mineral Mountains, Beaver and Millard Counties, Utah. Univ. of Utah Res. Inst. Earth Sci. Lab. Division, April 20-21, 1978, open-file release, 430 p.

Kozintseva T. N. (1964) Solubility of hydrogen sulfide in water at elevated temperatures. *Geochim. Int.* 750-756.

Lenzer R. C., Crosby G. W. and Berge C. W. (1976) Geothermal exploration of Roosevelt KGRA, Utah *17th U.S. Symp. Rock Mechanics,* Abs., 13 p.

Mahon W. A. J., McDowell G. D. and Finlayson J. B. (1980) Carbon dioxide: Its role in geothermal systems. *New Zealand J. Sci.* **23,** 133-148.

Mower R. W. and Cordova R. M. (1974) Water resources of the Milford area, Utah, with emphasis on ground water. Utah Dept. Nat. Resources Tech. Pub. No. 43, 99 p.

Mundorff J. C. (1970) Major thermal springs of Utah. *Utah Geol. and Mineral Surv. Resource Bull.* No. 13, 60 p.

Naumov G. B., Ryzhenko B. N. and Khodakovsky I. L. (1974) *Handbook of Thermodynamic Data* (translated from the 1971 Russian original). Nat. Tech. Info. Service PB-226-722.

Nehring N. L. and Mariner R. H. (1979) Sulfate-water isotopic equilibrium temperatures for thermal springs and wells of the Great Basin. *Geothermal Resources Council, TRANS.* **3,** 485-488.

Nielson D. L., Sibbett B. S., McKinney D. B., Hulen J. B., Moore J. N. and Samberg S. M. (1978) Geology of Roosevelt Hot Springs KGRA, Beaver County, Utah. Univ. of Utah Res. Inst. Earth Sci. Lab. Division Rep. No. 12, DOE/DGE contract No. EG-78-C-07-1701, 120 p.

Nielson D. L. and Moore J. N. (1979) The exploration significance of low-angle faults in the Roosevelt Hot Springs and Cove Fort-Sulphurdale geothermal systems, Utah. *Geothermal Resources Council, TRANS.* **3,** 503-506.

Parry W. T. (1978) Hydrothermal alteration at the Roosevelt Hot Springs thermal area, Utah: Part I - Mineralogy of the clay fractions from cuttings, Thermal Power Company Well Utah State 14-2. Univ. of Utah Dept. of Geology and Geophysics, Tech. Rep. No. 78-1701.a.1.1.2, DOE/DGE contract No. EG-78-C-07-1701, 24 p.

Rimstidt J. D. (1979) The kinetics of silica-water reactions. Ph. D. dissertation, Pennsylvania State Univ., 126 p.

Rohrs D. and Parry W. T. (1978) Hydrothermal alteration at the Roosevelt Hot Springs thermal area, Utah: Thermal Power Company Well Utah State 72-16. Univ. of Utah Dept. of Geology and Geophysics Topical Rep. No. 78-1701.a.1.1.3, DOE/DGE contract no. EG-78-C-07-1701, 23 p.

Segnit E. R., Holland H. D. and Biscardi C. J. (1962) The solubility of calcite in aqueous solutions—I. The solubility of calcite in water between 75° and 200° at CO_2 pressures up to 60 atm. *Geochim. Cosmochim. Acta* **26,** 1301-1331.

Sibbett B. S. and Nielson D. L. (1980) Geology of the Central Mineral Mountains, Beaver County, Utah. Univ. of Utah Res. Inst. Earth Sci. Lab. Division Rep. No. 33, DOE/DGE contract No. DE-AC07-78ET28392, 42 p.

Smith R. L. and Shaw H. R. (1975) Igneous related geothermal systems. In *Assessment of Geothermal Resources of the United States-1975* (eds. D. E. White and D. L. Williams), U. S. Geol. Surv. Circ. 726, 58-83.

Thermal Power Co. (1978) Data for Roosevélt Hot Springs KGRA, Utah. Univ. of Utah Res. Inst. Earth Sci. Lab. Division, January 23-25, 1978, open-file release.

Truesdell A. H. and Singers W. (1974) The calculation of aquifer chemistry in hot-water geothermal systems. *J. Res. U.S. Geol. Surv.* **2,** No. 3, 271-278.

Truesdell A. H. and Fournier R. O. (1976) Calculation of deep temperatures in geothermal systems from the chemistry of boiling spring waters of mixed origin. *Proc. 2nd U.N. Symp. Dev. Use Geothermal Resour.,* San Francisco, 1975. Vol. 1, U.S. Government Printing Office, Washington, D. C., 837-844.

Wilson W. R. and Chapman D. S. (1980) Thermal studies at Roosevelt Hot Springs, Utah. Univ. of Utah Dept. of Geology and Geophysics Technical Rep. No. DOE/ID/12079-19, DOE/DGE contract No. DE-AC07-80ID12079, 102 p.