MANAGEMENT ASSISTANCE FOR
THE DEVELOPMENT OF HYDROTHERMAL
ENERGY IN THE ROCKY MOUNTAIN/BASIN
AND RANGE REGION

FINAL REPORT

FOR THE PERIOD
October 19, 1977 - December 31, 1979

Work performed under Contract No.

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(Formerly Contract No. EG-78-C-07-1701)

Department of Geology and Geophysics

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Salt Lake City, Utah (USA)

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Prepared for
DEPARTMENT OF ENERGY
Division of Geothermal Energy

SEPTEMBER 1980

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SEPTEMBER 1980

PREPARED FOR THE
U.S. DEPARTMENT OF ENERGY
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DIVISION OF GEOTHERMAL ENERGY
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1.0 INTRODUCTION

The Department of Geology and Geophysics, University of Utah, was awarded a contract to conduct geothermal research for the U.S. Department of Energy, Division of Geothermal Energy on October 19, 1977 under Contract No. EG-78-C-07-1701. The contract number was changed on October 1, 1978 to DE-AC07-78ET28392 for the 1979 Fiscal Year research program. The contract accounts for all the geothermal research during the period October 19, 1977 through the termination date of December 31, 1979, and has 47 research reports (including this Final Report) delivered during this time period (see Section 2.0).

A uniform contract report numbering system was implemented by DOE/ID on March 26, 1979. Twenty-four research reports processed during this contract prior to the new numbering system are listed in Section 2.0, under the new numbering system for reference purposes. Previous report numbers used on these delivered reports are shown at the end of each report title description.

Attachment 1 (Contract No. DE-AC07-79ET/27002) and Attachment 2 (Contract No. EY-76-S-07-1601) provide a comprehensive list of technical reports produced by geothermal research sponsored by the U.S. Department of Energy.

A substantial amount of the research initiated under the contract will be continued in Fiscal Year 1980 under the U.S. Department of Energy Contract No. DE-AC07-80ID12079 "Management Assistance and Technical Support for Geothermal Programs Administered by the Idaho Operations Office of DOE."

2.0 COMPREHENSIVE LIST OF REPORTS
Contract DE-AC07-78ET28392
(Formerly Contract EG-78-C-07-1701)

<u>Report No.</u>	<u>Report Title</u>
DOE/ET/28392-1	Hydrothermal Alteration at the Roosevelt Hot Springs Thermal Area, Utah: Petrographic Characterization of the Alteration to 2 Kilometers Depth: Ballantyne, J. M. and Parry, W. T.; April 1978 (IDO/78-1701.a.1.1).
DOE/ET/28392-2	Magnetotelluric Investigations at the Roosevelt Hot Springs KGRA and Mineral Mountains, Utah: Wannamaker, Philip; May 1978 (IDO/78-1701.a.6.1).
DOE/ET/28392-3	Program Review: Resource Evaluation, Reservoir Confirmation, and Exploration Technology: Ward, S. H.; May 1978 (IDO/78-1701.b.5.1).
DOE/ET/28392-4	Geology and Alteration of the Coso Geothermal Area, Inyo, Co., CA: Hulen, J. B.; 1978 (IDO/78-1701.b.4.1.; ESL-3).
DOE/ET/28392-5	Geological and Geophysical Analysis of Coso Geothermal Exploration Hole No. 1 (CGEH-1), Coso Hot Springs KGRA, California: Galbraith, R. M., 1978, (IDO/7801701.b.4.2, ESL-5).
DOE/ET/28392-6	Hydrothermal Alteration at the Roosevelt Hot Springs Thermal Area, Utah: Part I. Mineralogy of the Clay Fraction from Cuttings, Thermal Power Co. Well Utah State 14-2. Part II. Chemical Composition Rocks, Thermal Power Co. Well Utah State 14-2: Parry, W. T.; May 1978 (IDO/78-1701.a.1.1.2).
DOE/ET/28392-7	Hydrothermal Alteration at the Roosevelt Hot Springs Thermal Area, Utah: Thermal Power Co. Well Utah State 72-16: Rohrs, D., Parry, W. T.; July, 1978 (IDO/78-1701.a.1.1.3).
DOE/ET/28392-8	Aspects of Forced Convective Heat Transfer in Geothermal Systems: Kilty, K., Chapman, D. S., Mase, C.; July, 1978 (IDO/78-1701.a.6.4.1).
DOE/ET/28392-9	Stratigraphy and Alteration, 15 Shallow Thermal Gradient Holes, Roosevelt Hot Springs KGRA and Vicinity, Millard and Beaver Counties, Utah: Hulen, J. B., 1978 (IDO/78-1701.b.1.1, ESL-9).

- DOE/ET/28392-10 Annotated Bibliography of the Geology of the Roosevelt Hot Springs Known Geothermal Resource Area and the Adjacent Mineral Mountains, March 1978: McKinney, D. B.; 1978 (ID0/78-1701.b.1.1.4, ESL-10).
- DOE/ET/28392-11 Topographic Effects in Resistivity Surveys: Fox, R. C., Hohmann, G. W., and Rijo, L.; 1978 (ID0/78-1701.b.3.2.1, ESL-11).
- DOE/ET/28392-12 Hydrothermal Alteration at the Roosevelt Hot Springs Thermal Area, Utah: Characterization of Rock Types and Alteration in Getty Oil Co. Well Utah State 52-21: Ballantyne, G. H.; November, 1978 (ID0/78-1701.a.1.1.4).
- DOE/ET/28392-13 Three Dimensional Magnetotelluric Modeling: Ting, S. C., Hohmann, G. W.; October, 1978 (ID0/78-1701.a.6.2).
- DOE/ET/28392-14 Monroe, Utah, Hydrothermal System: Results from Drilling of Test Wells MC1 and MC2: Chapman, D. S., Harrison, R.; October, 1978 (ID0/78-1701.a.6.4.2, ID0/76-1601 vol. 77-16).
- DOE/ET/28392-15 Geothermal Exploration and Assessment Technology Program Plan, Final Report: Ward, S. H., and Wright, P. M.; October 30, 1978 (ID0/78-1701.b.5A).
- DOE/ET/28392-16 Hydrothermal Alteration at the Roosevelt Hot Springs Thermal Area, Utah: Modal Mineralogy, and Geochemistry of Sericite, Chlorite, and Feldspar From Altered Rocks, Thermal Power Co. Well Utah State 14-2: Ballantyne, J. M.; November, 1978 (ID0/78-1701.a.1.1.5).
- DOE/ET/28392-17 Hydrothermal Alteration at the Roosevelt Hot Springs Thermal Area, Utah: W. T. Parry, N. L. Bryant, R. E. Dedolph, Ballantyne, J. M., Ballantyne, G. H., Rohrs, D. T., and Mason, J. L.; November, 1978 (ID0/78-1701.1.1).
- DOE/ET/28392-18 Radon Emanometry as a Geothermal Exploration Technique: Theory and an Example from Roosevelt Hot Springs KGRA, Utah: Nielson, D. L.; 1978 (ID0/78-1701.b.1.1.2, ESL-14).
- DOE/ET/28392-19 Geology of Roosevelt Hot Springs KGRA, Beaver County, Utah: Nielson, D. L., 1978, Sibbett, B. W., McKinney, D. B., Hulen, J. B., Moore, J. N., and Samberg, S. M.; 1978 (ID0/78-1701.b.1.1.3, ESL-12).
- DOE/ET/28392-20 Initial Investigation of Soil Mercury Geochemistry as an Aid to Drill Site Selection in Geothermal Systems: Capuano, R. M., and Bamford, R. W.; 1978 (ID0/78-1701.b.3.3, ESL-13).

- DOE/ET/28392-21 Self Potential Survey, Roosevelt Hot Springs, Utah: Sill, W. E., and Johng, D. S.; January, 1979 (ID0/78-1701.a.2.3).
- DOE/ET/28392-22 Interactive Dipole-Dipole Resistivity and IP Modeling of Arbitrary Two-Dimensional Structures (IP2D Users Guide and Documentation); Killpack, T. J., and Hohmann, G. W.; 1979 (ID0/78-1701.b.3.2.3, ESL-15).
- DOE/ET/28392-23 Induced Polarization Measurements at Roosevelt Hot Springs Thermal Area, Utah: Chu, J. J., Sill, W. R., and Ward, S. H.; June, 1979 (ID0/78-1701.a.2.4.1).
- DOE/ET/28392-24 Interpretation of a Seismic Refraction Profile Across the Roosevelt Hot Springs, Utah and Vicinity: Gertson, R. C., and Smith, R. B.; March, 1979 (ID0/78-1701.a.3).
- DOE/ET/28392-25 The Telluric-Magnetotelluric Method in Two- and Three-Dimensional Environments: Stodt, J. A., Hohmann, G. W., and Ting, S. C.; August 1979.
- DOE/ET/28392-26 Cancelled as a report; information was given in 1979 SPE talk.
- DOE/ET/28392-27 Geology of the Cove Fort-Sulphurdale KGRA with Bibliographic Annotations and Petrographic Descriptions by B. Sibbett: Moore, J. N., and Samberg, S. M.; 1979 (ESL-18).
- DOE/ET/28392-28 Multielement Geochemical Exploration Data for the Cove Fort-Sulphurdale Known Geothermal Resource Area, Beaver and Millard Counties, Utah: Bamford, R. W., and Christensen, O. D.; 1979 (ESL-19).
- DOE/ET/28392-29 Bipole-Dipole Interpretation with Three-Dimensional Models (including a field study of Las Alturas, New Mexico): Hohmann, G. W., and Jiracek, G. R.; 1979 (ESL-20).
- DOE/ET/28392-30 Detailed Gravity and Aeromagnetic Surveys of the Cove Fort-Sulphurdale Known Geothermal Resource Area (KGRA) and Vicinity, Millard and Beaver Counties, Utah; Cook, K. L., Serpa, L. F., and Peo, Pe; 1980.
- DOE/ET/28392-31 Structural Fabric and In-situ Stress Analyses of the Roosevelt Hot Springs KGRA: Yusas, M. R., and Bruhn, R. L.; November, 1979.
- DOE/ET/28392-32 An Evaluation of Hypocenter Location Techniques With Applications to Southern Utah: Regional Earthquake Distributions and Seismicity of Geothermal Areas: Wechsler, D. J., and Smith, R. B.; December, 1979.

- DOE/ET/28392-33 Geologic Map of San Emidio Geothermal Area: Moore, J. N.; December 1979 (ESL-23).
- DOE/ET/28392-34 Geology of the Soda Lake Geothermal Area: Sibbett, B. S.; 1979 (ESL-24).
- DOE/ET/28392-35 Interpretation of Electrical Resistivity and Shallow Seismic Reflection Profiles, Whirlwind Valley and Horse Heaven Areas, Beowawe KGRA, Nevada: Smith, C.; 1980 (ESL-25).
- DOE/ET/28392-36 Geology and Alteration of the Baltazor Hot Springs and Painted Hills Thermal Areas, Humboldt County, Nevada: Hulen, J. B.; 1979 (ESL-27).
- DOE/ET/28392-37 Numerical Modeling and Interpretation of Dipole-Dipole Resistivity and IP Profiles, Cove Fort-Sulphurdale KGRA, Utah: Ross, I. P.; 1979 (ESL-26).
- DOE/ET/28392-38 Interpretation of Well Log Data from Four Drill Holes at Roosevelt Hot Springs KGRA: Glenn, W. E., and Hulen, J. B.; 1979 (ESL-28).
- DOE/ET/28392-39 Detailed Gravity and Aeromagnetic Surveys in the Black Rock Desert Area, Utah: Serpa, L. F., and Cook, K. L.; 1980.
- DOE/ET/28392-40 Geology of the Central Mineral Mountains, Beaver County, Utah: Sibbett, B. S., and Nielson, D. L.; March 1980 (ESL-33).
- DOE/ET/28392-41 Summary of Potassium/Argon Age Dating: Evans, S. H., Jr.; March 1980.
- DOE/ET/28392-42 Geothermal Exploration at Hill Air Force Base, Ogden, Utah: Glenn, W. E., Chapman, D. S., Foley, D., Capuano, R. M., Sibbett, B. S., Cole, D. and Ward, S. H.; March 1980 (ESL-34).
- DOE/ET/28392-43 Geochemistry of Sericite and Chlorite in Well 14-2, Roosevelt Hot Springs Geothermal System, and in Mineralized Hydrothermal Systems: Ballantyne, J. M.; June, 1980.
- DOE/ET/28392-44 Model Study of the Regional Hydrogeologic Regime, Roosevelt Hot Springs, Utah: Smith, J. L.; May 1980.
- DOE/ET/28392-45 Compositional Gradient In Natural Silicic Liquids: Evans, S. H., Jr.; 1980.
- DOE/ET/28392-46 A Light Stable Isotope Study of the Roosevelt Hot Springs Thermal Area, Southwestern Utah: Rohrs, D. T.; May 1980.
- DOE/ET/28392-47 Final Report.

3.0 ABSTRACTS OF TECHNICAL REPORTS

Contract No. DE-AC07-78ET28392, formerly Contract No. EG-78-C-07-1701)

Report No. DOE/ET/28392-1

Hydrothermal Alteration at the Roosevelt Hot Springs Thermal Area, Utah:
Petrographic Characterization of the Alteration to 2 Kilometers Depth, by
J. M. Ballantyne and W. T. Parry, April 1978 (ID0/78-1701.a.1.1).

Hydrothermal alteration in drill cuttings from Thermal Power drill hole 14-2, Roosevelt Hot Springs Thermal area, has been studied petrographically. The hole is sited in alluvium approximately 1.6 km southeast of the old resort and was rotary drilled to a depth of 1866.0 m. The exact hole location is 2310 FNL, 350 FWL, Sec. 2, T 27S, R 9W, elevation 1908.5 m. Core was extracted from 792.5 to 795.5 m. Thin sections were made from samples at 15.2 m intervals of drill cuttings collected at 1.5 or 3.0 m intervals during drilling. Thin sections were made of 1.5 or 3.0 m intervals from 274.3 to 304.8 m, 487.9 to 581.2 m, and 863.7 to 899.2 m. These intervals were chosen for close-spaced sampling on the basis of increases in temperature, porosity, conductivity and acoustic velocity shown in geophysical logs. A total of 153 thin sections of cuttings were made, and an additional 9 sections were made from the core. Depths of thin section samples are listed in the appendix of the report. A visual estimate of the percentage of each rock type was made for each thin section.

Magnetotelluric Investigations at the Roosevelt Hot Springs KGRA and Mineral Mountains, Utah, by Philip Wannamaker, May 1978 (ID0/78-1701.a.6.1).

During the summer of 1976, twenty-five magnetotelluric sites were monitored for the Department of Geology and Geophysics by Geotronics Corp. of Austin, Texas. Among other MT functions, transverse electric (TE) and transverse magnetic (TM) apparent resistivity and impedance phase data were provided for the frequency range 3×10^{-3} Hz to 100 Hz.

Some one-dimensional inversion results for this area have yielded very low values of estimated true resistivity. Such values are unrealistic in light of established notions about conductivity mechanisms in earth materials. Furthermore, the assembly of such inversions to form a crude two-dimensional model has yielded a calculated 2-D pseudosection far removed from the observed pseudosection. Trial-and-error modeling has provided a better fit although strong differences between observed and modeled data remain and cannot be overcome by any purely two-dimensional model. The most noteworthy difficulty is the presence of exaggerated contrasts in apparent resistivity persisting to the lowest frequency of observation for both modes of wave excitation.

Single-conductor, 2-D, TE and TM modeling may explain such problems in terms of three-dimensional effects. Discontinuities in electric fields from preservation of normal current density will result in the above-stated persistent apparent resistivity contrasts. This boundary condition must be obliged down to zero frequency.

Electrical strike estimation may be a meaningless endeavour in a strongly three-dimensional area. The total fields do not decompose into the standard principal modes (TE and TM) and H_z depend on horizontal derivatives of both electric field components. Multiple symmetry axes result in multiple estimated strike directions depending on where the observer is located. When derivatives of electric field are relatively small, noise may be the determining factor. The estimated strike directions for the Roosevelt stations are, however, quite consistent. The elongate resistivity horst structure of the Mineral Mountains situated in conductive valley fill is felt to be the overwhelming reason for such a consistency.

Report No. DOE/ET/28392-3

Program Review: Resource Evaluation, Reservoir Confirmation, and Exploration Technology, by Stanley H. Ward, May 1978 (ID0/78-1701.b.5.1).

In order to seek to match the DOE/DGE proposed program with the needs of the nation, the states and industry, and to meet the national goals set forth in Table 1, the University of Utah has assisted DOE/DGE in a review of its programs in resource evaluation, reservoir confirmation, and exploration technology.

To effect this review, seven consortia of specialists were identified. These consortia met and discussed the specialists' viewpoints on the specific needs for DOE/DGE support to ensure reaching the national goals.

Additionally, 28 managers of industrial geothermal exploration programs were contacted to obtain their opinions.

Finally, a Program Review Panel Meeting was held in Salt Lake City, Utah, on March 8, 1978 to review all inputs received to that date and to recommend a program of geothermal resource evaluation, reservoir confirmation, and exploration technology to DOE/DGE. The next section contains a summary of the recommendations so obtained.

As a means of stimulating discussion, a document, describing a tentative (or straw-man) strategy for Resource Evaluation Reservoir Confirmation and Exploration Technology, was distributed to 28 managers of geothermal exploration programs and to each of the members of the seven technical consortia.

This report intends to convey the details of the program review as well

as to provide a summary of the recommendations, means for their implementation, and a six-year program of expenditures which would accomplish the objectives of the recommendations. The summary of recommendations, plans for implementation, and plan of expenditures is the sole work of the author but is based on the input of all others involved in the review process. This document is intended as a guide to program managers as they develop specific program planning documents.

Geology and Alteration of the Coso Geothermal Area, Inyo Co., CA, by J. B. Hulen, 1978. (ID0/78-1701.b.4.1; ESL-3).

Geology and alteration of the Coso geothermal area were mapped in conjunction with geophysical surveys and a deep drill test (CGEH-1) to facilitate selection of a follow-up drill site.

The oldest rocks exposed at Coso are intermediate to mafic metamorphic rocks of uncertain age intruded by dikes and pods of quartz latite porphyry and felsite, and by a small stock of Late Cretaceous (?) granite. These rocks are locally overlain by Late Cenozoic volcanic rocks which include the domes, flows, and associated pyroclastic deposits of the Coso rhyolite dome field.

Principal structures in the geothermal area are older high-angle faults of uncertain displacement trending northwest, west-northwest, and east-northeast, and younger high-angle faults with a normal component of displacement trending north-northwest, north-northeast, and (subordinately) northeast. Active surface thermal phenomena and hydrothermal alteration are concentrated along the younger northerly-trending faults, especially where these faults intersect older structures. Deep thermal fluid flow at Coso will be controlled entirely by structural permeability developed in otherwise tight and impermeable host rocks. Neither geologic mapping nor deep drilling have revealed potential deep primary aquifers.

Surface alteration at Coso is of three main types: (1) clay-opal-alunite alteration, (2) weak argillic alteration, and (3) stockwork calcite veins and veinlets, which are locally associated with calcareous sinter.

Clay-opal-alunite and weak argillic alteration are typically developed around

active thermal emissions. These are almost entirely restricted in distribution to an east-northeast-trending belt roughly one mile in width and four miles in length. Calcareous alteration is much more widely distributed, but is confined to a broad zone of anomalous geophysical response. The southern end of the Coso Hot Springs fault zone (S. 1/3, Sec. 4, T22S, R39E) satisfies these requirements, and appears to be the most favorable site for discovery of a high-temperature geothermal resource.

Report No. DOE/ET/28392-5

Geological and Geophysical Analysis of Coso Geothermal Exploration Hole No. 1 (CGEH-1), Coso Hot Springs KGRA, California, by R. M. Galbraith, 1978 (ID0/7801701.b.4.2, ESL-5).

The Coso Geothermal Exploration Hole number one (CGEH-1) was drilled in the Coso Hot Springs KGRA, California from September 2 to December 2, 1977. Chip samples were collected at ten-foot intervals and extensive geophysical logging surveys were conducted to document the geologic character of the geothermal system as penetrated by CGEH-1. The major rock units encountered include a mafic metamorphic sequence and a leucogranite which intruded the metamorphic rocks. Only weak hydrothermal alteration was noted in these rocks. Drill hole surveys and drilling rate data indicate that the geothermal system is structurally controlled and that the drill hole itself was strongly influenced by structural zones. Water chemistry indicates that this geothermal resource is a hot-water rather than a vapor-dominated system.

Several geophysical logs were employed to characterize the drill hole geology. The natural gamma and neutron porosity logs indicate gross rock type and the acoustic logs indicate fractured rock and potentially permeable zones. A series of temperature logs run as a function of time during and after the completion of drilling were most useful in delineating the zones of maximum heat flux. Convective heat flow and temperatures greater than 350°F appear to occur only along an open fracture system encountered between depths of 1850 and 2775 feet. Temperature logs indicate a negative thermal gradient below 3000 feet.

Report No. DOE/ET/28392-6

Hydrothermal Alteration at the Roosevelt Hot Springs Thermal Area, Utah:
Part I. Mineralogy of the Clay Fraction from Cuttings, Thermal Power Co.
Well Utah State 14-2. Part II. Chemical Composition of Rocks, Thermal
Power Co. Well Utah State 14-2, by W. T. Parry, May 1978
(ID0/78-1701.a.1.1.2).

The mineralogy of the clay fraction from drill cuttings from Thermal Power Co. well Utah State 14-2 has been determined using x-ray diffraction techniques as part of an investigation of hydrothermal alteration at the Roosevelt Hot Springs Thermal Area. A petrographic description of the alteration observed in thin sections of cuttings from well Utah State 14-2 is included in Ballantyne and Parry (1978). Optical methods have been supplemented by x-ray diffraction to identify clay minerals reported here.

Hydrothermal Alteration at the Roosevelt Hot Springs Thermal Area, Utah:
Thermal Power Co. Well Utah State 72-16, by D. Rohrs, and W. T. Parry,
July 1978 (ID0/78-1701.a.1.1.3).

Hydrothermal alteration in drill cuttings from Thermal Power Co. well Utah State 72-16, Roosevelt Hot Springs Thermal Area, Utah, has been studied petrographically, supplemented by x-ray diffraction identification of clay minerals and x-ray fluorescence determination of major element composition.

The well is located 4.3 km southwest of the old resort and 500 m east of the Opal Mound. The well was rotary drilled to a total depth of 1254 ft (382 m). All samples described in this report are rotary-drill cuttings collected at 10 ft (3.05 m) intervals during drilling. One such sample at 50 ft (15.2 m) intervals was selected for analysis. Each sample was carefully washed to remove all traces of drilling mud, lost circulation material, and other contaminants. Thin sections were prepared from a portion of each sample. A second portion of each sample was ground in a Spec Shatterbox for chemical analysis and x-ray diffraction determination of clay mineralogy. The clay fraction was extracted by peptizing the pulverized sample with Calgon and centrifuging. X-ray diffraction patterns were obtained for oriented smears on glass slides following air drying, heating to 250°C, heating to 550°C, and vapor glycolation at 60°C. Fused-glass disks were prepared for x-ray fluorescence analysis using the method of Shapiro (1975), and sulfur was determined by the LECO induction furnace technique.

Aspects of Forced Convective Heat Transfer in Geothermal Systems, by K. Kilty, D. S. Chapman, and C. Mase, July, 1978 (ID0/78-1701.a.6.4.1).

A knowledge of convective heat transfer is essential to understanding geothermal systems and other systems of moving groundwater. A simple, kinematic approach toward convective heat transfer is taken here. Concern is not with the cause of the groundwater motion but only with the fact that the water is moving and transferring heat.

The mathematical basis of convective heat transfer is the energy equation which is a statement of the first law of thermodynamics. The general solution of this equation for a specific model of groundwater flow has to be done numerically. The numerical algorithm used here employs a finite difference approximation to the energy equation that uses central differences for the heat conduction terms and one-sided differences for the heat convection terms. Gauss-Seidel iteration is then used to solve the finite difference equation at each node of a non-uniform mesh.

The Monroe and Red Hill hot springs, a small hydrothermal system in central Utah, provide an example to illustrate the application of convective heat transfer theory to a geophysical problem. Two important conclusions regarding small geothermal systems follow immediately from the results of this application. First, the most rapid temperature rise in the convection part of a geothermal system is near the surface. Below this initially rapid temperature increase, the temperature increases very slowly, and thus temperatures extrapolated from shallow boreholes can be seriously in error.

Second, the temperatures and heat flows observed at Monroe and Red Hill, and probably at many other small geothermal areas, can easily result from moderate vertical groundwater velocities in faults and fracture zones in an area of normal heat flow.

Stratigraphy and Alteration, 15 Shallow Thermal Gradient Holes, Roosevelt Hot Springs KGRA and Vicinity, Millard and Beaver Counties, Utah, by J. B. Hulen, 1978 (ID0/78-1701.b.1.1, ESL-9).

Fifteen shallow thermal gradient drill holes were recently completed by Geothermal Power Corporation (GPCR) in the vicinity of the Roosevelt Hot Springs KGRA. Five holes penetrated Tertiary granitic rocks and Precambrian gneiss east of the KGRA. Seven holes completed entirely in alluvium near the southwestern corner of the KGRA encountered a near-surface marker horizon of Pleistocene pumice and perlite. Maximum calculated alluvial sedimentation rates since initial deposition of this pumice and perlite range from 1 foot in 12,500 years to 1 foot in 2,300 years. Three holes east of the Mineral Mountains penetrated late Cenozoic basaltic andesite beneath a thin veneer of alluvium.

Tertiary granitic and Precambrian gneissic bedrock penetrated by the GPCR holes is pervasively but weakly altered. Alteration products in the bedrock consist of trace to minor amounts of clay and sericite after plagioclase and potassium feldspar, chlorite after mafic minerals, and erratically distributed calcite and epidote after plagioclase and leucosene ($\pm$ calcite) after sphene. Alluvial grains derived from the bedrock are similarly altered. Unaltered Pleistocene pumice and perlite coexist in the alluvium with altered bedrock grains, indicating that alteration in these grains antedates alluvial deposition and therefore antedates the presently active geothermal system.

Calcite cement is abundant in nearly all alluvium penetrated by the GPCR

holes. In several of the holes at the southwestern corner of the KGRA, much of the alluvium seems to have been firmly indurated by the cement. This cemented alluvium may function locally as a caprock, preventing fluid and heat loss from the active geothermal system.

Manganese and iron oxides occur in highly variable amounts in samples from all the GPCR holes. Dendritic films and crusts of manganese oxide in alluvium postdate carbonate cement and may be genetically related to the presently active geothermal system. Disseminated and veinlet-controlled manganese oxide in bedrock is of uncertain age relative to the geothermal system. Most of the iron oxides were formed after sample collection by oxidation of drill steel and of steel lids on sample jars.

All 15 GPCR drill holes appear to be peripheral to a central zone of anomalously high thermal gradient and low resistivity delineated by previous investigations. GPCR-8 and -14, however, are characterized by high heat flow and relatively abundant manganese oxide mineralization, which may reflect a favorable hydrologic system controlling thermal fluid flow at depth. These holes thus seem most encouraging for discovery of a deeper high-temperature geothermal resource.

Report No. DOE/ET/28392-10

Annotated Bibliography of the Geology of the Roosevelt Hot Springs Known Geothermal Resource Area and the Adjacent Mineral Mountains, March 1978, by D. B. McKinney, 1978 (ID0/78-1701.b.1.1.4, ESL-10).

This bibliography is a result of the need to present a unified account of the geologic and geothermal literature of the Roosevelt Hot Springs KGRA in Utah. References are compiled to March 31, 1978, and are complete to that date as far as is known.

Since ninety-nine references were found, it seemed worthwhile to append a brief annotation of the contents to provide researchers a starting point for further investigations in the Roosevelt area. Hopefully the annotations will limit the amount of necessary literature search to a minimum in a given type of research.

Additional studies by ESL in the Roosevelt area will assume this Bibliography to be inclusive and will list only pertinent publications and new material published after March 31, 1978.

Topographic Effects in Resistivity Surveys, by R. C. Fox, G. W. Hohmann, and L. Rijo, 1978 (ID0/78-1701.b.3.2.1, ESL-11).

The nature and significance of topographic-effect resistivity anomalies are discussed and a two-dimensional, finite element computer technique is described that provides a means for: 1) analyzing the nature of these anomalies, 2) correcting apparent resistivity data for topographic effects, and 3) incorporating topography in interpretative models. We have studied the effects of slope length and slope angle on the shapes and amplitudes of these anomalies for a valley, a ridge and a slope.

For an in-line, dipole-dipole electrode array, a valley produces a central resistivity low flanked by zones of higher resistivity. A ridge produces just the opposite anomaly pattern, a central high flanked by zones of lower resistivity. A slope generates a resistivity low at its base and a high at its top. Topographic effects increase with slope length until the terrain feature becomes large with respect to the dipole length. Increasing the slope angle causes larger effects irrespective of slope length. Electrode positioning has an important effect on anomaly shape and amplitude, especially when detailed modeling is required.

A technique for correcting apparent resistivity for topographic effects uses the finite element program to compute the correction factors. The accuracy of these corrections depends upon how closely the actual case approximates an ideal two-dimensional model.

Examples are given to show how topographic effects produce anomalies that can lead to erroneous interpretations. An actual field case is included to demonstrate the importance of including topography in the interpretative model.

The results of this study show that:

- 1) topographic-effect resistivity anomalies are significant in areas where slope angles are 10 degrees or more,
- 2) topography must be included to insure valid interpretative models of survey results, and
- 3) the two-dimensional finite element technique provides a method for effectively treating this problem.

Hydrothermal Alteration at the Roosevelt Hot Springs Thermal Area, Utah: Characterization of Rock Types and Alteration in Getty Oil Co. Well Utah State 52-21, by G. H. Ballantyne, November, 1978 (ID0/78-1701.a.1.1.4).

Getty Oil Company well 52-21 in the Roosevelt Hot Springs Thermal Area was drilled to 7500 feet in predominantly upper amphibolite facies metamorphic rocks. All lithologies in the drill hole are pervasively but weakly altered: the alteration assemblage is chlorite + sericite + clays with occasional traces of calcite above 2300 feet. A zone of increased alteration intensity from approximately 1800 feet to 2300 feet occurs within and adjacent to a dacite dike which cuts the metamorphic rocks. A second zone of stronger alteration extends from 6000 feet to the bottom of the drill hole.

The drill hole which is located approximately 5000 feet south of the center of the silica apron known as the Opal Mound was apparently drilled beyond the influence of acid, high-sulfate brines such as have affected the upper portions of drill holes 72-16, 76-1 and University of Utah 1A and 1B.

Three-Dimensional Magnetotelluric Modeling, by S. C. Ting, and G. W. Hohmann, October, 1978 (ID0/78-1701.a.6.2).

We have adapted a three-dimensional (3D) volume integral equation to magnetotelluric (MT) modeling. Incorporating an integro-difference scheme increases the accuracy somewhat. Utilizing the two symmetry planes of a buried prismatic body and a normally incident plane wave source greatly reduces the required computation time and storage.

Convergence checks and comparisons with one-dimensional (1D) and two-dimensional (2D) models indicate that our results are valid. Because of space charges at conductivity boundaries, low-frequency 3D responses are much different from 1D and 2D responses. Hence 3D models are required for interpreting much MT data, especially in the complex geological environment.

In this paper, we show theoretical anomalies due to 3D prisms. The surface impedance tensor is obtained by imposing two different source polarizations. We have found that the principal directions derived by the analytical method (Sims and Bostick, 1969) are inappropriate compared with those obtained by actually incrementally rotating the coordinate system. Three-dimensionality is revealed by measuring differences between these principal directions and direction calculated from the vertical-horizontal magnetic field relationship. The impedance tensor is plotted in polar diagrams on the surface. It is shown that the relative magnitude and shapes of plots on the polar diagrams can be used to determine the dimensionality of subsurface structures.

Monroe, Utah, Hydrothermal System: Results from Drilling of Test Wells MC1 and MC2, by D. S. Chapman, and R. Harrison, October, 1978 (ID0/78-1701.a.6.4.2).

Following detailed geological (Parry et al., 1976; Miller, 1976) and geophysical (Mase, Chapman, and Ward, 1978; Kilty, Mase, and Chapman, 1978) studies of the Monroe, Utah hydrothermal system, a program of drilling two intermediate-depth test wells was undertaken. The objectives of the test well drilling were three-fold: (1) to obtain structural information bearing on the poorly known dip of the Sevier Fault, (2) to obtain temperature information below the shallow depths (approximately 300 ft.) sampled in the first phase of exploration, and (3) to provide cased wells which could act as monitor wells during the production phase of the project. The test well drilling was seen to be vital to the selection of a site for a production well. This report describes the results from the drilling of the two test wells, designated MC1 and MC2, and offers interpretation of the hydrothermal system which may be used as a basis for selecting production wells.

Report No. DOE/ET/28392-15

Geothermal Exploration and Assessment Technology Program Plan, Final
Report, by S. H. Ward, and P. M. Wright, October 30, 1978
(ID0/78-1701.b.5A).

This document describes a plan for the Department of Energy (DOE) Program in Geothermal Exploration and Assessment Technology. The purpose of this Program is to provide assistance to the Nation's industrial community by helping to remove technical and associated economic barriers which presently inhibit efforts to bring geothermal electric power production and direct heat applications on line. Federal involvement in providing such assistance is detailed in Public Law 93-410, the Geothermal Energy Research, Development, and Demonstration Act of 1974, and in ERDA-86, the Definition Report for the Geothermal Energy Research, Development and Demonstration Program, published by ERDA in October, 1975, in response to P. L. 93-410.

Hydrothermal Alteration at the Roosevelt Hot Springs Thermal Area, Utah: Modal Mineralogy, and Geochemistry of Sericite, Chlorite, and Feldspar From Altered Rocks, Thermal Power Co. Well Utah State 14-2, by J. M. Ballantyne, November, 1978 (ID0/78-1701.a.1.1.5).

Sericite, chlorites, feldspars, biotite and hornblende from hydrothermally altered rocks at several depths in Thermal Power Company well Utah State 14-2, Roosevelt Hot Springs Thermal Area, Utah, have been analysed using the electron microprobe. Sericites and ferromagnesian minerals have been analysed for 12 major elements, and feldspars for 3. The results have been used, along with whole-rock chemical analyses, to computer calculate modal mineralogy for samples from the drillhole. Calculated modes for hydrothermal minerals are in reasonable agreement with observations from thin sections.

Chlorite compositions plotted in terms of ions on a graph of Si^{4+} versus $\text{Mg}^{2+}/(\text{Mg}^{2+} + \text{Fe}^{2+} + \text{Fe}^{3+})$ fall in the ripidolite-pycnochlorite-brunsvigite field and show distinct differences due to host mineral type. Tetrahedral occupancy in chlorite by Si^{4+} ions increases according to host mineral in the order: biotite, plagioclase, hornblende; and octahedral occupancy by Mg^{2+} ions increases in the order: plagioclase, hornblende, biotite. A ternary plot of Mg^{2+} , $\text{Fe}^{2+} + \text{Fe}^{3+}$, and Al^{3+} ions in octahedral positions shows a less distinct effect of host mineral control. No systematic compositional trends within the drillhole are evident but compositions do vary with depth.

Sericites replace plagioclase and, rarely, biotite. No host mineral effect is evident. All of the sericites are phengitic, having $\text{Si}^{4+}:\text{Al}^{3+}$ ratios greater than 3:1, and Si^{4+} content shows an overall downhole increase with depth in the drill hole. An overall downhole decrease is exhibited by F^- relative to Mg^{2+} .

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
(ID0/78-1701.a.1.1).

Hot springs 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 60 m. Marcasite and pyrite occur below the water table at about 30 m. 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 spring temperature is 250°C but in 1950 the spring temperature was 850°C. Computed Na-K-Ca temperature is 2410°C for the present spring, 2740°C for a well and 2830°C for the 1957 spring. Quartz saturation temperatures are 1700°C for the present spring, 2830°C for the well, and 2130°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.

Radon Emanometry as a Geothermal Exploration Technique: Theory and an Example from Roosevelt Hot Springs KGRA, Utah, by D. L. Nielson, 1978 (IDO/78-1701.b.1.1.2, ESL-14).

Rn^{222} is the longest lived radon isotope and has commonly been used as a geologic tracer. This isotope is a product of the U^{238} decay series and is present in some amount in all geologic systems. From published literature, radon flux in geothermal systems is evaluated in terms of: 1) the formation of radon by disintegration of parent material and the release of radon from the crystalline structure, and 2) the movement of radon through diffusion and transport processes. Rn^{222} originates from the decay of Ra^{226} which emits an alpha particle. The recoil energy of the newly formed Rn^{222} is sufficient to transport the atom 0.03-0.04 m in rocks. This is the principal method of release of Rn from the rock matrix. It has been found that the amount of radon contributed to geofluids is inversely proportional to the particle size and the flux is thus increased in areas of fracturing.

Because of the short half-life of Rn^{222} and slow rates of diffusion, a transport mechanism must predominate if radon is to migrate appreciable distances. In the near-surface environment, transport processes are dependent on atmospheric variables including barometric pressure, wind velocities, and precipitation. These factors are very difficult to quantify but they can be compensated for by integrating the radon flux over time.

Four radon survey lines were established over the geothermal field of Roosevelt Hot Springs KGRA. The radon flux was determined using the

Westinghouse Alpha 2 system which measures the flux at each station over a period of 30 days using an alpha-sensitive dosimeter. The method was very successful in locating mapped fault systems that communicate with the structurally controlled geothermal reservoir. It is concluded that this method, coupled with a structural analysis, can be useful as a site-specific exploration tool, particularly in locating exploration holes in known geothermal areas.

Geology of Roosevelt Hot Springs KGRA, Beaver County, Utah, by D. L. Nielson, B. W. Sibbett, D. B. McKinney, J. B. Hulen, J. N. Moore, and S. M. Samberg, 1978 (IDO/78-1701.b.1.1.3, ESL-12).

The Roosevelt Hot Springs KGRA is located on the western margin of the Mineral Mountains in Beaver County, Utah. The bedrock geology of the area is presented in this report. It is dominated by metamorphic and plutonic rocks of Precambrian age as well as felsic plutonic phases of the Tertiary Mineral Mountains Pluton. Rhyolite flows, domes, and pyroclastics reflect igneous activity between 0.8 and 0.5 million years ago. All lithologies present in the map area are described in detail with an emphasis on characteristics which will allow them to be distinguished in drill cuttings.

The geothermal system at Roosevelt Hot Springs KGRA is structurally controlled with reservoir rocks demonstrating little primary permeability. The structure is mainly a result of low-angle normal faulting which has produced low-angle, westward-dipping mylonites, steeply dipping, northwest-trending mylonites, and brecciation localized in the hanging wall of the principal low-angle fault. These mylonites are up to 15 m thick and they are silicified and retrograded to greenschist facies assemblages. East-west faulting is also present and has been produced by deep-seated regional zones of weakness. North to north-northeast-trending faults are the youngest structures in the area, and they control present fumarolic activity and recent hot spring activity which has deposited opaline and chalcedonic sinters. It is proposed here that the geothermal reservoirs are controlled primarily by

intersections of the principal zones of faulting. This conclusion is supported by the configurations of the fault patterns. It indicates the importance of regional geologic mapping and structural analysis in the exploration for hydrothermal resources.

Logs from Thermal Power Utah State 72-16, Getty Oil Utah State 52-21, and six shallow thermal gradient holes drilled by the University of Utah are presented in this report and have been utilized in the construction of geologic cross sections of the geothermal field.

Initial Investigation of Soil Mercury Geochemistry as an Aid to Drill Site Selection in Geothermal Systems, by R. M. Capuano, and R. W. Bamford, 1978 (ID0/78-1701.b.3.3., ESL-13).

A mercury-in-soil survey was conducted at the Roosevelt Hot Springs Known Geothermal Resource Area (KGRA), Utah, to evaluate mercury soil geochemistry as a method of selecting exploration well sites in a hot-water geothermal system. Samples of -80 mesh soil were collected at 30.5 m intervals along traverses crossing known structures, surficial geothermal alteration, and exploration well sites, and were analysed using a Model 301 Gold Film Mercury Detector (Jerome Instrument Corp., Jerome, Arizona).

Strong mercury anomalies occur at locations along known structures in close proximity to subsurface thermal activity; examples include areas over hot spring deposits and near a shallow producing well. In contrast, background mercury concentrations are present in nearby locations with little or no indication of subsurface thermal activity, such as areas around deep marginal producing wells and dry wells, and areas lacking hot spring deposits. These results indicate that mercury geochemical surveys can be useful for identifying and mapping structures controlling fluid flow in geothermal systems and for delineating areas overlying near-surface thermal activity. Soil mercury geochemistry thus provides information which may aid in the cost-effective selection of exploration well site.

Self Potential Survey, Roosevelt Hot Springs, Utah, by W. R. Sill, and D. S. John, January, 1979 (ID0/78-1701.a.2.3).

A large scale (35 km^2) self-potential (SP) survey was made at Roosevelt Hot Springs. The survey consisted of approximately 47 line-km of profiles at station spacings of 100 m. The profiles were run using a fixed electrode and a traveling electrode out to distances of 1 to 2 km, before advancing the fixed electrode up to the last occupied station. Repeated measurements show a standard deviation of about ± 6 mv, although the spread on groups of measurements might be as large as 30 mv.

Some of the SP profiles show correlations with the thermal system, having generally low values over the thermal high and the coincident resistivity low. Some of the smaller scale features appear to be associated with mapped faults. In plan view, the contoured self potential shows a character very similar to the 300 m, dipole-dipole resistivity. The SP values are generally low where the resistivity is low. Along the eastern margin of the system, in the vicinity of steep resistivity gradients, the contour map shows a series of localized highs.

Electrokinetic (streaming potential) and thermoelectric effects are likely candidates for the sources of these self potential anomalies. The (near-surface) hydrothermal clay alteration should increase the cross coupling coefficients for these two effects, although excess clay alteration may reduce the effects through the reduction in electrical resistivity.

Thermoelectric effects, combined with vertical temperature gradients or spherical or point sources below the clay alteration zone (large coupling coefficient), generally produce positive SP anomalies. Negative thermoelectric anomalies can be produced by point sources within the cross coupling zone (clay alteration), but this would probably be limited to relatively shallow sources (less than hundreds of meters). On the other hand, electrokinetic effects combined with various spherical or point sources generally produce negative anomalies. For this reason, the electrokinetic effects might be favored as the source of the large-scale low region. Other sources or geometries might be postulated for the localized highs, but their proximity to the steep resistivity gradients might suggest a cause related to the electrical structure.

Report No. DOE/ET/28392-22

Interactive Dipole-Dipole Resistivity and IP Modeling of Arbitrary Two-Dimensional Structures (IP2D Users Guide and Documentation), by T. J. Killpack, and G. W. Hohmann, 1979 (ID0/78-1701.b.3.2.3, ESL-15).

An interactive IP-resistivity modeling computer program has been developed at the Earth Science Laboratory. This program can be used to model arbitrary two-dimensional IP-resistivity structures for comparison with data from dipole-dipole surveys. The program computes the potential difference between the two potential electrodes of a conventional dipole-dipole array using a finite-element approach. The original program was developed by Luis Rijo at the University of Utah. Additional software has been written around Rijo's program to provide interactive input and output functions. This report is a user's guide and documentation for the interactive program called IP2D.

Report No. DOE/ET/28392-23

Induced Polarization Measurements at Roosevelt Hot Springs Thermal Area,
Utah, by J. J. Chu, W. R. Sill, and S. H. Ward, June, 1979
(ID0/78-1701.a.2.4.1).

During the summer of 1978 an induced polarization survey was conducted at Roosevelt Hot Springs using the dipole-dipole array. The survey consisted of two profile lines, one across the southern end of the system (2200N) and another across the northern portion (5950N). A total of 15 line-km of profiles was run, with 100 m and 300 m dipoles out to n spacings of 4 to 6.

Apparent resistivity amplitude and phase data were gathered with a phase-sensitive receiver at frequencies between 32 Hz and 1/256 Hz. The data are presented in the form of apparent resistivity and phase pseudo-sections.

Induced polarization effects in geothermal environments can result from clays and pyrite which are associated with hydrothermal alteration. Laboratory measurements on altered material show some induced polarization effects at frequencies below 1 Hz which are thought to be due to pyrite. A higher frequency polarization (>1 Hz) is attributed to the effects of clays. The primary purpose of this survey was to investigate the feasibility of mapping clay alteration zones, and separating them from other conductive features, by making use of their polarization characteristics.

The field data show some small, low frequency phase anomalies which may be the result of pyrite deposition. The higher frequencies show considerable phase effects which can be the result of clays, but the effects of electromagnetic coupling have not, as yet, been assessed.

Report No. DOE/ET/28392-24

Interpretation of a Seismic Refraction Profile Across the Roosevelt Hot Springs, Utah and Vicinity, by R. C. Gertson, and R. B. Smith, March, 1979 (ID0/78-1701.a.3).

In April, 1977 a seismic refraction profile was recorded across the Milford Valley, the Roosevelt Hot Springs KGRA, and the northern Mineral Mountains in southwestern Utah. Seven shot points were used to provide multiple subsurface seismic refraction coverage along the 30 km east-west profile line. Since an inspection of power spectrums revealed large components of 60 Hz noise on some traces, computer routines were used to low-pass filter all seismograms. Amplitude information was utilized by normalizing all traces that recorded the same blast.

Subsurface structural modeling was conducted by means of first arrival P-wave delay-time analysis and ray tracing. Herglotz-Wiechert travel-time inversion was used for the velocity-depth distribution in the Mineral Mountains. The interpretation of the P-wave travel-times suggests that the Milford Valley fill consists of two units with a total thickness of at least 1.8 km. The surficial layer is composed of Quaternary sands and clays with a velocity of 1.8 km/s. A deeper horizon with a velocity of 4.0 km/s is interpreted to be Tertiary sediments on the basis of gravity modeling across the Milford Valley using estimated densities from velocity-density relationships. The deepest layer identified from the seismic data is interpreted as a bedrock unit of Precambrian(?) gneisses. A true velocity of 6.7 km/s for the valley basement was determined from reversed subsurface

P-waves and from a sonic log obtained in a well drilled into metamorphics near the refraction line.

In the vicinity of the Roosevelt KGRA, a thin, low-velocity alluvial layer covers a basement igneous complex with a velocity of 5.2 km/s. Synthetic seismograms suggest that a slight velocity gradient in the upper 0.1 km of basement rock may account for the absence of reflections in the record sections. Analysis of the refraction data also indicates that the main range front faulting begins at least one kilometer west of the Opal Mound fault. Amplitude decay of the first P-wave arrivals shows decreased attenuation for seismic waves that propagate across the hot springs area.

Granite velocities between 3.3 km/s and 4.0 km/s were calculated from the travel-times in the Mineral Mountains. These velocities may not be representative of the majority of the pluton because the refraction profile closely followed the east-west Hot Springs fault zone. An east-dipping 5.5 km/s layer at a depth between 0.7 km and 1.5 km beneath the range corresponds to an increase in velocity indicated on a sonic log at the eastern edge of the geothermal area.

The Telluric-Magnetotelluric Method in Two- and Three- Dimensional Environments, by J. A. Stodt, G. W. Hohmann, and S. C. Ting, August 1979.

Through two- and three-dimensional computer modeling we have shown that the assumption of spatial uniformity of the horizontal magnetic field, which is an implicit assumption made in straightforward applications of the telluric-magnetotelluric (T-MT) method, is not always valid near conductivity inhomogeneities. For a two-dimensional case, the TE mode horizontal magnetic field may vary as much as a factor of three in five kilometers. The spatial variation of the horizontal magnetic field is not as great over three-dimensional inhomogeneities, but may still contribute significantly to impedance magnitude and phase over shallow inhomogeneities at higher frequencies.

Spatial variation of the horizontal magnetic field can cause T-MT impedances to differ significantly from magnetotelluric (MT) impedances. Consequently, MT modeling of T-MT field data could result in a misleading interpretation of conductivity structure. To avoid erroneous interpretation, numerical modeling programs should calculate actual T-MT responses, rather than MT responses, for comparison with T-MT data. Resolution of a conductivity structure which produces significant spatial variation of the magnetic field is less with T-MT data than with an equal amount of MT data. However, the increased amount of data one obtains from a T-MT survey may offset this shortcoming if the data are properly interpreted.

Report No. DOE/ET/28392-26

Cancelled as a report; information was given in 1979 SPE talk.

Report No. DOE/ET/28392-27

Geology of the Cove Fort-Sulphurdale KGRA with Bibliographic Annotations and Petrographic Descriptions by B. Sibbett, by J. N. Moore, and S. M. Samberg, 1979 (ESL-18).

The Cove Fort-Sulphurdale Known Geothermal Resource Area (KGRA) is located on the northwestern margin of the Marysvale volcanic field in southwestern Utah. The geology of the KGRA is dominated by lava flows and ash-flow tuffs of late Oligocene to mid-Miocene age that were deposited on faulted sedimentary rocks of Paleozoic to Mesozoic age. The rocks of the Cove Fort-Sulphurdale area were metamorphosed and mineralized by stocks of quartz monzonite and latite porphyry during the lower Miocene. An unrelated hydrothermal event produced small fluorite deposits near Cove Fort. Quaternary volcanic activity produced extensive andesitic basalt flows along the western margin of the KGRA.

The geothermal system of the Cove Fort-Sulphurdale KGRA is structurally controlled by normal faults. The principle structures include: north-northwest- and northeast-trending steeply dipping faults and low-angle west-dipping faults. The low-angle faults bound large-scale gravitational glide blocks in the central part of the Cove Fort-Sulphurdale area. High-angle faults control fluid flow within the geothermal reservoir, while the gravitational glide blocks provide an impermeable cap for the geothermal system in the central part of the field.

Surficial activity occurring to the north and south of the glide blocks is characterized by the evolution of hydrogen sulfide and deposition of native sulphur. Intense acid alteration of the alluvium, resulting from downward migration of sulphuric acid, has left porous siliceous residues that retain many of the original sedimentary structures. The acid-altered areas are concentrated along mineralized, steeply dipping faults. It is suggested that the intense low magnitude earthquake activity in the Cove Fort area reflects reactivation of older faults.

This report includes detailed logs of Union Oil Company drill holes Forminco #1, Utah State 42-7, and Utah State 31-33.

Multielement Geochemical Exploration Data for the Cove Fort-Sulphurdale Known Geothermal Resources Area, Beaver and Millard Counties, Utah, by R. W. Bamford, and O. D. Christensen, 1979 (ESL-19).

Multielement geochemical exploration data have been acquired for the Cove Fort-Sulphurdale Known Geothermal Resource Area (KGRA). This was accomplished by analysis of both whole rock and +3.3 specific gravity concentrate samples from cuttings composites collected from shallow rotary drill holes. Area distributions are reported for arsenic, mercury, lead and zinc. These are elements indicated by previous studies to be broadly zoned around thermal centers in geothermal systems and thus to be useful for selecting and prioritizing drilling targets.

Results from this work suggest that reservoir temperature and/or reservoir-to-surface permeability, and thus possibly overall potential for a geothermal resource, increase northward beneath the approximately 18 square mile area containing shallow drill holes, possibly to beyond the northern limits of the area. The data provide a basis for development of three principal target models for the geothermal system but do not permit prioritization of these models. It is recommended that geochemical, geological, and temperature gradient surveys be expanded northward from the present survey area to more fully define the area which appears to have the best resource potential and to aid prioritization of the target models.

Bipole-Dipole Interpretation with Three-Dimensional Models (including a Field Study of Las Alturas, New Mexico), by G. W. Hohmann, and G. R. Jiracek, 1979 (ESL-20).

We have studied the bipole-dipole responses of three-dimensional (3D) prisms using an integral equation numerical solution. Although response patterns are quite complex, the bipole-dipole method appears to be a useful, efficient means of mapping the areal distribution of resistivity. However, 3D modeling is required for quantitative interpretation. Computer time for our solution varies from negligible for small bodies to 6 minutes on a UNIVAC 1108 for the largest possible body (85 cubes).

Bipole-dipole response varies significantly with bipole orientation and position, but simply changing the distance between the bipole and the body does not greatly affect the response. However, the response is complex and interpretation ambiguous if both transmitter electrodes are located directly over a body. Boundaries of shallow bodies are much better resolved than those of deep bodies. Conductive bodies produce "false" polarization highs that can confuse interpretation. It is difficult to distinguish the effects of depth and resistivity contrast, and, as with all electrical methods, depth extent is difficult to resolve.

Interactive interpretation of bipole-dipole field results from a geothermal prospect in New Mexico illustrates the value of the 3D modeling technique.

Detailed Gravity and Aeromagnetic Surveys of the Cove Fort/Sulphurdale Known Geothermal Resource Areas (KGRA) and Vicinity, Millard and Beaver Counties, Utah, by K. L. Cook, L. F. Serpa and W. Pe.

During the summer of 1978, a detailed survey (comprising 231 stations over about 900 km²) was made in the Cove Fort-Sulphurdale Known Geothermal Resource area (KGRA) and vicinity, Millard and Beaver counties, Utah to assist in the appraisal of the potential of this area as a geothermal resource. The survey reinforced the results and information obtained in the previous regional gravity surveys (comprising 522 stations, of which 55 stations were repeated in the present survey) by Brumbaugh (1977) and Sontag (1965).

The gravity data from about 700 stations were reduced and compiled as a terrain-corrected (out to 20 km) Bouguer gravity anomaly map with 1-mgal contour interval. A sinuous belt of gravity contours with a total relief of 15-20 mgal extends across the survey area with a right-lateral offset that is probably related to the major Wah Wah-Tushar east-west lineament. An elongate gravity nose (with a total relief of about 19 mgal) that extends about 18 km west-southwestward from the southern Pavant Range indicates a probable extension of the Laramide overthrust sheet (Paleozoic rocks thrust eastward over Mesozoic rocks) observed in the range. A large north-trending gravity low, extending for more than 32 km from Beaver Valley to Dog Valley, indicates a large graben, herein designated the "Beaver-Cove Fort graben." Within the western part of the large gravity low, a north-trending belt of small gravity low centers (with 3-5 mgal closure) corresponds to the north-trending zone of

rhyolite flows, including Gillies Hill and Fourmile Ridge. North-trending belts of gravity contours, with steep gradients, are interpreted as step faulting along the western and eastern margins of the Beaver-Cove Fort graben. The Sulphurdale Hot Springs occur along the Cove Fort-Sulphurdale fault zone (downthrown on the west), which extends along the western margin of the Tushar Mountains and Pavant Range and forms the eastern margin of the Beaver-Cove Fort graben. Four east-west gravity profiles, interpreted using a 2 1/2-dimensional modeling technique, indicate a maximum thickness of valley fill (Quaternary and Tertiary rocks) of about 1.2 km (assuming a density contrast of 0.5 g/cc between the bedrock and valley fill) within the Beaver-Cove Fort graben in the survey area.

In August 1975, an aeromagnetic survey was flown over part of the survey area at a constant barometric elevation of 12,000 ft (3,660 m). The aeromagnetic data are used to supplement the interpretation of the gravity data. The aeromagnetic field intensity residual anomaly map and the second-order polynomial residual aeromagnetic map (obtained by removing a second-order polynomial surface) are presented with a 20-gamma contour interval. Two north-south profiles and one east-west profile were selected for magnetic interpretive modeling. The two north-south profiles were also stacked and averaged over 6-km-wide strips and modeled.

Three major anomalies are observed in the aeromagnetic data, each of which correlates well with a geologic feature in its vicinity. The interpretive magnetic models were assumed to have a magnetic susceptibility of 0.003 cgs for the magnetic basement rock in the survey area; and, based on

this assumption, the depth to the magnetic basement was estimated. In general the magnetic basement is shallow in the southern portion of the survey area where two magnetic highs are observed. One of the highs corresponds with the Cinder Pit volcanic cone and its associated basalt field. The other magnetic high corresponds with the high peaks of the Tushar Mountains where intrusive rocks crop out at the surface. In the northern portion of the survey area, the magnetic basement deepens to a maximum depth of 8-9 km in the valleys, where a broad low magnetic anomaly is observed in the data. In this region, no igneous material has been mapped.

A comparison of the patterns of the gravity and magnetic anomalies in the survey area shows similarities and dissimilarities that are helpful in deciphering some of the geologic features. The trend of both the regional gravity and magnetic anomalies is approximately east-west and hence parallel to the Wah Wah-Tushar trend. However, the regional gravity anomaly values decrease to the south and/or southeast, whereas the regional magnetic anomaly values do not. According to Snow (1978), this feature of the regional gravity is probably related to the deepening of the Moho to the southeast, and the east-west regional magnetic anomaly trend probably reflects a relatively shallow intrusive belt along the Wah Wah-Tushar trend. The local gravity anomalies, superimposed on the regional gravity, are mainly attributed to 1) north-south trending Basin and Range fault zones and 2) folding and/or thrusting of the denser sedimentary rocks. The local magnetic anomalies, superimposed on the regional magnetic anomalies, correspond with the extrusive and shallow intrusive igneous rocks.

The occurrences of hydrothermal alteration, hot spring deposits, and flowing hot springs coincide with inferred fault zones. No evidence of extensive alteration can be interpreted from the magnetic data. A large intrusive body forming the Tushar Mountains is indicated in the magnetic data. The pronounced gravity high commonly associated with regional subsidence due to a densification process in geothermal activity was not observed in the survey area.

Structural Fabric and In-situ Stress Analyses of the Roosevelt Hot Springs KGRA, by M. R. Yusas and R. L. Bruhn, November 1979.

The Roosevelt Hot Springs Known Geothermal Resource Area (KGRA) is located along the west-central flank of the Mineral Mountains in southwestern Utah. The geothermal reservoir is a hot-water-dominated system in fractured plutonic and metamorphic rock. A principal purpose of this study was to determine the geometry and origin of fractures as an aid to developing a structural model for the reservoir. The results may also be useful for the design of hydrofracture experiments at the Roosevelt KGRA.

Three major normal fault trends are present in the Mineral Mountains. North-northeast-trending faults, including the Opal Mound Fault, form the center of low electrical resistivity and high heat flow anomalies. Major east-west-trending structures such as the Hot Springs Fault form structural boundaries for the geothermal reservoir. A set of northwest-trending faults also occurs in the KGRA.

Structural analysis was conducted by field mapping of joints, small shear zones, and dikes. Aplitic and rhyolitic dike patterns define three structural domains in the central Mineral Mountains. North of Hot Springs Fault a strong north-south trend of steeply dipping dikes is present. South of Hot Springs Fault within the KGRA the dominant trend is N20-30E. Diking in the interior of the pluton shows no strong, preferred orientation.

Three major styles of fracturing have been identified. A fracture foliation occurs as a dense system of parallel, open fractures in

coarse-grained rocks of the pluton. Parallelism of the foliation with macroscopic cooling cracks and dikes has led to the interpretation that the foliation formed as a set of extension fractures due to cooling and contraction of the pluton.

Two orthogonal or nearly orthogonal sets of steeply dipping joints are present in all lithologies throughout most of the study area. Cataclasite and hydrothermal alteration along the joint surfaces increases near shear zones. The joint morphology and the orthogonal pattern leads us to conclude that most joints in this set formed as extensional fractures during cooling and uplift of the pluton. The amount of cataclasite and hydrothermal alteration along the joint surfaces increases near shear zones, suggesting that movement occurred along some of the joints during, or subsequent to, their formation.

The third major set is found throughout the central Mineral Mountains and consists of shallow to moderately dipping fractures. Joint density and evidence for shear is again directly related to proximity to shear zones. This joint set dips consistently 20 to 50 degrees to the west.

Strain relief tests for in-situ applied and residual stresses were made through repeated overcoring of resistance strain gauge rosettes. Strains measured were dominantly extensional. No preferred extension direction was found for the study area as a whole or for any individual site. Measured orientations were controlled by outcrop fracture patterns rather than by regional stress field. All principle strains measured fell within 10 degrees of an outcrop fracture. Strains recorded upon second overcoring were consistently smaller than the original measurements, while orientations of principal strains remained smaller.

An Evaluation of Hypocenter Location Techniques with Applications to Southern Utah: Regional Earthquake Distributions and Seismicity of Geothermal Areas, by D. J. Wechsler, and R. B. Smith, December, 1979.

Three techniques for the computation of earthquake hypocenter locations were compared through empirical results of synthetic test cases utilizing four different computer programs. The three approaches, (1) the single event method, (2) the master event method, and (3) the joint hypocenter determination method, were analyzed with respect to their application to regional (epicenter-to-station distances from 10 to 500 km) and local (epicentral distances from 0 to 70 km) seismic network recording situations. It was found that the joint hypocenter technique can significantly correct for inadequacies in assumed velocity models by simultaneous computation of station adjustments. Earthquakes located using the joint hypocenter technique are located more precisely with respect to each other. The joint epicenter location technique was then applied to relocations of epicenters in southern Utah below 40°N latitude with the intent of resolving some spatial relationships of epicenter occurrence on this regional scale. Earthquakes in Utah occur in a diffuse zone 150 km to 200 km wide that coincides with the physiographic boundary of the Colorado Plateau. Swarm activity is prevalent where the zone changes from a north-south to a southwest orientation but, except for a cluster northwest of Cedar City, the only major alignments of epicenters are north-south.

On a local scale an objective was to determine some relationships of

epicenters to two known geothermal resource areas: Cove Fort and Roosevelt Hot Springs, Utah. The differences in the character of these two areas as expressed by the earthquake occurrence was emphasized by the jointly determined relocations. Areas of possible active east-west and northeast faulting near Cove Fort were delineated, but it was verified that seismic activity in the Milford area is sparse. Attention was given to possible effects of lateral inhomogeneities in the velocity model on earthquake locations. Evidence for substantial lateral variations in the velocity models used in the locations was contributed from an analysis of P-wave residuals from broadside refraction data. Arrival times of P-waves were found to be early near the Opal Mound fault, possibly due to local siliceous cementation of alluvium. Contacts between the gneissic basement and the granitic pluton could account for some of the observed delays in P-wave arrival times. Effects of lateral velocity variations on earthquake locations were minimized by precise relocation using joint hypocenter determination, thus aiding in defining seismically active areas. Results of earthquake relocation for the Cove Fort-Roosevelt Hot Springs KGRAs and adjacent areas indicate that methods of systematically and precisely locating earthquakes can better contribute to understanding the seismicity and velocity structure and the relationships of geothermal areas to regional and local stress fields and geological characteristics.

Geologic Map of San Emidio Geothermal Area, by J. N. Moore, December 1979 (ESL-23).

The San Emidio geothermal area is adjacent to the northern end of the Lake Range, approximately 15 miles south of Gerlach, Nevada (Figure 1). The Lake Range forms a tilted block bounded on the west by steeply dipping Basin and Range faults. Associated with one of these faults are hydrogen sulfide seeps, acid alteration, and hot water wells, indicative of an active geothermal system (Garside, 1979).

During the mid-1970s, Chevron Resources Company initiated a broad-based exploration program of the San Emidio geothermal area that included detailed geophysical studies and deep exploratory drilling. The ongoing interpretation of these data by the Earth Science Laboratory as part of the Department of Energy/Division of Geothermal Energy's Industry Coupled Case Studies Program points out the need for additional geologic mapping, particularly on the eastern margin of the San Emidio Desert. This report summarizes our reconnaissance geologic work in this area.

Geology of the Soda Lake Geothermal Area, by B. S. Sibbett, 1979
(ESL-24).

The Soda Lake geothermal area is located in the Carson Desert, west-central Nevada. Hot springs activity has occurred in the Soda Lake area in the past, resulting in surface deposits which have motivated present geothermal exploration. The geothermal anomaly is in Quaternary clastic sediments which are as much as 4600 feet thick. The sediments consist of interbedded deltaic, lacustrine, and alluvial sediments.

Quaternary basaltic igneous activity has produced cinder cones, phreatic explosions that formed the maar occupied by Soda Lake, and possible dikes.

Opal deposition and soil alteration are restricted to a small area two miles north of Soda Lake. The locations of hot springs activity and the surface thermal anomaly may be partially controlled by north-northeast-trending faults.

Interpretation of Electrical Resistivity and Shallow Seismic Reflection Profiles, Whirlwind Valley and Horse Heaven Areas, Beowawe KGRA, Nevada, by C. Smith, 1980 (ESL-25).

Numerical modeling and analysis of surface electrical and seismic data from the Beowawe KGRA, north-central Nevada, permit extrapolation of mapped geologic units and structures to approximately a mile (1.6 km) depth from which inferences about the geothermal system can be made. Detailed numerical modeling was completed for 78 line-mi (125 km) of dipole-dipole resistivity data and includes compensation for topographic effects caused by the Malpais Rim scarp. The interpreted sections have as many as five distinct electrical units, one of which occurs only within the area of hydrothermal alteration along the fault set at the base of the Malpais Rim. The weight-drop seismic reflection data show numerous normal faults sub-parallel to the Malpais Rim within Whirlwind Valley west and southwest of The Geysers.

A 1,500 ft (450 m) thick zone of low resistivity at the surface northeast of The Geysers deepens to 2,000 ft (600 m) below the surface at the two Chevron Resource Co. exploration wells southwest of The Geysers. This suggests that the post-Miocene east-northeast fault set at the base of the Malpais Rim is not a conduit for hot water at shallow depths to the southwest of The Geysers. The north-northwest-striking Miocene Dunphy Pass fault zone, immediately east of The Geysers, does display low resistivities at depths greater than 2,000 ft (600 m) and may provide a deep-seated path for upwelling geothermal water to the Malpais Rim fault set.

A widespread conductive anomaly in Horse Heaven appears to be distinct from the anomaly at The Geysers. The resistivity interpretation cannot determine whether this three- by two-mile area (5 x 3 km) represents a thick sequence of rock saturated with hot water, or carbonaceous or altered units within the Ordovician Valmy Formation. Any vast, deep geothermal reservoir lies below the depth of resolution of these surveys.

Geology and Alteration of the Baltazor Hot Springs and Painted Hills
Thermal Areas, Humboldt County, Nevada, by J. B. Hulen, 1979 (ESL-27).

The Baltazor Hot Springs KGRA and nearby Painted Hills thermal area are situated in Humboldt County, northwestern Nevada, along the northwestern margin of the Basin and Range province.

The oldest rocks exposed in the Baltazor area are eugeosynclinal metasedimentary and subordinate metavolcanic rocks of Permian to Triassic(?) age intruded by Cretaceous diorite and quartz diorite. These are overlain by a thick volcanic and volcanoclastic sequence of Miocene through Pliocene age. Pre-Tertiary rocks are not exposed in the Painted Hills. Here, only Miocene to Pliocene volcanics and volcanoclastics crop out, and only the youngest of these can be confidently correlated with rocks of similar age and character in the Baltazor area.

Principal structures in the Baltazor area are intersecting high-angle normal faults which trend northerly and northwesterly. Quaternary landslides are dominant in the Painted Hills, although northerly- and northwesterly-trending high-angle faults are also present.

Hydrothermal alteration and mineralization at Baltazor and in the Painted Hills are of several different styles and ages. Copper-bearing quartz veins in pre-Tertiary rocks antedate Cenozoic volcanism and sedimentation. Wide-spread argillization, silicification, hematization and local mercury mineralization in the Painted Hills are probably pre-Pleistocene in age, even

though coincident with a contemporary thermal anomaly. Small calcite-bearing opaline sinter deposits at Baltazor Hot Springs are probably genetically related to chalcedony-calcite veins in adjacent mid-Miocene volcanics and Quaternary landslide debris.

Baltazor Hot Springs and associated thermal phenomena and alteration are controlled by the intersection of northerly- and northwesterly-trending high-angle faults and permeable Tertiary volcanic and volcaniclastic horizons. The heat source for thermal phenomena and alteration in both areas is probably deep fault-controlled fluid circulation coupled with an abnormally high regional thermal gradient.

Numerical Modeling and Interpretation of Dipole-Dipole Resistivity and IP Profiles, Cove Fort-Sulphurdale KGRA, Utah, by H. P. Ross, 1979 (ESL-26).

The Cove Fort-Sulphurdale Known Geothermal resource Area (KGRA) is located near the junction of the Pavant Range and the Tushar Mountains in south-central Utah. The area has been the site of an intensive geothermal exploration effort by Union Oil Company since 1975. This report presents the electrical resistivity data obtained by Union Oil Company and a subsequent survey conducted for the Earth Science Laboratory, and a detailed numerical interpretation of both data sets.

The detailed modeling permits a characterization of the intrinsic electrical resistivity to depths exceeding 2,000 feet. An area of over two square miles with bulk in-situ resistivities of four to five ohm-m is delineated at Sulphurdale near the Union Oil Co. well CFSU #42-7. The low-resistivity rocks define the area of extensive hydrothermal alteration in response to the presence of clay minerals and conductive thermal fluids. In contrast the area north and east of Cove Fort is typified by high (100-300 ohm-m) resistivities to depths exceeding 2,000 feet. This is an area of Cretaceous and Paleozoic sedimentary rocks where two attempts to drill to reservoir depth failed because of extreme drilling problems. The high resistivities are not considered encouraging for the presence of a deeper reservoir. The electrical resistivity interpretation has defined several areas of probable upward migration of thermal fluids along north-trending normal faults. Some of these areas may have potential for direct heat

geothermal utilization.

Two lines of induced polarization data indicate large volumes of Cretaceous and Paleozoic sedimentary rocks may be mineralized with one- to two-weight-percent sulfides. Geologic studies indicate much of this mineralization predates the present geothermal system.

Interpretation of Well Log Data from Four Drill Holes at Roosevelt Hot Springs KGRA, by W. E. Glenn, and J. B. Hulen, 1979 (ESL-28).

Well logs from four drill holes, Utah State Geothermal Wells 14-2, 52-21 and 72-16 and Geothermal Power Corporation's thermal gradient hole GPC-15 have been digitized, plotted and studied. This study had three objectives: 1) to present the well log data in a convenient format for easy study, 2) to determine the nature of the geothermal reservoir rock and fluid properties, and 3) to make some inference on fluid entry locations in the boreholes and their effect on heat flow.

The alluvium, which varies in thickness from 160 feet (49 m) at 72-16 to over 1900 feet (580 m, TD) at GPC-15, exhibits compaction and cementation with depth. Bulk density increases and porosity decreases with depth, from 2.28 to 2.46 gm/cc and from 23% to 15%, respectively, between 558 and 1989 feet (170-579 m), which is below the interpreted water table at 540 feet (165 m). Over the same interval, the acoustic velocity increases from 8200 ft/sec (2.5 km/sec) to about 14,00 ft/sec (4.3 km/sec) at the bottom of the hole. Above the water table the bulk density varies considerably, but averages approximately 2.05 gm/cc.

Bedrock in Utah State 14-2 and 52-21, various granitic intrusives and mafic to granitic gneisses, exhibits highly variable log properties throughout the length of the holes. The log responses have been interpreted in terms of lithologic effects peculiar to igneous and metamorphic rocks. Dense, hydrous-mafic mineral contributions can be identified in acoustic, density and

neutron logs. Acoustic velocities vary between 15,500 and 22,000 ft/sec (4.7 and 6.7 km/sec). Bulk densities vary between 2.5 and 2.8 gm/cc; resistivities vary from 40 to greater than 2000 ohm-m, and neutron porosities vary between nearly zero to 15%. Lower velocity, density and resistivity, and higher neutron porosity are fracture-related values and occur above 2000 to 3000 feet (610-915 m) in both holes. Potentially permeable and possibly related production zones correspond to these log responses, correlate with fractures, and occur primarily in the upper levels of each hole. However, permeability in 52-21 is quite low and the hole is considered a non-producer.

The temperature logs and gradient computed from these logs have been used to examine heat flow in the vicinity of the four drill holes. Assumed and calculated thermal conductivities have been used in the analyses, 4 mcal/cm °C sec for the alluvium and 7 mcal/cm °C sec for the crystalline rocks. The data indicate that 14-2 and 72-16 reside in a dominantly convective heat flow environment, whereas GPC-15 and 52-21 reside in a dominantly conductive heat flow environment. The convective regions are believed to be fracture controlled and only portions of each hole reside totally in a convective region; in each case it is the upper bedrock portion of the hole. In every case the alluvium or upper portion of the alluvium acts as a thermal blanket over the system. Maximum heat flow among the holes, 40 cal/cm² sec, occurs in the vicinity of 72-16 and the lowest heat flow, 4 cal/cm² sec, in the vicinity of GPC-15.

Detailed Gravity and Aeromagnetic Surveys in the Black Rock Desert Area, Utah, by L. F. Serpa and K. L. Cook, 1980.

Aeromagnetic and gravity surveys were conducted during 1978 in the Black Rock Desert, Utah over an area of about 2400 km² between the north-trending Pavant and Cricket Mountains. The surveys assisted in evaluating the geothermal resources in the Meadow-Hatton Known Geothermal Resource Area (KGRA) and vicinity by delineating geophysical characteristics of the subsurface.

The gravity measurements from approximately 700 new stations were reduced to complete Bouguer gravity anomaly values with the aid of a computerized terrain-correction program and contoured at an interval of 1 millgal. The aeromagnetic survey was drupe-flown at an altitude of 305 m (1000 ft) and a total intensity residual aeromagnetic map with a contour interval of 20 gammas was produced. Two gravity and aeromagnetic east-west profiles and one north-south profile were modeled using a simultaneous 2 1/2-dimensional modeling technique to provide a single model satisfying both types of geophysical data.

The central survey area is dominated by a north-trending zone of young volcanics, less than 1 m.y. old, consisting predominately of basalt, clearly outlined by the aeromagnetic contours. The volcanics are highly fractured and faulted with the general sense of displacement down to the west along interpreted listric normal faults.

A gravity high occurs over the eastern side of the map, decreasing to the south. The Cenozoic rocks and sediments in this region are assumed to be shallow, approximately 1 km deep in Pavant Valley. To the west of the volcanic zone is a north-trending gravity low where Neogene rocks are interpreted as attaining a thickness of about 4 km.

An approximately 2 mgal gravity high is located over much of the area of geothermal interest. This gravity high is attributed to travertine deposits associated with the hot springs in this area. A small (20 gamma) magnetic low north of the hot springs is also interpreted as a result of the travertine deposition and possibly some hydrothermal alteration. A comparison of the Meadow-Hatton KGRA with the Roosevelt and Monroe KGRAs indicates that the Meadow-Hatton geothermal system may bear a closer resemblance to the Monroe geothermal system where hot water is produced by circulation along deep faults. Additional studies are needed to fully assess the geothermal potential of the Meadow-Hatton KGRA.

Geology of the Central Mineral Mountains Beaver County, Utah, by
B. S. Sibbett, and D. L. Nielson, March 1980 (ESL-33).

The Mineral Mountains are located in Beaver and Millard Counties, southwestern Utah. The range is a horst located in the transition zone between the Basin and Range and Colorado Plateau (Stokes, 1977) geologic provinces. A multiple-phase Tertiary pluton forms most of the range, with Paleozoic rocks exposed on the north and south and Precambrian metamorphic rocks on the west in the Roosevelt Hot Springs KGRA (Known Geothermal Resource Area). Precambrian banded gneiss and Cambrian carbonate rocks have been intruded by foliated grandioritic to monzonitic rocks of uncertain age.

The Tertiary pluton consists of six major phases of quartz monzonitic to leucocratic granitic rocks, two diorite stocks, and several more mafic units that form dikes.

During uplift of the mountain block, overlying rocks and the upper part of the pluton were partially removed by denudation faulting to the west. The interplay of these low-angle faults and younger northerly trending Basin and Range faults is responsible for the structural control of the Roosevelt Hot Springs geothermal system. The structural complexity of the Roosevelt Hot Springs KGRA is unique within the range, although the same tectonic style continues throughout the range.

During the Quaternary, rhyolite volcanism was active in the central part of the range and basaltic volcanism occurred in the northern portion of the

map area. The heat source for the geothermal system is probably related to the Quaternary rhyolite volcanic activity.

This study did not document any additional evidence of recent geothermal activity. It has, however, documented several areas of young basaltic volcanism in the northern portion of the Mineral Mountains. In addition, a structural framework has been developed which will be of use to geothermal explorationists working in the area.

Summary of Potassium/Argon Age Dating, by S. H. Evans Jr., March 1980.

During FY-79 the K/AR dating laboratory at the Department of Geology and Geophysics of the University of Utah became operational. During the past calendar year forty-seven dates have been produced from areas predominantly in Utah. Dating has also been done in support of University of Utah Research Institute/Earth Science Laboratory programs on areas in Nevada and Montana through the State-Coupled program and Case Studies Support program.

Areas in which activity was concentrated include:

Cove Creek Domes/Twin Peaks Area, SW Utah. Here volcanic activity spanned the time from 2.74 to 2.27 m.y., with a mean age of 2.47 ± 0.17 m.y.

Black Rock desert, SW Utah. Two dates on a single flow indicate an age of 1.50 ± 0.10 m.y. for a flow previously undated.

Wildcat Creek Area, SW Utah. Dating of rhyolite flows from this area gives a mean age of volcanism of 9.38 ± 0.11 m.y., considerably older than previously inferred by the work of Haugh (1978).

Mineral Mountains Pluton, SW Utah. Twelve dates on phases of the pluton indicate a complex history of intrusion, and more work is indicated in order to derive a coherent picture of the magmatic events leading to the formation of this batholith.

Blackfoot Reservoir, Idaho. Two dates on rhyolite domes, previously undated, give ages of 1.59 ± 0.06 m.y. and 1.41 ± 0.15 m.y.

In addition to the previous dating activity, ages of units in areas of interest in Nevada have been obtained. These areas include Beowawe, San Emidio, and Soda Lake. This work was done under the Industry Coupled Program. Four samples were also dated for the Montana Geological Survey as part of the State Coupled Program.

Report No. DOE/ET/28392-42

Geothermal Exploration at Hill Air Force Base, Ogden, Utah, by
W. E. Glenn, D. S. Chapman, D. Foley, R. M. Capuano, B. S. Sibbett,
D. Cole, and S. H. Ward, March 1980 (ESL-34).

This report summarizes the results obtained from a program designed to locate geothermal resources, if such occur, at Hill Air Force Base (Hill AFB), Utah. This work was carried out under modification A002 to Department of Energy Contract DE-AC07-78ET28392, issued to the University of Utah with the Earth Science Laboratory of the University of Utah Research Institute designated as a subcontractor. The assessment of geothermal resources at Hill AFB is part of a cooperative agreement between the Department of Energy and the Department of Defense.

Previous reports on geothermal potential and utilization at Hill AFB include Donovan and others (1978), who discuss an overall resource assessment and utilization program, Austin and Whelan (1978), who discuss geothermal potential at Air Force bases in general, Headquarters AFLC (1979), who discuss a phased development program at Hill AFB, and Glenn and others (1979), who present a preliminary report on this geothermal exploration program at Hill AFB.

Geochemistry of Sericite and Chlorite in Well 14-2, Roosevelt Hot Springs Geothermal System and in Mineralized Hydrothermal Systems, by J. M. Ballantyne, June, 1980.

Chemical compositions of chlorite and sericite from one production well in the Roosevelt geothermal system have been determined by electron probe methods and compared with compositions of chlorite and sericite from porphyry copper deposits. Modern system sericite and chlorite occur over a depth interval of 2 km and a temperature interval of 250°C.

Mineral composition variation within samples of cuttings from individual depth intervals from the geothermal well is as large as that between samples, and is sufficiently large to obscure any effects related to present hot water entry zones, at least on the scale sampled. Recent suggestions are that the well may have been drilled parallel and close to a major fluid-bearing fracture, and if so would not provide a good test situation. Sericites range between illites and muscovites on the basis of K and Si content. Chlorites are ripidolites, brunsvigites and pynochlorites. Sericite compositional ranges are 0.6 to 1.0 K, 3.1 to 3.5 Si, 0.0 to 0.3 Fe, 0.0 to 0.3 Mg and 1.7 to 2.8 Al per formula unit. Fe/Mg is usually near 1. Chlorites contain 2.8 to 3.2 Si, 1.9 to 2.5 Al, 1.7 to 2.6 Fe and 1.3 to 2.4 Mg.

Comparison with porphyry copper systems shows that interlayer chemistry in hydrothermal sericites is related to the alteration assemblage, and chemical heterogeneity is related to alteration intensity or extent of recrystallization of the rock. Analyzed chlorite compositions in porphyry

systems are similar to or more magnesian than those at Roosevelt. Sericites from porphyry systems tend to have higher interlayer (K+Na) site occupancies and less Si in tetrahedral sites than those from Roosevelt. Southwest Tintic sericites have nearly constant Fe but variable Al and Mg in octahedral sites, Santa Rita sericites have nearly constant Mg, and Roosevelt sericites nearly constant Fe/Mg. The differences between systems may be at least partly due to differences in alteration assemblages analyzed. F correlates with Mg content in sericites from all systems.

Sericite and chlorite chemistry is a function, not merely of bulk fluid chemistry and temperature, but also of the local chemical environment, distance from fluid-bearing veins, and the type of mineral being replaced. Thermodynamic modeling shows that the sensitivity of sericite and chlorite chemistry to fluid composition is such that changes in aqueous species activities can cause changes of similar magnitude in the activities of solid solution end members. Temperature changes of a few tens of degrees can cause order of magnitude changes in solid phase activities.

Chemical inhomogeneity of alteration minerals, isotopic evidence and thermodynamic modeling indicate a state of disequilibrium between the Roosevelt bulk geothermal fluid and hydrothermal sericite and chlorite. The amount of disequilibrium calculated depends upon the thermodynamic data base used. Alteration minerals may well be in equilibrium with local portions of the present fluid which have changed composition by reacting with the rock. Sericite solid solution end members and calcite appear to be close to equilibrium with the bulk fluid, feldspars are slightly undersaturated, and

chlorite is strongly undersaturated. These data suggest, unless the chlorite thermodynamic data is highly inaccurate, that chlorite may have formed earlier, perhaps during a previous hydrothermal event.

Model Study of the Regional Hydrogeologic Regime, Roosevelt Hot Springs, Utah, by J. L. Smith, May 1980.

A regional hydrogeologic model is used to investigate the potential for water recharging in the Tushar Mountains to move at depth beneath the Mineral Mountains to discharge in Milford Valley. Simulations carried out over a range of water table positions and assumed depths to a lower impermeable boundary suggest it is unlikely that the topographic configuration alone could drive such a flow system. Specific geologic conditions are necessary if interbasin flow is to occur. However, simulations based on a simplified hydrologic model of the regional geology suggest this is not the case. A regional hydraulic anisotropy greater than 10:1 (K_x/K_z) leads to interflow if the granitic Mineral Mountain pluton and the volcanics in the Tushar Mountains have similar hydraulic conductivities. If either of these units is more nearly isotropic or if the granitic rocks have a greater vertical than horizontal hydraulic conductivity, no interbasin flow is observed. On the basis of available geologic evidence, this latter case seems to be the most likely.

Compositional Gradient In Natural Silicic Liquids, by S. H. Evans, Jr.,
1980.

Electron microprobe analyses of natural rhyolite glass reveal chemical gradients 10-15 μm wide adjacent to microphenocrysts of plagioclase, alkali feldspar, and magnetite. The presence of such gradients has previously been interpreted as indicative of disequilibrium between liquid and solid. If crystals and liquid are not in equilibrium, temperatures determined from the compositions of coexisting mineral phases might be erroneous. Chemical gradients may be attributed, however, to diffusion-controlled equilibrium crystallization. Because the concentration of minor constituents in the crystal is not equal to that in the liquid at some distance from the diffusion zone, the steady state model of Tillier, Jackson, Rutter, and Chalmers (1) is not appropriate for rhyolites. The microprobe data are consistent with the model of Burton, Prim, and Slichter (2) in which the liquid is stirred by convection and the crystals are surrounded by a diffusive boundary layer. Computed apparent and equilibrium distribution coefficients for natural rhyolites, combined with published diffusion coefficients for K, yield linear growth rates for feldspars on the order of $2 \times 10^{-7} \text{ cm sec}^{-1}$, similar to experimentally determined equilibrium growth rates. The analytical data are consistent with equilibrium crystallization in natural silicic liquids, and the utilization of coexisting phases for thermometry remains reasonable in the presence of narrow chemical gradients.

A Light Stable Isotope Study of the Roosevelt Hot Springs Thermal Area,
Southwestern Utah, by D. T. Rohrs, May 1980.

The isotopic composition of hydrogen, oxygen, and carbon has been determined for regional cold springs, thermal fluids, and rocks and minerals from the Roosevelt Hot Springs thermal area. The geothermal system has developed within plutonic granitic rocks and amphibolite facies gneiss, relying upon fracture-controlled permeability for the migration of the thermal fluids. Probably originating as meteoric waters in the upper elevations of the Mineral Mountains, the thermal waters sampled in the production wells display an oxygen isotopic shift of at least +1.2. Depletions of $\sigma^{18}\text{O}$ in whole rock, K-feldspar, and biotite have a positive correlation with alteration intensity. W/R mass ratios, calculated from the isotopic shifts of rock and water, range up to 3.0 in a producing horizon of one well, although the K-feldspar has experienced only 30 percent exchange with the thermal waters. While veinlet quartz has equilibrated with the thermal waters, the $\sigma^{18}\text{O}$ values of K-mica clay, an alteration product of plagioclase, mimic the isotopic composition of K-feldspar and whole rock. This suggests that locally small W/R ratios enable plagioclase to influence its alteration products by isotopic exchange.

Oxygen-isotope temperatures based on observed $\sigma^{18}\text{O}$ values of calcite and an assumed constant $\sigma^{18}\text{O}$ value of thermal fluid are erratic and significantly lower than measured thermal gradients or fluid inclusion filling temperatures. This lack of agreement is the result of our assumption of a constant oxygen

isotopic composition of thermal fluid at all levels within the system. Rather, the $\sigma^{18}\text{O}$ values of calcite indicate enrichment of the thermal water with $\sigma^{18}\text{O}$ in weakly altered rocks, probably from isotopic exchange under low W/R ratios and slow circulation rates in relatively impermeable rocks. These complications indicate that casual application of mineral isotope thermometers without consideration of potential variations in fluid isotopic composition can lead to misinterpretation. The calcite, like the K-mica, may also be influenced by the host plagioclase. The systematic increase in $\sigma^{13}\text{C}$ values of calcite, generally from -6.0 to -2.4 approaching shallower depths, can be reproduced by two separate models. Each model requires the interaction of the three components of the carbon reservoir: $\text{CO}_2(\text{g})$, fluid ($\text{H}_2\text{CO}_3\text{app} + \text{HCO}_3$), and calcite. Precipitation of calcite modifies the $\sigma^{13}\text{C}$ of $\text{CO}_2(\text{g})$ and fluid and provides a decrease in the molality of the total dissolved carbonate which is consistent with the decrease in molality predicted by mineral equilibria. The $\sigma^{13}\text{C}$ of the total carbon reservoir is between -4.5 and -5.8. It is not possible to unambiguously assign a carbon source to these values.

The small isotopic shift of the thermal waters, the small extent of exchange experienced by the rocks in the production zone, and the enriched $\sigma^{18}\text{O}$ values of K-mica clay attest to the lack of communication between the rock and the bulk of the thermal waters. The circulation of the thermal water is evidently restricted to permeable fracture zones with little infiltration into the surrounding impermeable rocks, accounting for the variabilities in alteration and W/R ratios. However, a lack of systematically collected core samples has precluded closer definition of the processes responsible for these characteristics.

4.0 USER ASSISTANCE

During calendar year 1979 the Earth Science Laboratory received numerous User Assistance requests, summarized in Table 1. Many of the requestors listed also received engineering and economic aid from EG&G Idaho, Inc. and the Oregon Institute of Technology User Assistance programs as well as the geologic information supplied by the Earth Science Laboratory.

TABLE 1. Summary of User Assistance Requests Fulfilled in 1979

<u>REQUESTOR</u>	<u>AREA OF REQUEST</u>	<u>PROPOSED USE</u>	<u>WORK PERFORMED BY ESL</u>
Peter Janns Bellevue, ID	Janns Farm - near Magic Reservoir Hot Springs, ID	Space heating	Site visited, resource information provided, exploration program suggested.
Big Horn Barley Growers Association	Cody, WY area	Ethanol generation	Attended meeting, resource information provided.
Thiokol Corp., Wasatch Division	Thiokol plant facilities Brigham City, UT	Industrial process heat, space heating.	Site visited with EG&G, water samples collected, geothermometers calculated, exploration program suggested, resource information provided.
Bob Schultz (for an investor)	Diamond Valley, NV	?	Preliminary resource information provided.
Half Circle Ranch Corp.	Crescent Valley, NV	Agriculture	Resource information provided.
Bob O'Connor	Subdivision near Decker, MT	District space heating	Resource information provided.
Crown Zellerbach Camas, WA	Camas, WA	Industrial processing	Attended meeting, resource information provided.

<u>REQUESTOR</u>	<u>AREA OF REQUEST</u>	<u>PROPOSED USE</u>	<u>WORK PERFORMED BY ESL</u>
Sylvia Goeltz	Beryl, UT	Industrial applications	Resource information provided.
EMMA	Therino Hot Springs, UT	Direct use	Preliminary resource information provided.
Two Ravens Corp. Lowman, ID	Near Lowman, ID	Space heating for planned resort.	Site visited w/Idaho Office of Energy. Resource information provided, exploration program outlined.
Snow College	Ephraim, UT	Space heating	Attended meeting, resource information provided.
Dr. Rusty Butler, Ontario, OR	Vale Hot Springs KGRA, OR	Undecided	Site visited with OIT, resource information provided, exploration program suggested, work may continue.
Stan Clements Payette, ID	Roystone Hot Springs, ID	Ethanol production	Site visited with Idaho Office of Energy, well logged in cooperation with IDWR, water samples collected, geothermometers calculated, resource information provided,

<u>REQUESTOR</u>	<u>AREA OF REQUEST</u>	<u>PROPOSED USE</u>	<u>WORK PERFORMED BY ESL</u>
			exploration program suggested, information transported to the users' consultant.
Greg Graham Weiser, ID	Crane Creek KGRA, ID	Ethanol production	Site visited with Idaho Office of Energy, water samples collected, geothermometers calculated, exploration program outlined, resource information provided.
John Pitt Nyssa, OR	Proposed vegetable processing plant site near Nyssa, OR	Vegetable processing	Site visited, resource information provided, further work may continue.
College of Southern Idaho Twin Falls, ID	Warm-water well on CSI campus	Space heating	Site visited, water samples collected, geothermometers calculated, resource information provided.
Aqualife Corp. Twin Falls, ID	Warm-water well in Twin Falls, ID	Aquaculture and ethanol production	Site visited, water samples collected, geothermometers calculated, resource information provided, suggested exploration program outlined.

<u>REQUESTOR</u>	<u>AREA OF REQUEST</u>	<u>PROPOSED USE</u>	<u>WORK PERFORMED BY ESL</u>
Idaho Office of Energy	Harley Hot Springs, ID	Area Development Plan	Reconnaissance site visit, resource information provided for Area Development Plan.
Idaho Office of Energy	Magic Reservoir Hot Springs, ID	Area Development Plan	Reconnaissance site visit, resource information provided for Area Development Plan.
Bruce LeFavour Clayton, ID	Robinson Bar Hot Spring	Space heating	Site visited, resource information provided, suggested exploration program outlined.
Steve Munson (Developer)	general	Ethanol production	General resource information provided.
Shelly Gordon Chilton Engineering	Southeastern ID, Vernal, UT areas	Industrial process heat (phosphate industry)	Preliminary resource information provided.
Salmon, ID School Board	Salmon, ID (Salmon Hot Springs)	Space heating for a new high school	Preliminary resource information provided.
Williams AFB	Williams AFB, AZ	Space cooling	Attended meetings, provided critical review of geologic data interpretation

<u>REQUESTOR</u>	<u>AREA OF REQUEST</u>	<u>PROPOSED USE</u>	<u>WORK PERFORMED BY ESL</u>
			for DOE report, digitized well logs, estimated fracture and porosity from well logs, constructed lithologic log.
U.S. Steel, Corp.	General	Industrial processing	General resource information provided.
Crown Zellerbach Paper Co.	Camas, WA	Industrial processing	Resource information provided, attended meeting, modeled electronic resistivity data.
Wyoming Energy Extension Service	Wyoming geothermal resources	Direct and electric	Presentation given on Wyoming geothermal resources and national geothermal legislation.

Table 2 is a summary of those 1979 User Assistance requests for which work will continue in 1980. Engineering and economic assistance will be provided by EG&G and OIT as needed.

TABLE II. 1979 User Assistance Requests for Which Work Will
Continue in 1980

<u>REQUESTOR</u>	<u>AREA OF REQUEST</u>	<u>PROPOSED USE</u>	<u>PLANNED ESL ACTIVITY</u>
Ron Adams Hagerman, ID	610 ft well @ 70°F Thousand Springs area, Hagerman, ID.	Aquaculture and space heating	Will visit site, may include in Twin Falls district work.
Jack Gentry Kimberly, ID	870 ft well @ 94°F, 180 gpm, Kimberly, ID	Ethanol generation, space heating	Will visit site in Feb., 1980, may include in Twin Falls district work.
Burton Johnson American Fork, UT	American Fork, Utah and Crystal Hot Springs, UT	Greenhouse heating	Preliminary resource information already provided, will schedule meeting to discuss further plans.
Bob Helber	Cove Fort, UT Lance-Udy Hot Spring, UT	Ethanol generation	Preliminary resource information provided, will schedule meeting to discuss further plans.
Toren Klinge Mountain States Resources	Roosevelt Hot Springs, UT	?	Will schedule meeting to discuss resource potential and ESL activity at Roosevelt.

<u>REQUESTOR</u>	<u>AREA OF REQUEST</u>	<u>PROPOSED USE</u>	<u>PLANNED ESL ACTIVITY</u>
Ike Bracy	Baldwin County, AL	Ethanol generation	Referred to Alabama State Coupled Team and others working locally on geopresured resources, some work may continue.
Frank Weedham Twin Falls, ID	Leadore, ID	Space heating	Will schedule site visit as weather allows.
Greg Hahn Blackbird Mines Mining Corp. Inc.	Big Creek Hot Springs, ID	Potential electrical generation as auxiliary power source for Cobalt Mine, space heating	Will schedule site visit as weather allows.
Dick Durkin and CAS Associates Phoenix, AZ	Northern Hassayampa Plains (Southwest of Wickenburg, AZ) shallow well with 510C water	Industrial complex	Will review help evaluate existing reports, may schedule a site visit.
Joe Rainwater American Potato Co.	Blackfoot, ID Rexburg, ID Moses Lake, WA Vacaville, CA Winnemucca, NV King City, CA	Potato Processing	ESL and EG&G visit scheduled for late January, 1980.
John Dixon & Assoc. Idaho Falls, ID	Snake River, ID	Space heating for new high school	ESL and EG&G will visit site in Jan. 1980.
Galen Park Rupert, ID	Raft River Valley (has 138°F well)	Ethanol generation	Will request IDWR to log the well, may schedule a site visit.
Robert LeFevre IECO Boise, ID	Hot springs along the Salmon River from Stanley to Challis, ID.	Space heating of a planned mining camp	Will schedule a meeting with IECO, EG&G, ESL and Idaho Office of Energy.

REQUESTOR

Brent Goff
Pocatello, ID

AREA OF REQUEST

Nebraska corn belt
Beowawe Area, NV
Gerlach Area, NV
Rye Patch Area, NV

PROPOSED USE

Ethanol
generation

PLANNED ESL
ACTIVITY

Referred to
Nebraska State
Coupled Team
Preliminary
resource
information
provided, may
do more work on
Nevada sites.

Future Plans

In 1980, the User Assistance project staff will increase to three geologists, allowing the Earth Science Laboratory to pursue more detailed geologic studies of user assistance sites and to answer requests faster. This increase in personnel will also enable the User Assistance project to initiate a low- to moderate-temperature geothermal exploration program in several areas. Based upon initial data gathered during User Assistance site studies, the Twin Falls, Idaho area, the Wood River area (Bellevue to Sun Valley, Idaho), and the Stanley to Challis, Idaho area are three districts meriting further work.

ATTACHMENT 1

Contract No. DE-AC07-79ET/27002

- DOE/ET/27002-1 An Interactive Modeling System for 2-D Magneto-telluric and Line Source Resistivity Data (MT2D Users Guide and Documentation), by Carleen Nutter, September, 1979.
- DOE/ET/27002-2 Documentation and Analysis of the Schlumberger Interactive 1-D Inversion Program SLUMB, by Stewart Sandberg, September, 1979.
- DOE/ET/27002-3 Three-Dimensional Resistivity Inversion Using Alpha Centers, by W. R. Petrick, Jr., W. R. Sill and S. H. Ward, December, 1979.
- DOE/ET/27002-4 Intergral Equation Modeling of Three-Dimensional Magneto-telluric Response, by S. C. Ting and G. W. Hohmann, December, 1979.
- DOE/ET/27002-5 A Strategy of Exploration for High Temperature Hydrothermal Systems in the Basin and Range Provinces, by S. H. Ward, H. P. Ross and D. L. Nielson, December, 1979.
- DOE/ET/27002-6 Program Review, Geothermal Exploration and Assessment Technology Program (Including a Report of the Reservoir Engineering Group) by D. L. Nielson, December, 1979.
- DOE/ET/27002-7 Multielement Geochemistry of Solid Materials in Geothermal Systems and Its Application Part 1: The Hot-Water System at the Roosevelt Hot Springs KGRA Utah, by R. W. Bamford, O. D. Christensen and R. M. Capuano, February, 1980.
- DOE/ET/27002-8 Magnetotelluric Models of the Roosevelt Hot Springs, KGRA, Utah by Philip E. Wannamaker, August, 1980.
- DOE/ET/27002-9 Induced Polarization Data at Roosevelt Hot Springs Geothermal Area, Utah by Jean J. Chu, August, 1980.
- DOE/ET/27002-10 Final Report

ATTACHMENT 2

Contract EY-76-S-07-1601 FINAL REPORTS

- 77-0 Final Report, Volume 77-0 by S. H. Ward, October, 1977.
- 77-1 An Evaluation of AIRTRACE in the Geothermal Environment, by Laurence P. James and Robert W. Bamford, September, 1977.
- 77-2 Part I - Geology and Geochemistry of the Roosevelt Hot Springs - A Summary Part II - Geophysics of the Roosevelt Hot Springs Thermal Area, Utah Part III - Roosevelt Hot Springs Area Field Trip, by W. T. Parry, S. H. Ward, W. P. Nash, and others, December, 1977.
- 77-3 Long-Term Seismic Monitoring of the Roosevelt - Cove Fort KGRA's, by Robert B. Smith, December, 1977.
- 77-4 Refraction Shooting Near Roosevelt Hot Springs: Data, by Micro Geophysics, December, 1977.
- 77-5 Final Report, Volume 77-5, by S. H. Ward, J. A. Whelan, and others, December 1977.
- 77-6 The Analysis of Sodium and Potassium in Silicate Rocks by a Lithium Metaborate Fusion Method, by W. P. Nash and Harrison Crecraft, December, 1977.
- 77-7 Gravity and Ground Magnetic Surveys in the Monroe and Joseph KGRA's and Surrounding Region, South Central Utah, by M. E. Halliday and K. L. Cook, June, 1978.
- 77-8 Electrical Energizing of Well Casings, by W. R. Sill and S. H. Ward, January, 1978.
- 77-9 Precision Leveling and Gravity Studies at Roosevelt Hot Springs KGRA, Utah by Kenneth L. Cook and James A. Carter, March, 1978.
- 77-10 Quaternary Rhyolite from the Mineral Mountains, Utah, U.S.A., by S. H. Evans, Jr. and W. P. Nash, March, 1978.
- 77-11 Regional Gravity and Aeromagnetic Surveys of the Mineral Mountains and Vicinity, Millard and Beaver Counties, Utah, by James A. Carter and Kenneth L. Cook, April, 1978.
- 77-12 Seismic Refraction Survey, Roosevelt Hot Springs Thermal Area, edited data tape release, January, 1979.

- 77-13 Fluid Dynamic Properties of Rhyolitic Magmas, Mineral Mountains, Utah Part I: Volatile Content and Flow Characteristics Part II: Physical Properties, by W. P. Nash and S. H. Evans, Jr., July 1978.
- 77-14 Geochemistry of Solid Materials From Two U.S. Geothermal Systems and Its Application to Exploration, by Robert W. Bamford, July 1978. (IDO/77.3.2, ESL-6).
- 77-15 Three Dimensional Magnetotelluric Modeling, by G. W. Hohmann and Sam C. Ting, July, 1978.

Contract EY-76-S-07-1601
TOPICAL REPORTS

- 76-1 Dipole-Dipole Resistivity Delineation of the Near Surface at the Roosevelt Hot Springs KGRA, by S. H. Ward and W. R. Sill, November, 1976.
- 76-2 A Thermodynamic Model of the Hydrolysis of Microcline in Acid Sulfate Solutions, by R. E. Dedolph and W. T. Parry, December, 1976.
- 76-3 Magnetotelluric Survey and Resistivity Maps, Roosevelt Hot Springs, Utah, by Geotronics Corporation, October 1976.
- 77-1 Attempt at Paleomagnetic Dating of Opal, Roosevelt Hot Springs KGRA, by F. H. Brown, February, 1977.
- 77-2 Geothermal Exploration Architecture, by S. H. Ward, April, 1977.
- 77-3 Thermal Gradients and Heat Flow at Roosevelt Hot Springs, by W. R. Sill and J. Bodell, July 1977.
- 77-4 Gravity Survey of the Cove Fort-Sulphurdale KGRA and the North Mineral Mountains Area, Millard and Beaver Counties, Utah, William D. Brumbaugh and Kenneth L. Cook, August, 1977.
- 77-5 Hydrothermal Alteration at Roosevelt Hot Springs KGRA - DDH 1976-1, by Nancy Lee Bryant and W. T. Parry, August, 1977.
- 77-6 Gravity and Ground Magnetic Surveys of the Thermo Hot Springs KGRA Region Beaver County, Utah, by Robert F. Sawyer and K. L. Cook, September, 1977.

- 77-7 Geologic Map of the Central and Northern Mineral Mountains, Utah, compiled by S. H. Evans, Jr., from the work of D. Bowers, F. H. Brown, S. Davies, R. Dedolph, S. H. Evans, Jr., H. C. Liese, W. P. Nash, W. T. Parry and J. A. Whelan, July 1977.
- 77-8 Geophysical Study of the Monroe-Red Hill Geothermal System, (formerly 77-17) by Charles Mase, David S. Chapman and S. H. Ward, October 1978.
- 77-9 Mineral Mountains Magmatism: Chemical and Thermal Evolution, by W. P. Nash and S. H. Evans, Jr., February, 1979.
- 77-10 Stable Isotope Investigation of Fluids and Water-Rock Interaction in the Roosevelt Hot Springs Thermal Area, Utah, by J. R. Bowman, January 1979.