GL01153

Final Report

Contract No. EY-76-S-07-1601

Department of Energy

Part I: Technical

1.0 Introduction:

During the performance period of contract EY-76-S-07-1601, 15 volumes of topical reports and 21 volumes of final technical reports were issued. These reports are listed in Tables I and II, respectively. In this ultimate volume of the final technical report we include abstracts of all reports, a summary of the highlights of achievements under these reports, and copies of published papers which acknowledge financial support from the contract.

Table I

TOPICAL REPORTS

Contract EY-76-S-07-1601

A. Prime Contractor - University of Utah

1. "Dipole-Dipole Resistivity Delineation of the Near Surface Zone at the Roosevelt Hot Springs KGRA," Volume 76-1 by S. H. Ward and W. R. Sill, November 1976.

2. "A Thermodynamic Model of the Hydrolysis of Microcline in Acid Sulfate Solutions," Volume 76-2 by R. E. Dedolph and W. T. Parry, December 1976.

3. "Magnetotelluric Survey and Resistivity Maps, Roosevelt Hot Springs, Utah," Volume 76-3 by Geotronics Corporation, October 1976.

4. "Attempt at Paleomagnetic Dating of Opal, Roosevelt Hot Springs KGRA," Volume 77-1 by F. H. Brown, February 1977.

5. "Geothermal Exploration Architecture," Volume 77-2 by S. H. Ward, April 1977.

6. "Thermal Gradients and Heat Flow at Roosevelt Hot Springs," Volume 77-3 by W. R. Sill and J. Bodell, July 1977.

7. "Gravity Survey of the Cove Fort-Sulphurdale KGRA and the North Mineral Mountains Area, Millard and Beaver Counties, Utah," Volume 77-4 by William D. Brumbaugh and Kenneth L. Cook, August 1977.

8. "Hydrothermal Alteration at Roosevelt Hot Springs KGRA - DDH 1976-1," Volume 77-5 by Nancy Lee Bryant and W. T. Parry, August 1977.

9. "Gravity and Ground Magnetic Surveys of the Thermo Hot Springs KGRA Region, Beaver County, Utah," Volume 77-6 by Robert F. Sawyer and K. L. Cook, September 1977.

10. "Geologic Map of the Central and Northern Mineral Mountains, Utah," Volume 77-7 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.

11. "Geophysical Study of the Monroe-Red Hill Geothermal System," Volume 77-8 by Charles Mase, David S. Chapman and S. H. Ward, October 1978.

12. "Mineral Mountains Magmatism: Chemical and Thermal Evolution", Volume 77-9 by W.P. Nash and S.H. Evans, Jr., February 1979.

13. "Isotopic Studies, Roosevelt Hot Springs Thermal Area, Utah", Volume 77-10 by J.R. Bowman, January 1979.

14. "Escalante Desert Heat Flow", Volume 77-11, by D.S. Chapman.

15. "Electrical Properties of Core Samples", Volume 77-12, by W.R. Sill.

TABLE II

FINAL REPORTS

Contract EY-76-S-07-1601

A. Prime Contractor - University of Utah

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 KGRAs," 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 KGRAs 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.

* Indicates available for public distribution.

B. Sub Contractor - University of Utah Research Institute

1. "Geochemistry of Solid Materials from Two U.S. Geothermal Systems and Its Application to Exploration," Volume 77-14 (ESL No. IDO/77.3.2) by Robert W. Bamford, July, 1978.

2. "Three Dimensional Magnetotelluric Modeling," Volume 77-15 (ESL No. IDO/77.3.1) by Gerald W. Hohmann and Sam Ting, July, 1978.

3. "Dipole-Dipole Resistivity of a Portion of the Coso Hot Springs KGRA, Inyo County, California," Volume IDO/77.5.6 by Richard C. Fox, May, 1978.

4. "Low-Altitude Aeromagnetic Survey of a Portion of the Coso Hot Springs KGRA, Inyo County, California," Volume IDO/77.5.7 by Richard C. Fox, May, 1978.

5. "Geothermal Reservoir Assessment Case Study, Utah (CSU)," ESL Report No. 77-1 by Phillip M. Wright, July, 1977.

6. "Retrospective Case Studies," ESL Report No. 77-2 by Phillip M. Wright, September, 1977.

7. "State-Coupled Direct Heat Program, Western States," ESL Report No. 77-3 by Phillip M. Wright, September, 1977.

2.0 ABSTRACTS

2.1 TOPICAL

TECHNICAL: VOLUME 76-1

Dipole-Dipole Resistivity Delineation of the Near-Surface Zone at the Roosevelt Hot Springs Thermal Area, Utah

Recent dipole-dipole resistivity surveys using 100 m and 300 m dipoles at Roosevelt Hot Springs thermal area, near Milford, Utah have suggested that the north-south length of the convective hydrothermal system may be as great as 20 km. Tertiary granite of the Mineral Mountain pluton seems to be intensely fractured along a narrow (500 m?) sinuous zone trending north and coinciding in part with the Opal Mound Fault. This north-south fracture zone is crosscut by numerous east-west and some northwest-southeast faults. The brine in the fractures and alteration of feldspars to clay both result in lowered resistivities. Leakage of brine westward from the Opal Mound Fault fracture zone is still a realistic interpretation of low resistivity values several kilometers west of this Fault.

TECHNICAL: VOLUME 76-2

A Thermodynamic Model of the Hydrolysis of Microcline in Acid Sulfate Solutions

A theoretical model of the hydrolysis of microcline by a hydrothermal solution has been determined for a closed system at constant temperature.

Hypothetical solution compositions and temperatures were chosen to match the known geothermal system at Roosevelt Hot Springs thermal area, Utah. The calculated reaction paths indicate that the overall reaction process is an exchange of potassium from the reactant mineral, microcline, for hydrogen from the solution. Aluminum is nearly conserved among solid phases. The amount of microcline reacted per kilogram of solution before overall equilibrium is reached is a function of temperature and initial solution pH. Since the system is closed and at constant temperature, natural conditions are not reproduced well enough to apply the model as a geothermometer. The reaction paths suggest qualitative models of alteration mineral zoning patterns that are similar to zoning at Roosevelt Hot Springs thermal area, Utah; Steamboat Springs, Nevada, and Butte, Montana. The models presented view alteration zoning as a function of temperature and pH gradients within homogeneous host rocks where microcline and quartz are abundant.

TECHNICAL: Volume 76-3

Magnetotelluric Survey and Resistivity Maps,
Roosevelt Hot Springs Thermal Area, Utah

[DATA RELEASE ONLY]

TECHNICAL: Volume 77-1

Attempt at Paleomagnetic Dating of Opal,
Roosevelt Hot Springs Thermal Area, Utah

In an attempt at paleomagnetic dating of the opal and siliceous sinter at Roosevelt Hot Springs thermal area, a core was drilled on the Opal Mound to a depth of 16.8 meters. The first 7 meters consist dominantly of massive or banded opal with some clay interbeds, which become more abundant near the bottom of this section of the core. From 7 to 10 meters the core consists mainly of silicified sediment with minor opal layers. Below this to the bottom the core is made of cemented alluvium, either brown or light green, and varying considerably in its coherence.

Paleomagnetic measurements were made on each of the samples cut from the core. Because of the close sample spacing, measurements were averaged for each piece of core. Because it was not possible to control the declination of the core, and because the core was so badly fragmented, only inclinations were considered. There is a marked difference in the scatter of measurements above about 5 meters, and below that depth, the upper part of the core having greater scatter than the lower. This corresponds roughly to the lithologic transition from the part of the core mainly composed of opal (upper) to the part of the core which has a greater admixture of detrital sediment.

There is a difference in demagnetization behavior within the samples which are predominantly opal. Those above about 3 meters have more stable magnetism than those between 3 and 5 meters. NRM intensities for the opal samples range from 6.11×10^{-6} gauss to about 1×10^{-7} gauss, the mean and standard deviation for 31 samples being $1.63 \pm 1.53 \times 10^{-6}$ gauss. The mode lies below 1×10^{-6} gauss.

At first sight, the only bit of geochronologic data that would appear to be forthcoming from the paleomagnetic results is that the opal was all deposited during the Brunhes epoch, that is during the last 690,000 years.

This was expected, and may be considered confirmed by this study. It should also be noted that the alluvium underlying the opal is also of normal polarity, and as it is involved in the faulting along the Opal Mound Fault, this fault is believed to have been active more recently than 690,000 years.

One further bit of data regarding the time over which the opal was deposited is also present from the magnetic data without straining ones credulity too far. This is found in the great swing in both declination and inclination.

It is felt that because the opal is banded, deposition of the opal took place under surface conditions, and was sequentially deposited, rather than deposited by volume precipitation. Thus increasing depth is correlated with increasing age of the opal. The changes in declination and inclination observed with depth from the block samples of opal are thus thought to record a series of magnetic directions at the site distributed in time.

Were we to correlate the change in declination and inclination with one of the known excursions during the Brunhes Epoch, we could set a minimum time for the activity of the deposition of opal on the Opal Mound. The best known, recent, well documented excursion is called the Laschamp event, and supposing that the correlation be made with this event sets a minimum time of ca. 12,000 years on the activity of the Roosevelt Hot Springs thermal system. There is, of course, the possibility that a later excursion took place locally, in which case the minimum estimate for the length of activity would have to be correspondingly shortened.

The duration of magnetic excursions is short, being approximately

1000-2000 years. Using these rough estimates, and noting that the excursion which is believed to have been recorded is confined to about 20 cm. of opal leads to an estimate of the rate of deposition of opal of about 1m/5000 years or 1m/10,000 years. Applying the slower rate to the observed thickness of opal (ca. 7m) results in an estimate of ca. 70,000 years for opal deposition on this part of the Opal Mound, although it may have taken only half that long. Even if the excursion is to be correlated with the Biwa II event, of the Brunhes Epoch, the length of activity on the Opal Mound would thus be confined to the last 350,000 years or so. The estimate is gross, but better than no estimate at all.

TECHNICAL: Volume 77-2

Geothermal Exploration Architecture

A basic modular exploration sequence which includes a carefully balanced selection of geological, geochemical, and geophysical modules is developed for geothermal prospecting in the eastern Basin and Range. The cost per square mile for application of this exploration architecture is $461.00. If one were to expand this basic system to include virtually all techniques being routinely employed in geothermal prospecting today, then the cost per square mile would increase to $790.00. This latter expenditure rate is difficult to justify, but some increase above the $461.00 basic cost appears to be warranted to make exploration costs about equal to land acquisition costs and model-test drilling costs. Total costs per discovery appear to range from 6M to 27M depending upon assumptions, when the costs of exploring for "dry" prospects are included in the costs of the discoveries. Development and operating costs are not included in the analysis.

The basic exploration architecture described here is compared with others previously advanced in the literature. While differences in approach are abundant, there is a central core of exploration activities and an order to these activities to which most of us "architects" probably would subscribe. If a common basis is used for computing costs of individual exploration modules, then there is no great cost disparity between any of the architectures reviewed.

TECHNICAL: Volume 77-3

Thermal Gradients and Heat Flow at Roosevelt Hot Springs Thermal Area

Thermal gradient and electrical resistivity surveys both outline anomalous zones along the system of faults that control the near surface flow at Roosevelt Hot Springs thermal area. The source of both anomalies is the circulation of thermal water, which gives rise to the high heat flow and the lowered resistivity due to the hot brine and the associated hydrothermal alteration.

The nature of the temperature profiles and the asymmetry of the thermal gradient profile across the system are suggestive of a leakage and mixing of thermal water with the regional groundwater flow to the west. This interpretation is consistent with the resistivity data in which conductive regions to the west of the fault system have been interpreted in terms of brine-saturated sediments.

The maximum conductive heat flow over the anomaly is 40 HFU ($1.7 W/m^2$)

and the total conductive heat loss is estimated at 2 MW. Heat flow in the Mineral Mountains, to the east of the near-surface thermal anomaly, is low or near average for the Basin and Range. Recharge may be taking place in this region.

TECHNICAL: Volume 77-4

Gravity Survey of the Cove Fort - Sulphurdale KGRA and the North Mineral Mountains Area, Millard and Beaver Counties, Utah

During the summers of 1975 and 1976, a gravity survey was conducted in the Cove Fort - Sulphurdale KGRA and north Mineral Mountains area, Millard and Beaver counties, Utah. The survey consisted of 671 gravity stations covering an area of about 1300 km^2, and included two orthogonal gravity profiles traversing the area. The gravity data are presented as a terrain-corrected Bouguer gravity anomaly map with a contour interval of 1 mgal and as an isometric three-dimensional gravity anomaly surface. Selected anomaly separation techniques were applied to the hand-digitized gravity data (at 1-km intervals on the Universal Transverse Mercator grid) in both the frequency and space domains, including Fourier decomposition, second vertical derivative, strike-filter, and polynomial fitting analysis, respectively.

Residual gravity gradients of 0.5 to 8.0 mgal/km across north-trending gravity contours observed through the Cove Fort area, the Sulphurdale area, and the areas east of the East Mineral Mountains, along the west flanks of the Tushar Mountains, and on both the east and west flanks of the north Mineral Mountains, were attributed to north-trending Basin and Range high-angle faults. Gravity highs exist over the community of Black Rock area, the north Mineral Mountains, the Paleozoic outcrops in the east Cove Creek-Dog Valley-White Sage Flats areas, the sedimentary thrust zone of the southern Pavant Range, and the East Mineral Mountains. The gravity lows over north Milford Valley, southern Black Rock Desert, Cunningham Wash, and northern Beaver Valley are separated from the above gravity highs by steep gravity gradients attributed to a combination of crustal warping and faulting. A gravity low with a closure of 2 mgal corresponds with Sulphur Cove, a circular topographic feature containing sulphur deposits.

An extension of the Laramide overthrust sheet observed in the southern Pavant Range is indicated as extending westward under alluvial and volcanic cover by a southwest-trending gravity saddle that lies over the Paleozoic sedimentary exposures in the east Cove Creek area and the Pinnacle Pass igneous-sedimentary contact zone, and that separates the gravity low over north Milford Valley into northern and southern closures with a right-lateral offset. The possible buried, upwarped edge of this thrust sheet is indicated by a steep gravity gradient on the north-south gravity profile; Basin and Range high-angle faulting is indicated on the east-west gravity profile.

The gravity saddle over the Pinnacle Pass Contact zone overlies a possible east-west strike-slip fault zone between the Mineral Mountains pluton on the south and the Laramide overthrust on the north. The gravity highs lying north and south of Pinnacle Pass indicate a right-lateral offset along an east-west zone that continues eastward along an east-west geomorphic and structural feature to Clear Creek Canyon (which includes Sulphur Cove) in the Tushar Mountains outlining an inferred east-west strike-slip fault zone (supported also by aeromagnetic data).

TECHNICAL: Volume 77-5

Hydrothermal Alteration at Roosevelt Hot Springs Thermal Area - DDH 1976-1

Hot waters of the Roosevelt Hot Springs thermal area, Utah, have altered granitic rocks and detritus of the Mineral Range pluton, Utah. Alteration and mineral deposition recognized in a 200' drill core from DDH 1-76 is most intense in the upper 100 feet which consists of altered alluvium and opal deposits; the lower 100 feet is weakly altered quartz monzonite. Petrographic, X-ray, and chemical methods were used to characterize systematic changes in chemistry and mineralogy.

Major alteration zones include: 1) an advanced argillic zone in the upper 30 feet of altered detritus containing alunite, opal, vermiculite, and relic quartz; 2) an argillic zone from 30 feet to 105 feet containing kaolinite, muscovite, and minor alunite; and 3) a propylitic zone from 105 to 200 feet containing muscovite, pyrite, marcasite, montmorillonite, and chlorite in weakly altered quartz monzonite.

Comparison of the alteration mineral assemblages with known water chemistry and equilibrium activity diagrams suggests that a simple solution equilibrium model cannot account for the alteration. A model is proposed in which upward moving thermal water super-saturated with respect to quartz and a downward moving cool water undersaturated with respect to quartz produces the observed alteration.

An estimate of the heat flow contributions from hydrothermal alteration was made by calculating reaction enthalpies for alteration reactions at each depth. In calculating heat flow, the uncertain variables included: 1) depth of alteration, 2) duration of hydrothermal activity, 3) thermal gradient, and 4) amount of sulfide oxidized to sulfate. The estimated heat flow varied from .02 HFU (for 200' depth, 400,000 yr duration, and no sulfur oxidation) to 67 HFU (for 5,000' depth, 1,000 yr duration, and all sulfur oxidized from sulfide). Heat flow contributions from hydrothermal alteration may be comparable with those from a cooling granitic magma.

TECHNICAL: Volume 77-6

Gravity and Ground Magnetic Surveys of the Thermo Hot Springs KGRA Region Beaver County, Utah

During the period June to September 1976, gravity and ground magnetic surveys were made in the Thermo Hot Springs KGRA region which is located southwest of the town of Milford, Beaver County, Utah. The regional surveys comprised 273 new gravity and magnetic stations and incorporated 104 previous gravity stations over an area of approximately 620 km^2. The detailed surveys consisted of 9 east-west profiles in the immediate vicinity of the Thermo Hot Springs KGRA.

The gravity data were reduced and are presented as terrain-corrected Bouguer gravity anomaly maps. Terrain corrections were made to a distance of 18.8 km. The regional gravity map shows the following features: 1) a large north-south trend with total relief of 5 mgal extending through the central portion of the study area; 2) an east-west trend with relief of about 7-8 mgal south of the Star Range and Shauntie Hills; 3) a north-south trend with 5 mgal relief east of Blue Mountain; and 4) a broad low of approximately 5 mgal closure southwest of the Shauntie Hills. The trends are probably caused by major faults and the gravity low is probably caused by the southern end of the Wah Wah Valley graben.

The detailed gravity map indicates two possible east-west trending faults intersecting a major north-south trending fault in the immediate vicinity of the Thermo Hot Springs. The location of the hot springs appears to be fault controlled.

To facilitate interpretation of the gravity data, the following processing and modeling techniques were used: 1) high-pass frequency filtering; 2) polynomial fitting; 3) second derivative; 4) strike filtering; 5) two-dimensional modeling; and 6) three-dimensional modeling. These techniques proved helpful as they more clearly delineated features of interest. The residual maps outlined an elongate north-south graben that extends through the survey area. The strike - filtered maps emphasize the major north-south and east-west faults of the region. Modeling provided reasonable depth estimates for bedrock in the vicinity of the hot springs and supported the structural interpretation for the hot springs area.

The magnetic data are presented as total magnetic intensity anomaly maps for both the regional and detailed surveys. The regional map delineates a magnetic high with 60-gammas closure that corresponds to a Tertiary quartz monzonite intrusive in the northeast part of the survey area. An east-west trend with about 300-gammas relief is delineated south of the Shauntie Hills and Star Range and possibly corresponds to an east-west fault.

The detailed magnetic map outlines an anomalous low with nearly 100-gammas closure associated with the Thermo Hot Springs. This magnetic low may reflect an alteration zone which is structurally controlled.

The following processing and modeling techniques were applied to aid interpretation of the magnetic data: 1) low-pass frequency filtering; 2) strike-filtering; 3) pseudogravity; 4) two and one-half dimensional modeling; and 5) three-dimensional modeling. The low-pass filtering clearly delineates the intrusive and the east-west trend south of the Star Range. The strike-filtering outlines north-south and east-west trends which correlate with faults implied by gravity data. The pseudogravity map indicates that the magnetic and gravity anomalies are not caused by the same bodies. The two and one-half dimensional modeling in the hot springs area provides a possible model for an alteration zone which appears to be structurally controlled. The three-dimensional model of the Tertiary quartz monzonite intrusive indicates a relatively shallow, slightly elongate intrusion that continues to a depth of at least 1 km.

TECHNICAL: Volume 77-7

Geologic Map of the Central and Northern Mineral Mountains, Utah

[THIS TOPICAL REPORT WAS A GEOLOGIC MAP, WITHOUT A REPORT.]

TECHNICAL: Volume 77-8

Geophysical Study of the Monroe-Red Hill Geothermal System

A detailed geophysical study consisting of heat flow, dipole-dipole resistivity, ground magnetics and gravity was conducted in the vicinity of Monroe, Utah to assess the resource potential of an identified hydrothermal system. The detailed study covered a 40 km^2 area along the Sevier fault near the Monroe-Red Hill hot springs. Fourteen 100m dipole-dipole resistivity profiles across the system were used to construct a first separation apparent resistivity contour map. The map effectively outlines the trace of the Sevier fault and reveals an elongate zone of low resistivity (<10 Ω-m) associated with the hydrothermal system. Similar features are evident on the total magnetic intensity anomaly map. Gravity modeling across the system indicates that the Sevier fault is comprised of three or more nearly vertical en echelon faults. On the basis of geological mapping and surface geophysical surveys a series of eleven shallow boreholes (40-90m) was drilled on two profiles across the system. Surface geothermal gradients vary from 240°C km^{-1} to over 1000°C km^{-1} along the profiles. Heat flow values vary smoothly from 550 mW m^{-2} to over 3000 mW m^{-2}, a significant enhancement over background Basin and Range heat flow of 80 mW·m^{-2}. Heat budget calculations based on conductive heat loss and enthalpy of the discharge waters indicate a net power loss of 7.8 MW.

Models of the system picture deep circulation and heating of groundwater and subsequent discharge to the surface through the Sevier fault zone. The lack of Pleistocene and Quaternary volcanism in the area suggests that the system is a stable stationary phase supported by high regional heat flow and forced convection.

TOPICAL: Volume 77-9

Mineral Mountains Magmatism: Chemical and Thermal Evolution

Results are presented for X-ray fluorescence and instrumental neutron activation analyses of rhyolites from the Roosevelt Hot Springs thermal area and adjoining regions. Obsidians from the two rhyolite flows of

Bailey Ridge and Wildhorse Canyon are extremely homogeneous. The average error for 16 elements measured with high precision on five samples is ±1.20% of the amount present. Younger rhyolites display systematic shifts in elemental concentrations from earlier rhyolites similar to those observed at Long Valley and the Jemez Mountains. Elements that are enriched in later lavas include Li, Be, F, Na, Mg, Al, Cl, Sc, Mn, Zn, Rb, Y, Nb, Mo, Sb, Cs, Tm, Yb, Lu, Hf, Ta, W, Th and U. Relatively depleted elements are P, K, Ca, T, Fe, Co, Sr, Zr, Ba, La, Ce, Pr, Nd, Sm, Eu, Gd, Th, and Dy. The chemical evolution of the rhyolites is consistent with a derivation of all lavas from a single magma body whose composition had been modified systematically over the period from 800,000 to 500,000 years ago. If so, this requires either a sizeable magma body in order to remain molten over this interval, or there must have been periodic reinjections of heat into a smaller system to sustain the magmatic system.

TOPICAL: Volume 77-10

Isotopic Studies, Roosevelt Hot Springs Thermal Area, Utah

Carbon-hydrogen-oxygen isotope compositions have been measured in regional cold waters, geothermal fluids, and hydrothermally altered rocks from the Roosevelt Hot Springs thermal area. These data have been used, in conjunction with other geological and geochemical data from this geothermal system, to place some limits on the origin of geothermal fluids and the reservoir carbon, the fluid recharge area, the physical-chemical environment of hydrothermal alteration, and the relative permeability of the geothermal system. The similarity of hydrogen isotope compositions of local meteoric water and geothermal reservoir fluid indicate that the geothermal fluids are almost entirely of surface derivation. An isotopically reasonable source area would be the Mineral Mountains directly to the east of the Roosevelt Hot Springs system. Hydrothermal calcite appears to be in isotopic equilibrium with the deep reservoir fluid. The C^{13} values of deep calcites and T- pH-fO_2 conditions of the reservoir defined by measured temperature, fluid chemistry, and alteration mineralogy fix the ^{13}C value of the geothermal system to -5 to -6.5 °/∘∘ (PDB). These values do not unambiguously define any one source or process, however. There is a relatively small increase in ^{18}O of geothermal fluids relative to their cold surface water precursors and significant ^{18}O depletion accompanying hydrothermal alteration of the granitic host rock. These isotopic shifts indicate a high ratio of geothermal fluid to altered rock for the geothermal system, implying relatively rapid (geologically) recirculation rates and significant permeability of the geothermal system.

TOPICAL: Volume 77-11

Escalante Desert Heat Flow

Heat flow results at ten new sites surrounding the Escalante Desert (ED) in southwest Utah range from 79 to 148 mW m^{-2} (1.9 to 3.5 HFU) with a mean of 114 mW m^{-2} (2.7 HFU). High heat flow occurs near Keel Spring and

Lund to the north of the ED, and between Beryl Junction and Uvada towards the western margin of the ED. Three new sites along a northwest-southeast axis through the Antelope range have a mean of 100 mW m^{-2} (2.4 HFU) consistent with a published value of 96 mW m^{-2} (2.3 HFU) for nearby Iron Mountain.

All the sites above are located in Tertiary age rhyolites and it is possible that the relatively high heat flow is a result of a widespread magmatic event which produced the Tertiary volcanic belt of southwest Utah. The geothermal significance of these results is twofold: (1) the two regions of heat flow greater than 120 mW m^{-2} (2.9 HFU) have been delineated within which the possibility of locating a blind high temperature system is enhanced and (2) a broader area of high heat flow and high geothermal gradients, locally up to 70°C/km, indicates a widespread potential for lower temperature resources.

TOPICAL: Volume 77-12

Electrical Properties of Core Samples

Complex resistivity (amplitude and phase) measurements were made on fifteen core samples from Roosevelt Hot Springs, at frequencies from 10^{-2} to 10^{5} Hz. These samples included altered granite alluvium, altered gneiss, unaltered gneiss as well as two synthetic samples composed of clay and quartz sand grains. The unaltered gneiss samples were sampled on the surface and the core samples came from two thermal gradient holes and represent materials from depths of 70 ft to 226 ft.

At salinities appropriate for the geothermal fluids (.1n) the unaltered material has a resistivity of about 500 Ω-m. The altered materials have resistivities in the range from 5 Ω-m to 50 Ω-m. The lowest resistivity samples have the highest porosities and clay contents. All of the altered material (high clay content) show phase angles in the range of 10 mrad to 100 mrad. The high frequency portion of the dispersion curves, due to the clays, increases from phase angles of 5-10 mrad around 1-10 Hz to 50-100 mrad at 10^5 Hz. Some of the samples containing pyrite (<5%) show an additional dispersion region (maximum phase angles around 10 mrad) at frequencies below 10 Hz.

A simple model for the conductive effects of clays has been developed by Waxman and Smits (1968, 1974). This model is in reasonable agreement with measured clay contents and the electrical measurements. The model indicates that in most of the low resistivity altered material the clay conduction carries 2 to 3 times more current than the pore water. Therefore, the near surface electrical properties are largely dominated by the clay alteration, with only small contributions due to the higher salinities and temperatures.

2.2 FINAL TECHNICAL REPORTS

FINAL: Volume 77-0

[SUMMARY MANAGEMENT DOCUMENT ONLY, NO TECHNICAL INFORMATION OTHER THAN AN MT DATA RELEASE.]

FINAL: Volume 77-1

The Barringer AIRTRACE Airborne Geochemical Exploration System and its Performance in Metal and Geothermal Resource Areas

1. The Barringer Research Ltd. AIRTRACE system uses a novel, complex method to sample coarse airborne particulate matter from a helicopter. The discrete samples obtained are analyzed for 25 major and trace elements. There are many variables introduced by nature and the system. Many of these need careful study.

2. During a test in southwestern Utah, 750 line miles of AIRTRACE survey were flown over known geothermal and base metal occurrences in six areas, with widely different conditions of vegetation, ambient dust, rock outcrop, geology, and cultural pollution. The system performed well under production conditions. Down time and the need to refly lines were minimal.

3. Laboratory analysis of the samples raised several problems and questions. Barringer personnel stated that the particles collected were coarser than usual, requiring development of a system to "crush" them prior to laser volatilization (the first step in the 25 element analysis). Ambient calcium levels were so high as to cause interferences. Fine, wind-blown dust was abundant, and may have decreased the sensitivity of the system in at least some of the areas.

4. Because of these problems, Barringer personnel recommended that analysis cease after preliminary values were calculated for the Rocky Range Copper district and the central one-third of the Mineral Range-Roosevelt Hot Springs thermal area. No further analysis, and no statistical data treatment, has been done.

5. In the Rocky Range Copper district, analysis showed strong copper and zinc anomalies over the old copper-rich tailings ponds at the

southernmost end of the Rocky Range. Smaller anomalies were detected in the vicinity of open pit copper mines and copper mineralization concealed beneath alluvium. Lead anomalies approximately flank the copper anomalies. Parts of this test area are far too contaminated with metal-rich mine wastes to allow a realistic test of the system. But the test did detect hidden mineralization.

Despite the reported adverse conditions, the system did generate a reasonable-appearing geochemical map of the area. No ground samples were analyzed, so only very general comparisons between airborne and ground geochemical patterns can be made. A general, though poor, correspondence between rock type and major elements was evident.

6. Analysis of the central one-third of the samples collected over the encompassing east-west flight lines over the Roosevelt Hot Springs thermal area and the adjacent Mineral Range and Escalante Desert yielded few distinct "anomalies", and apparently random patterns of element distribution. Some indication of non-random system noise (i.e. single data lines showing very high and very low values for one element) was noted. Possible small multi-metal anomalies over at least one geologic feature were noted.

7. During the survey, Barringer personnel conducted local soil sampling, and reported uranium, mercury and arsenic anomalies in coarse (40-80 mesh) surface soil fractions associated with faults and opaline sinter above the geothermal area. Finer fractions reportedly yielded no anomalies. Because of this, Barringer recommended re-flying all of the areas with the AIRTRACE system adjusted to collect coarser particles than were obtained in the initial six flights.

8. The argument that coarse particles will have to be sampled to obtain meaningful results over any of the areas may be fallacious. Particles in the 40-80 mesh range are extremely large, and may not even exist in any abundance in air over the test areas. The geochemistry and size distribution of airborne particulate matter over the other areas remains unknown. To refly these other areas, at a large cost, simply because of lack of results over a part of Roosevelt Hot Springs thermal area, is unrealistic. Each area was selected as having unique characteristics. Most of the other areas apparently contain far less ambient (wind blown) dust.

9. The AIRTRACE system, a new concept in airborne exploration, is technically almost operational. It should never be expected to detect every known geothermal or metal occurrence. If it can detect a significant percentage of them on a cost-effective basis, it is a useful exploration tool. However, serious questions exist as to whether the system can reliably detect geochemical differences over known geologic and concealed economic features. Costs of performing surveys with it are excessive.

FINAL: Volume 77-2

A Summary of the Geology, Geochemistry, and Geophysics of the Roosevelt Hot Springs Thermal Area, Utah

The Roosevelt Hot Springs thermal area is a newly discovered geothermal power prospect in Utah. Seven production wells have been drilled with a maximum per well flow capability averaging 4.5×10^5 kg of combined vapor and liquid per hour at a shut-in bottom hole temperature near 260°C.

The thermal area is located on the western margin of the Mineral Mountains, which consist dominantly of a Tertiary granitic pluton 32 km long by 8 km wide. Rhyolitic tuffs, flows, and domes cover about 25 km^2 of the crest and west side of the Mineral Mountains within 5 km of the thermal area. The rhyolitic volcanism occurred between 0.8 and 0.5 m.y. ago and constitutes a major Pleistocene thermal event believed to be significant to the evaluation of the Roosevelt Hot Springs thermal area. Thermal waters of the (now) dry spring, a seep, and the deep reservoir are dilute (ionic strength 0.1 to 0.2) sodium chloride brines.

Spring deposits consist of siliceous sinter and minor sulfur. Alluvium is cemented by sinter and altered in varying degrees by hot, acid-sulfate water to opal and alunite at the surface, grading successively to alunite-kaolinite, alunite-kaolinite-montmorillonite, and muscovite-pyrite within 60 m of the surface. Observed alteration and water chemistry are consistent with a model in which hot aqueous solutions containing H_2S and sulfate convectively rise along major fractures. Hydrogen sulfide oxidizes to sulfate near the surface decreasing the pH and causes alunite to form. Opal precipitates as the solutions cool. Kaolinite, muscovite, and K-feldspar are formed in sequence, as the thermal water percolates downward and hydrogen ion and sulfate are consumed.

Major swarms of earthquakes occur 30 km to the east-northeast near Cove Fort, Utah, but only minor earthquake activity occurs near the Roosevelt Hot Springs thermal area. Delayed P-wave traveltimes generated from the Cove Fort microearthquakes, and observed west of the northern Mineral Mountains, are suggestive of a low velocity zone beneath the Mineral Mountains; the vertical and lateral resolution of the data is inadequate to delineate the zone. Gravity and magnetic surveys are useful in determining the structure and depth of valley fill of the area of the northern Mineral Mountains, but neither one has detected an igneous intrusive source of heat. Thermal gradient measurements that range up to 960°C/km in 30 to 60 m deep holes outline a 6 by 12 km thermal field. Heat flow and resistivity data both outline anomalous zones along a system of faults that controls the near-surface fluid flow. The source of heat is interpreted to be the convective circulation of thermal water. The lowered resistivity is due to the hot brine and the associated hydrothermal alteration. Magnetotelluric data are highly anomalous over the field but means for their quantitative interpretation are unavailable at present; the anomalous data could as readily be interpreted as due to surface conductors as deep conductors which one might like to associate with a source of heat.

Any current model of the subsurface is highly speculative but can be expected to improve once existing seismic refraction and magnetotelluric data are fully interpreted. Then multiple-data-set modeling, combined with subsurface control from existing wells, should result in a reasonable model of the geothermal system. This modeling will be aided also by hydrologic, isotopic, structural, and additional P-wave delay studies currently in progress.

Based upon this case history, an exploration sequence appropriate to the eastern Basin and Range province should consist of phase 0, a digest and synthesis of available data; phase 1, a regional airphoto accumulation and analysis; phase 2, regional geologic mapping, regional radiometric dating of all intrusive and extrusive rocks, regional isotopic and chemical analysis of waters, regional aeromagnetic and gravity surveys, and regional collection of thermal gradients in available holes; phase 3, heat flow measurements in strategically located holes; phase 4, dipole-dipole resistivity surveys; phase 5, petrological, mineralogical, and geochemical studies on cuttings and cores from heat flow drill holes; phase 6, model test drilling accompanied by petrological, chemical, and isotopic analyses of cuttings and cores plus chemical and isotopic analyses of fluids; phase 7, detailed seismic refraction and reflection surveys; and phase 8; modeling and synthesis of all available data.

FINAL: Volume 77-3

Long-Term Seismic Monitoring of the Roosevelt - Cove Fort KGRA's

Earthquake monitoring of the Roosevelt Hot Springs and Cove Fort-Sulphurdale KGRA's was implemented by the installation of three RF telemetered, vertical component seismograph stations. The signals from the stations were FM-transmitted to a collecting site near Milford where they were telephone-transmitted to the University of Utah campus for recording. The limitations of only three stations precluded accurate hypocenter determinations but allowed detection to a minimum threshold of about M -0.5 for close-in events. Locations were determined for earthquakes of about M 0.7 or greater. Regional earthquake coverage of the south-central Utah KGRA's was supplemented by the use of other existing University of Utah stations to the east. During the period of 1 January 1977 to 30 June 1977 over 70 earthquakes were located in the south-central Utah area. Persistent activity continued throughout the Cove Fort-Sulphurdale KGRA.

Only two earthquakes were located north of Roosevelt Hot Springs during the report period of January 1977 to 30 June 1977. The close proximity of one earthquake to the Roosevelt Hot Springs thermal area suggests that although the seismicity is low, there is sufficient brittle strain release to warrant consideration as a potential area of earthquake inducement.

In conclusion, this period of earthquake locations shows continuing swarm activity near Cove Fort-Sulphurdale KGRA with relatively little activity at the Roosevelt Hot Springs KGRA.

FINAL: Volume 77-4

[DATA RELEASE ONLY]

FINAL: Volume 77-5a

Electromagnetic and Schlumberger resistivity

One- and two-dimensional modeling of the Schlumberger soundings at the Roosevelt Hot Springs thermal area have indicated a low-resistivity zone of approximately 5 Ω-m paralleling the Opal Mound fault. The low resistivity of this zone is probably due to intensely fractured and altered water-saturated rock. A zone of resistivity 12 Ω-m extending to the west of the fault is probably due to leakage of brine away from the geothermal system through alluvium or moderately altered rock. A resistive basement underlies the conductive zones and is believed to be essentially nonporous and unaltered rock.

A major problem in the application of one-dimensional (1-D) modeling of Schlumberger data in the Roosevelt Hot Springs thermal area is poor resolution of the 1-D parameters. The joint inversion of Schlumberger and electromagnetic sounding data gives a least-squares 1-D conductivity model in which parameters are much better resolved than are the model parameters estimated by the inversion of Schlumberger data alone.

One-dimensional modeling of Schlumberger soundings along a traverse does indicate the presence of a 2-D inhomogeneity but it gives no hint of the possible complexity of that inhomogeneity even though the parameters of the models fitting each sounding have acceptable standard deviations when constrained by electromagnetic sounding data. Since the model parameter standard deviations are model dependent, good resolution of 1-D model parameters does not indicate that the assumption of a 1-D model is valid. On the other hand, the possible complexities of structure is brought out by 2-D modeling of the same data, but since the degrees of freedom for complex 2-D models is large, a thorough study of the resolution of such models is prohibitively costly at present. In these circumstances, we must constrain the 2-D models with independent geological or geophysical data and then accept the subsequent best-fit model as semiquantitative.

FINAL: Volume 77-5b

Cost Analysis and Drilling Data Thermal Gradient and Heat Flow Holes, 1976

Ten heat flow holes were drilled in 1976 totaling 2732 feet. Total funds expended, not including University of Utah supervision, nor supplies, chiefly black-iron pipe, were $29,320. Cost per foot for NX-core drilling, on holes was $15.08. Cost per foot for rotary drilling in alluvium was $4.98 per foot.

FINAL: Volume 77-5c

[DATA RELEASE ONLY]

FINAL: Volume 77-5d

Ridge Regression Inversion Applied to Crustal Resistivity Sounding Data from South Africa

Ridge regression inversion has been used to test the applicability of various one-dimensional crustal models to the interpretation of deep Schlumberger sounding data from southern Africa (Van Zijl and Joubert, 1975). Four main models were investigated: a simple three-layered earth, a layered earth with a transition zone exhibiting a linear decrease in log resistivity with depth, a similar earth with the transition zone determined by cubic splines, and a model having exponential resistivity behavior at depth. The last model corresponds to temperature-dependent semiconduction through solid mineral grains (Brace, 1971). It was found that all of these models are capable of fitting the sounding data from south-western Africa, while all except the semiconduction model fit the data from southeastern Africa. One is, thereby, immediately alerted to the problem of lack of resolution in Schlumberger sounding data where geologic control is not available.

A major problem with the inversion of Schlumberger data alone is that accurate information is obtainable only for the resistivity-thickness product of the resistive portion of the crust. On the other hand, magnetotelluric data, when available, tends to provide information on the thickness, but very little information on the true resistivity of a resistive crust. In order to resolve both resistivity and thickness it is possible to invert simultaneously Schlumberger and magnetotelluric (MT) data. Results obtained from the combined inversion of the African resistivity data and hypothetical MT data show that a considerable improvement in model resolution can be achieved using MT amplitude data even of poor accuracy from a relatively limited frequency range (0.1 to 100 Hz), whereas inclusion of MT phase information is of negligible additional benefit.

Unfortunately, no significant test can be made, from data available at the time of our analysis, of the applicability of one-dimensional inversion in a geologic circumstance which probably demands more dimension.

FINAL: Volume 77-6

The Analysis of Sodium and Potassium in Silicate Rocks by a Lithium Metaborate Fusion Method

The lithium tetraborate fusion method for emission spectroscopy and flame photometry analysis of silicates has been modified slightly to produce rapid and precise analyses of sodium and potassium contents in silicate rocks. The analytical method we previously employed yields precise sodium and potassium values in the hands of a skilled analyst. However, the procedure requires considerable manipulation and is time consuming, taking about three days per batch of 6 to 12 samples. The new method makes it possible for a relatively unskilled analyst to analyze a dozen samples in half a day.

FINAL: Volume 77-7

Gravity and Ground Magnetic Surveys in the Monroe and Joseph KGRA's and Surrounding Region, South Central Utah

During the summer of 1977, regional gravity data were collected in portions of the Pavant Range, Tushar Mountains, northern Sevier Plateau, the Antelope Range, and throughout Sevier Valley approximately between the towns of Richfield and Junction, Utah. Additionally, detailed gravity and ground magnetic data were collected in the vicinity of hot springs in both the Monroe and Joseph Known Geothermal Resource Areas (KGRA's).

The regional gravity data were terrain corrected out to a distance of 167 km from the station and 948 gravity station values were compiled into a complete Bouguer gravity anomaly map of the survey area. Major features of this map include: 1) a pronounced regional gravity gradient associated with the Pavant thrust along which dense Paleozoic carbonate rocks structurally emplaced over Mesozoic sedimentary rocks are exposed not far from low-density volcanic rocks of the Marysvale volcanic field; 2) gravity lows over the alluvial-filled grabens of Sevier Valley and Marysvale Valley; 3) strong gravity gradients associated with the Sevier, Elsinore, Dry Wash, and Tushar faults; 4) gravity lows over the Mount Belknap, Red Hills, and Big John calderas; and 5) east-northeast-trending gravity contours in alignment with a belt of Tertiary intrusive rocks and the Wah-Wah-Tushar mineral belt of southern Utah.

Modeling of four regional gravity profiles throughout the survey area indicates that: 1) the Sevier Valley graben has an alluvial-fill about 1300 m in depth and Marysvale Valley graben has an alluvial-fill about 1200 m in depth; 2) the regional gravity gradient in the southern Pavant Range may be largely due to changes in densities of sedimentary rocks across the Cordilleran hingeline, and only partly the result of changes in the depth to the Moho across the Basin and Range-Colorado Plateau transition; and 3) the Mount Belknap caldera gravity low may be due to low-density Tertiary volcanic fill in the caldera surrounded by sedimentary and intrusive rocks. Polynomial residual gravity anomaly maps were helpful in delineating a closed gravity low in the Pavant Range which may be related to a volcanic source area.

A total of 840 ground magnetic stations established along 19 profiles in the Monroe KGRA were compiled into a diurnal-corrected total magnetic intensity anomaly map. Major features of this map include: 1) a magnetic anomaly of about 700 gammas relief across the Red Hill Hot Spring with the magnetic high on the Sevier Valley side of the hot spring; and 2) a linear magnetic low along the Monroe Hot Springs area. These magnetic features are believed to be due to alteration of magnetite in the alluvium by thermal waters rising along the Sevier fault zone. Modeling of gravity and magnetic profiles in the Monroe KGRA shows the faulting to consist of many individual en echelon faults along the Sevier fault zone instead of one large fault.

Detailed gravity and ground magnetic data were also collected along two profiles in the Joseph KGRA. Modeling of gravity and magnetic data along one of these profiles indicates: 1) relatively little throw along the Dry Wash fault, which controls the Joseph Hot Springs; and 2) the existence of a larger fault of about 800 m throw down on the east farther west in the valley near the Sevier River.

FINAL: Volume 77-8

Electrical Energizing of Well Casings

Electrical measurements of several kinds were made at Roosevelt Hot Springs KGRA using the casings of two production wells as electrodes. One purpose of these measurements was to determine if a "mise a la masse" measurement could provide useful information on the fault system which controls the near surface and deeper circulation. A second purpose was to determine if the introduction of the current deep into the conductive part of the system, via the well casing, would provide any additional information about the conductivity at depths below the near surface conductor.

The current excitation was a square wave with an amplitude of 20 amps and a frequency of 0.3 Hz. The current electrodes were the well casings of Phillips Petroleum Company wells numbers 13-10 and 12-35. The depth of the casing in these wells are 522 m (13-10) and 1340 m (12-35). The distance between the wells is about 4 km giving a bipole oriented at N25E°, which is situated over the near surface zone of low resistivity.

The equipotentials are highly distorted from the regular circular shape that would be observed in a homogeneous earth. The equipotentials around the southern electrode roughly parallel the mountain front in the east, except for a pronounced bulge to the southeast into Big Cedar Cove. The flattening of the contours parallel to the mountain front are caused in part by the strong resistivity contrast between the conductive alluvium and the resistive granite of the mountains. The bulge of the contours into Big Cedar Cove could be due to the extension of a conductor into this region or perhaps just a greater thickness of alluvium in the cove.

The potential difference measurements were also used to calculate apparent resistivities. In the vicinity of the electrodes, such apparent resistivities ranged from 10 to 50 ohm-meter, in general agreement with other surface measurements. These apparent resistivities were also used to look for conductive zones where the profiles crossed certain of the faults, without much success.

At distances between 2 and 15 km, potential measurements were made with an orthogonal set of 300 m dipoles. This set up is essentially the same as that used in the roving bipole-dipole scheme, except that vertical line source electrodes were used.

The apparent resistivities calculated from the magnitude of the observed electric field are about what might be anticipated from other resistivity surveys. Values from 10 to 50 ohm-meter are observed to the west in the alluvial valley fill and in the near vicinity of the electrodes which are in the near surface conductive region. The values in the Mineral Range and to east of the range are generally greater than 150 ohm-meter. There is some slight indication that the resistivity may be generally lower towards the northeast from the dipole. Toward the southeast the apparent resistivities generally increase with distance.

FINAL: Volume 77-9

Precision Leveling and Gravity Studies at Roosevelt Hot Springs Thermal Area, Utah

The objective of the precision gravity and precision leveling studies in the Roosevelt Hot Springs thermal area, Utah was to provide a baseline for detecting mass reduction or movement (displacement) related to injection or withdrawal of geofluids or to changes in tectonic strain, or both of these effects. In this project, the University of Utah obtained precision gravity and precision leveling data in the Roosevelt Hot Springs thermal area during the period September 1975 through October 31, 1977, and interpretations of these data were made (Cook and Carter, 1978). The project was conducted with the informal cooperation of the Phillips Petroleum Company, which authorized the inclusion of some of its data in this report, and the U.S. Geological Survey.

Two networks of benchmarks and/or monuments have been established in the Roosevelt Hot Springs thermal area: 1) a network of about 22 monuments by the Phillips Petroleum Company, for which precision leveling was done by Bulloch Bros. Engineering, Inc., in September to December 1975; and 2) a network of about 35 benchmarks, for which precision leveling was done by the USGS in May 1955 and for which precision horizontal control (not yet available) was done by the USGS during August 1976 and July 1977. The USGS precision leveling survey in may 1977 reoccupied only three of the Phillips monuments (E, G, and I), which were found to be about 0.7 to 0.8 feet <u>lower</u> in elevation than the precision leveling survey by Bulloch Bros. Engineering, Inc. in 1975. Because this difference is about the same for all three stations, it appears unreasonable and is attributed to a possible error in leveling along the 8-mile line between the datum and the Roosevelt Hot Springs thermal area.

Throughout the 4-day withdrawal test by the Phillips Petroleum Company in well #54-3 during February 12-16,, 1976, precision gravity readings taken at 1-hr intervals with two gravity meters at monument B (54-3) near the well showed no variation in gravity that could be attributed to mass reduction or ground movement (displacement) related to either withdrawal of geofluids or changes in tectonic strain.

During the period February 1976 to July 1977, four separate precision gravity surveys were conducted by the University of Utah on about 22 Phillips monuments and 8 USGS benchmarks in the Roosevelt Hot Springs thermal area. No changes in gravity at these stations were observed that can be attributed to either mass reduction or ground movement (displacement) associated with the withdrawal of geothermal fluids. An apparent decrease in observed gravity of about 0.106 mgal at station E during a 17-month period is believed unrealistic, and was probably caused by a fortuitous accumulation of errors involving both reading errors and insufficiently precise field techniques. These techniques have now been improved to assure greater accuracy in the future.

The precision gravity surveys made to date indicate that long-term changes in mass and/or elevation effects on the order of 0.1 mgal (corresponding to an elevation change of more than 1 foot) are detectable. Anticipated improvements in procedure, data reduction, and instrumentation should allow detection of smaller gravity changes.

FINAL: Volume 77-10

Quaternary Rhyolite from the Mineral Mountains, Utah, U.S.A.

A suite of silicic volcanic rocks is associated with the Roosevelt Hot Springs thermal area in southwestern Utah. The volcanic sequence includes

Tertiary rhyolite 8 m.y. old and obsidian, ash and rhyolite of Quaternary age.

The Quaternary lavas are characterized by high silica content (76.5% SiO_2) and total alkalies in excess of 9 percent. Obsidians commonly contain greater amounts of fluorine than water. Two older flows (0.8 m.y.) can be distinguished from younger dome and pyroclastic material (approximately 0.5 m.y.) by subtle differences in their chemistry. The mineralogy of the rhyolites consists of alkali feldspar, plagioclase, and small amounts of Fe-Ti oxides, biotite, hornblende and rare allanite. Fe-Ti oxide temperatures are 740-785°C for the flows and 635-665°C for the domes; two feldspar temperatures give similar results.

The phase relationships of bulk rock, glass and feldspar compositions demonstrate that the younger Quaternary rhyolites could have been derived from the earlier magma type, represented by the obsidian flows, by a process of crystal fractionation. The major phases which must fractionate are alkali feldspar, plagioclase and quartz with minor amounts of biotite, magnetite and ilmenite participating also. Trace element patterns support this scheme as well. The Tertiary lavas cannot be related to the Quaternary rhyolites and are thought to represent a separate event.

FINAL: Volume 77-11

Regional Gravity and Aeromagnetic Surveys of the Mineral Mountains and Vicinity, Millard and Beaver Counties, Utah

The results of gravity and aeromagnetic surveys of the Mineral Mountains and vicinity are presented as a terrain-corrected Bouguer gravity anomaly map (about 1450 stations with 1-mgal contour interval) and a total magnetic field intensity residual anomaly map (with contour interval 50 gammas), respectively. Combined interpretation of the gravity and aeromagnetic data was conducted based on comparing and contrasting various processed maps and interpretative geologic cross sections produced from each survey. Processing and modeling techniques which were used to facilitate the interpretation include:

1) Gravity -- a) a high-pass frequency filtering, b) polynomial fitting, c) pseudomagnetic filtering, d) strike filtering, e) upward continuation filtering, and f) two and one-half dimensional profile modeling.

2) Aeromagnetics -- a) low-pass frequency filtering, b) polynomial fitting, c) pseudogravity filtering, d) strike filtering, and e) two and one-half dimensional profile modeling.

Broad structural features apparent from the interpretation include: 1) Basin and Range normal faults which strike generally north-south and lie along the eastern and western margins of the Mineral Mountains; 2) the grabens of Milford and Beaver valleys which border the Mineral Mountains horst on the west and east, respectively; and 3) an east-northeastward-trending lineation which corresponds with the Black Rock offset and passes through the County line fault in the northern Mineral Mountains. This lineation probably corresponds to a major structural feature along which intrusive bodies have been emplaced. Modeling of the reduced gravity data using an assumed density contrast of 0.5 g/cc between the bedrock and valley fill resulted in a depth of alluvial fill of about 1.5 km at the deepest point in Milford Valley graben.

Quaternary rhyolite domes and flows are exposed along the crest of the Mineral Mountains. These volcanics are thought to be related to the heat source for the geothermal reservoir at Roosevelt Hot Springs thermal area. Roughly corresponding magnetic and gravity lows overlie the exposed volcanic domes which include Bearskin, Little Bearskin and North and South Twin Flat Mountains. These lows may be caused by a magma chamber at rather shallow depth, but are more likely caused by the lower density and magnetic susceptibility of the rhyolite. A gravity saddle in the area of Ranch Canyon and a roughly corresponding magnetic susceptibility body, but modeling has indicated that the gravity saddle may be caused by overlap of the gravity lows associated with Milford Valley and Beaver Valley grabens and the silicic volcanics. Removal of a different regional gravity could, however, alter this conclusion.

Over the known geothermal reservoir, possible expressions of hydrothermal magnetite alteration (a magnetic low area) and sediment densification (a gravity high area) have been observed. A north-south-trending magnetic high, which overlies alluvium, corresponds with the Opal Mound fault, which marks the westward extent of the reservoir. A pronounced magnetic low, which may represent a sedimentary or metamorphic rock unit, is located just south of the high thermal gradient anomaly area and corresponds with the southern boundary of the resevoir.

FINAL: Volume 77-13

Fluid Dynamic Properties of Rhyolitic Magmas, Mineral Mountains, Utah

Rhyolites from southwestern Utah display striking dissimilarities in morphology which are attributed to viscosity differences due to variations in water content. Temperature effects and fluorine concentrations are unable to account for the observed differences in morphology. Fluid dynamic calculations indicate that rhyolite flows of fluid aspect contained between 1 and 3 percent water upon eruption. More viscous domes contained less water which was expelled in pyroclastic eruptions preceding emplacement of the domal rhyolite magma.

Calculations that determine the physical properties of rhyolite magmas in the Mineral Mountains have been made. Data are presented on density, molar volume, heat capacity, gram formula mass, dynamic viscosity, thermal conductivity, thermal diffusivity, kinematic viscosity, and coefficient of thermal expansion.

FINAL: Volume 77-14

(ESL REPORT IDO/77.3.2)

Geochemistry of Solid Materials From Two U.S. Geothermal Systems and its Application to Exploration

This paper describes initial development of geochemical techniques for exploration and exploitation of geothermal systems. The techniques are based on analysis of solid materials. Distribution of Cu, Mo, Pb, Zn, Ag, As, Sb, Co, Ni, Mn, Fe, Bi, B, Te, In, Sn, and W are determined and evaluated for several sample types in a hot water system (Roosevelt Hot Springs thermal area, Utah) and a vapor dominated system (Geysers, California). The sample types analyzed are magnetic fractions, whole rock samples, and two different heavy liquid separates derived from cuttings composites from geothermal wells and shallow rotary drill holes. The results show that multi-element geochemical zoning is developed at both a relatively small scale of over hundreds of feet around individual steam entries (Se's) and hot water entries (HWE's) in geothermal wells, and at a larger scale of over thousands of feet both vertically and laterally in geothermal systems. Zoning is surprisingly similar for both hot-water and vapor-dominated systems. Trace elements which display the most consistent and useful zoning characteristics are As, Sb, Pb, Zn, Mn, B and W. Optimum delineation of the zoning is provided by +3.3 heavy liquid (HL) samples compared to the other sample types evaluated. Utilization of +3.3 samples maximizes detection of hydrothermal trace elements and markedly reduces or eliminates chemical signatures specifically related to rock type.

In small-scale zoning around HWE's and SE's, As, Sb, B(?), and W(?) are concentrated at or very close to the entries and Pb and Mn are concentrated between entries or for Pb at least, near cold water entries (CWEs). Pyrite abundance is generally greatest at or near HWE's and SE's and has a roughly antithetical relationship to overall magnetite distribution. Much Fe in the pyrite has probably been derived from magnetite which presumably is mainly non-hydrothermal in origin.

Large scale zoning, both vertical and lateral, is apparently characterized by As, Sb, B(?), and W(?) concentration in zones closest to the thermal anomaly and Zn, Mn(?), and Mo(?) concentration in peripheral zones. Pb is more closely associated with As near the thermal anomaly, but may occupy an intermediate zone close to and possibly overlapping the periphery of the high As zone. Comparison of large-scale lateral zoning results for Roosevelt Hot Springs thermal area with thermal gradient data shows a good correlation of high As anomalies with high thermal gradients (>100°C/km) and of high Zn anomalies with lower thermal gradients (<100°C/km).

Several important applications of these geochemical results to problems of exploration and exploitation of geothermal systems could be attempted during the FY 1978 and 1979 period. These include use for

1) location of steam or hot water entries in newly drilled geothermal wells,

2) definition of general and possibly specific drilling targets, and

3) prediction of approach to steam or hot water entries especially in order to facilitate decisions on additional drilling in sub-commercial wells as planned total depth is approached. Such applications could significantly contribute to power on stream in 1985 and to cost effectiveness in achieving this goal.

A considerable amount of additional work is required to optimize methods, corroborate results, and make some of these applications routine. Information to be obtained on depositional processes to aid understanding of the geochemical results should be of significant value in dealing with reservoir engineering problems. Work of this description could be expanded to deal specifically with such problems.

FINAL: Volume 77-15

(ESL REPORT IDO/77.3.1)

Three Dimensional Magnetotelluric Modeling

We have refined a three-dimensional (3D) volume integral equation solution, and have adapted it to magnetotelluric (MT) modeling. The refinement, incorporating an integro-difference scheme, increases the accuracy somewhat without increasing the computer time. Utilizing the two symmetry planes for a plane wave source decreases the computer storage by a factor of 8 and greatly reduces the computer time.

Convergence checks and comparisons with other solutions show that our results are valid. Because of space charges at resistivity boundaries, low-frequency 3D responses are much different from 1D and 2D responses. Hence 3D models are required for interpreting MT data in the complex geothermal environment.

FINAL: ESL REPORT NO. IDO/77.5.6

Dipole-Dipole Resistivity Survey of a Portion of the
Coso Hot Springs KGRA, Inyo County, California

A detailed electrical resistivity survey of 54 line-km was completed at the Coso Hot Springs KGRA in September 1977. This survey has defined a bedrock resistivity low at least 4 sq mi (10 sq km) in extent associated with the geothermal system at Coso. The boundaries of this low are generally well defined to the north and west but not as well to the south where an approximate southern limit has been determined. The bedrock resistivity low merges with an observed resistivity low over gravel fill east of Coso Hot Springs.

A complex horizontal and vertical resistivity structure of the surveyed area has been defined which precludes the use of layered-earth or two-dimensional interpretative models for much of the surveyed area. In general the survey data indicate that a 10 to 20 ohm-meter zone extends from near surface to a depth greater than 750 meters within the geothermal system. This zone is bordered on the north and west by bedrock resistivities greater than 200 ohm-meters and to the south by bedrock resistivities greater than 50 ohm-meters. A combination of observed increases in: 1) fracture density (higher permeability), 2) alteration (high clay content), and 3) temperature (higher ion activity of salts of ground water) within the bedrock low explain its presence.

FINAL: ESL REPORT NO. IDO/77.5.7

Low-Altitude Aeromagnetic Survey of a Portion of the
Coso Hot Springs KGRA, Inyo County, California

A detailed low-altitude aeromagnetic survey of 576 line-mi (927 line-km) was completed over a portion of the Coso Hot Springs KGRA in September 1977. The survey has defined a pronounced magnetic low that could help delineate the geothermal system. The magnetic low has an areal extent of approximately 10 sq mi (26 sq km). Direct and indirect evidence indicates that this anomaly is due, in part, to magnetite destruction by hydrothermal solutions associated with the geothermal system. The anomaly generally coincides with two other geophysical anomalies which are directly associated with the system: 1) a bedrock electrical resistivity low, and 2) an area of relatively high near-surface temperatures. The highest measured heat flow, 18 HFU, also occurs within its boundary.

The magnetic low occurs at the intersection of two major structural zones which coincide with a complementary set of strike-slip fault zones determined from seismic activity. The intersection of these two zones of active tectonism probably served as the locus for emplacement of a pluton at depth, above which are observed the coincidental geophysical anomalies and surface manifestations related to the geothermal system.

2.3 Management Task Reports

ESL REPORT NO. 77-1

Geothermal Reservoir Assessment Case Study, Utah (CSU)

The purpose of this report is to list the tasks which comprise the program of the above title. The tasks below were agreed upon with DOE.

Task 1. Phase Zero Study - to define objectives, tasks and milestones of this project and to assign priorities.

Task 2. Establish Internal Management Scheme.

Task 3. Establish Information Documentation Scheme.

Task 4. Assemble Background Technical Information and Worldwide Case History Reference Base.

Task 5. Establish Core and Cuttings Sample Library.

Task 6. Convert Information Control to In-House Computer Retrieval Format.

Task 7. Develop Standard Interpretation Procedures.

Task 8. Effect Standard Interpretation Procedures.

Task 9. Write and Distribute Case Histories.

Task 10. Provide Advisory Services.

Task 11. Gravity and Magnetic Data.

ESL REPORT NO. 77-2

Retrospective Case Studies

The purpose of this report is to list the tasks which comprise the program of the above title. The tasks below were agreed upon with DOE.

Task 1. Phase Zero Study - to define objectives, tasks and milestones of this project and to assign priorities.

Task 2. Establish Internal Management Scheme.

Task 3. Establish Information Documentation Scheme.

Task 4. Assemble Background Technical Information and Worldwide Case History Reference Base.

Task 5. Establish Core and Cuttings Sample Library.

Task 6. Convert Information Control to In-House Computer Retrieval Format.

Task 7. Develop Standard Interpretation Procedures.

Task 8. Develop and Pursue Strategies for Obtaining Data from Industry.

Task 9. Effect Standard Interpretation Procedures.

Task 10. Write and Distribute Case Histories.

ESL REPORT NO. 77-3

State-Coupled Direct Heat Program, Western States

The purpose of this report is to list the tasks which will comprise the program of the above title. The tasks below were agreed upon with DOE.

Task 1. Phase Zero Study - to define objectives, tasks and milestones of this project and to assign priorities.

Task 2. Establish Internal Management Scheme.

Task 3. Establish Information Documentation Scheme.

Task 4. Assemble Background Technical Information and Worldwide Case History Reference Base.

Task 5. Establish Core and Cuttings Sample Library.

Task 6. Convert Information Control to In-House Computer Retrieval Format.

Task 7. Aid DGE in Establishing Cooperative State Programs.

Task 8. Provide Consulting Expertise to Cooperative State Programs.

Task 9. Provide Advice to Developers of Low Temperature Geothermal Resources.

Task 10. Write and Distribute Reports.

3.0 HIGHLIGHTS

3.1 Topical Reports

TOPICAL: Volume 76-1

Dipole-Dipole Resistivity Delineation of the Near Surface Zone at the Roosevelt Hot Springs Thermal Area

The dipole-dipole resistivity method is useful in mapping shallow (<500m) hydrothermal alteration and fractures in a convective hydrothermal system. It can also detect leakage of brine from such a system.

TOPICAL: Volume 76-2

A Thermodynamic Model of the Hydrolysis of Microcline in Acid Sulfate Solutions

Theoretical modeling of the hydrothermal alteration zoning at Roosevelt Hot Springs thermal area, Utah, leads to the conclusion that this zoning is a function of temperature and pH gradients within homogeneous host rocks where microcline and quartz are abundant.

TOPICAL: Volume 76-3

Magnetotelluric Survey and Resistivity Maps, Roosevelt Hot Springs Thermal Area, Utah

The first MT data for Roosevelt Hot Springs thermal area was placed in the public domain by this data release. Some unexplained exceptionally low values of resistivity were observed.

TOPICAL: Volume 77-1

Attempt at Paleomagnetic Dating of Opal, Roosevelt Hot Springs Thermal Area

Paleomagnetic dating of the opal and siliceous sinter at Roosevelt Hot Springs thermal area has established that the main depositional activity at the area took place between 12,000 and 350,000 years ago.

TOPICAL: Volume 77-2

Geothermal Exploration Architecture

Several different strategies to be used in exploration for convective hydrothermal systems are described and costs for them computed.

TOPICAL: Volume 77-3

Thermal Gradients and Heat Flow at Roosevelt Hot Springs Thermal Area

Heat flow, as opposed to thermal gradients, can best delineate the near-surface thermal regime at Roosevelt Hot Springs thermal area. Heat flow and resistivity, when combined, can provide the best geophysical targets for drilling.

TOPICAL: Volume 77-4

Gravity Survey of the Cove Fort-Sulphurdale KGRA and the North Mineral Mountains Area, Millard and Beaver Counties, Utah

The principal occurrences of hydrothermal alteration, hot spring deposits, and flowing hot springs and hot-water wells in the Cove Fort-Sulphurdale and north Mineral Mountains area apparently coincide with the inferred intersections of: 1) east-west, and 2) north-south and/or north-northeastward trending fault zones. These occurrences include Sulphurdale Hot Springs, Sulphur Cove, and the Dog Valley area.

TOPICAL: Volume 77-5

Hydrothermal Alteration at Roosevelt Hot Springs
Thermal Area - DDH 1976-1

Major near-surface hydrothermal alteration zones at the Roosevelt Hot Springs thermal area include a 30 foot advanced argillic zone overlying a 75 foot argillic zone which in turn overlies a 95 foot propylitic zone. Upward moving thermal waters supersaturated with quartz and downward moving meteoric waters undersaturated with quartz both appear necessary to produce the observed alteration zones which are responsible for low electrical resistivities observed in the area.

TOPICAL: Volume 77-6

Gravity and Ground Magnetic Surveys of the Thermo Hot Springs KGRA
Region Beaver County, Utah

Detailed gravity surveying of the Thermo Hot Springs KGRA and vicinity indicates two possible east-west trending faults intersecting a major north-south trending fault in the immediate vicinity of Thermo Hot Springs. The locations of the springs appears to be controlled by faults.

TOPICAL: Volume 77-7

Geologic Map of the Central and Northern Mineral Mountains, Utah

The geologic map of the Mineral Mountains includes areas mapped by various researchers at the University of Utah. Map units include Precambrian basement, Paleozoic sediments, Tertiary intrusive stocks and dikes, Tertiary volcanics, Quaternary acid volcanics and Quaternary hot spring deposits and alluvium.

Significant features displayed by the map relating to the geothermal potential of the area include an East-West, North-South fault system which may be a significant structural control for the hot water system. Mapping has also shown the presence of significant amounts of Quaternary rhyolite flows and domes, active from 0.8 to 0.5 m.y. B.P. This igneous episode probably represents the eruption of magma from a chamber that may be the source of heat for the geothermal area.

TOPICAL: Volume 77-8

Geophysical Study of the Monroe-Red Hill Geothermal System

Resistivity, gravity, and magnetic surveys were interpreted to map the Sevier Fault; both the resistivity and magnetic surveys mapped hydrothermal alteration associated with hot fluids convecting up the Fault. Eleven shallow boreholes confirmed and constrained the geophysical interpretation and permitted heat flow measurements of 550 mWm^{-2} to over 3000 mWm^{-2}, a significant enhancement over background Basin and Range heat flow of 80mWm^{-2}. A target worthy of exploration as a source of direct heat has been delineated.

TOPICAL: Volume 77-9

Mineral Mountains Magmatism: Chemical and Thermal Evolution

Detailed analyses of rhyolites from the Roosevelt Hot Springs Thermal Area for 46 elements demonstrate that the initial eruption of two flows 800,000 years ago were from the same magma batch. Subsequent eruptions over the next 300,000 years produced lavas which exhibit a systematic evolution in their chemical composition which is consistent with the derivation of the younger lavas from the original magma source. The chemical patterns observed, such as depletion in the light rare earths and enrichment in the heavy rare earths, are virtually identical to those observed in the eruption products of Long Valley Caldera, California, and the Jemez Mountains, New Mexico.

If the volcanic activity is derived from a single magma source, the magma body must have been extremely large, or more likely, it was resupplied with heat periodically which sustained the molten mass for a period of at least 300,000 years.

TOPICAL: Volume 77-10

Isotopic Studies, Roosevelt Hot Springs Thermal Area, Utah

The Mineral Mountains are a logical recharge area for the geothermal system of the Roosevelt Hot Springs thermal area. The system exhibits rapid circulation rates and high permeability if the isotopic data is accepted.

TOPICAL: Volume 77-11

Escalante Desert Heat Flow

New heat flow results at ten sites surrounding the Escalante Desert greatly assists the regional geothermal resource assessment in southern Utah. Heat flow values are higher than normal Basin and Range values with two areas considered to have enhanced geothermal potential.

TOPICAL: Volume 77-12

Electrical Properties of Core Samples

Conduction of electricity along the surface of clay minerals carries 2 to 3 times more current than conduction through the pore water for rocks from the Roosevelt Hot Springs thermal area. Therefore, the near-surface electrical properties are largely dominated by the clay alteration, with only small contributions due to the higher salinities and temperatures.

3.2 Final Technical Reports

FINAL: Volume 77-1

An Evaluation of AIRTRACE in the Geothermal Environment

The probability of successfully delineating geothermal reservoirs by AIRTRACE was accepted to be a long shot from the outset. however, the predicted low cost of exploration using the method warranted a test of it. When the costs and uncetainties of AIRTRACE in practice turned out to be excessive, further testing of it was cancelled.

FINAL: Volume 77-2

A Summary of the Geology, Geochemistry, and Geophysics of the Roosevelt Hot Springs Thermal Area, Utah

A summary documentation of the geology, geochemistry, and geophysics of the Roosevelt Hot Springs thermal area, Utah, as of December, 1978, has been provided. Despite the amount of work carried out at the site, any model of the subsurface is highly conjectural. Work in progress is expected to aid materially in developing conceptual models.

FINAL: Volume 77-3

Long-Term Seismic Monitoring of the Roosevelt - Cove Fort KGRA's

Microearthquake swarm activity is common at Cove Fort-Sulphurdale, but is uncommon at Roosevelt Hot Springs thermal area.

FINAL: Volume 77-5a

Electromagnetic and Schlumberger Resistivity

One-dimensional interpretation of electromagnetic or Schlumberger survey data in the typically complex convective hydrothermal setting should be replaced by two- and three-dimensional modeling.

FINAL: Volume 77-5b

Cost Analysis and Drilling Data Thermal Gradient and Heat Flow Holes, 1976

Costs for drilling 100 m thermal gradient holes range from $5.00 per foot for rotary drilling in alluvium to $15.00 per foot for NX-core drilling in Tertiary granite.

FINAL: Volume 77-5d

Ridge Regression Inversion Applied to Crystal Resistivity Sounding Data from South Africa

It has been demonstrated that joint inversion of MT and Schlumberger resistivity data yields earth models of lower parameter uncertainty than inversion of either data set separately.

FINAL: Volume 77-6

The Analysis of Sodium and Potassium in Silicate Rocks by a Lithium Metaborate Fusion Method

The lithium metaborate fusion technique for alkali analyses in rocks and minerals produces rapid and precise analyses both for potassium argon dating and for general whole rock chemical analyses.

FINAL: Volume 77-7

Gravity and Ground Magnetic Surveys in the Monroe and Joseph KGRA's and Surrounding Region, South Central Utah

The results of this work have provided valuable information regarding large-scale faults throughout the survey area and particularly about faults which control hot springs in the Monroe and Joseph KGRA's. Such information should be of significant help in properly locating future test or production drill holes designed to tap the geothermal energy resources of this region.

FINAL: Volume 77-8

Electrical Energizing of Well Casings

The mise-a-la-masse method, as employed at Roosevelt Hot Springs thermal area, did not aid in delineating fractures nor did it detect a hypothesized highly conductive heat source at depth. The experiment, however, was not optimally designed due to logistical constraints.

FINAL: Volume 77-9

Precision Leveling and Gravity Studies at Roosevelt Hot Springs Thermal Area, Utah

A network of benchmarks and monuments has been established in the Roosevelt Hot Springs thermal area, and precision leveling data and precision gravity data have been taken to provide an initial baseline to detect mass reduction or changes in ground movement (displacement) related to the withdrawal of geothermal fluid. However, insofar as the precision gravity data are concerned, the baseline is considered to be inadequate until concrete monuments adjacent to the 30 new USGS benchmarks have been erected and precision gravity measurements taken at these monuments.

FINAL: Volume 77-10

Quaternary Rhyolite from the Mineral Mountains, Utah, U.S.A.

Although volcanic activity in the Mineral Mountain area extends as far back as 20 million years; activity in the Roosevelt Hot Springs thermal area is confined to the last 800,000 years. The rhyolite erupted during the period of 0.8 to 0.5 million years ago are chemically similar to Quaternary rhyolites of other geothermal areas in the western U.S. such as the Valles Caldera, Long Valley, Coso Mountains, and Yellowstone National Park.

Chemical and mineralogical evidence demonstrate that the youngest rhyolites were erupted from the same magma batch. That magma may have been derived from the earlier magma through a complex process of differentiation over a period of 300,000 years.

FINAL: Volume 77-11

Regional Gravity and Aeromagnetic Surveys of the Mineral Mountains and Vicinity, Millard and Beaver Counties, Utah

Gravity data at Roosevelt Hot Springs thermal area suggests normal range-front faulting west of the Opal Mound Fault. The depth of alluvium in Milford Valley is indicated to be 1400 m. No low-density rock, indicative of a high-temperature source rock, has yet been found. Aeromagnetic data is particularly useful for mapping magnetic phases within the Tertiary granite, for inferring the presence of Precambrian gneisses and schists beneath deep alluvium of the Milford Valley, and in mapping east-west faults.

FINAL: Volume 77-12

[DATA RELEASE ONLY]

FINAL: Volume 77-13

Fluid Dynamic Properties of Rhyolitic Magmas, Mineral Mountains, Utah

The morphological differences in rhyolite occurrences in the Roosevelt Hot Springs thermal area are due to differing water contents of the magmas at the time of extrusion. The more viscous dome lavas contained less water than the flow magmas. Water was lost from the magmas through pyroclastic eruptions which preceded eruption of the dome magmas. Water contents of the pre-eruptive magmas could have been in excess of 4 weight percent; however, water saturation of the magmas would be reached only within one or two kilometers from the earth's surface.

FINAL: Volume 77-14

ESL No. 77.3.2

Geochemistry of Solid Materials From Two U.S. Geothermal Systems and its Application to Exploration

Small-scale zoning was found around hot water entries (HWE's) and steam entries (SE's) in drill holes for As, Sb, B(?), and W(?) which are concentrated at or very close to the entries, and Pb and Mn, which are concentrated between entries. Large scale zoning, both vertical and lateral, is apparently characterized by As, Sb, B(?), and W(?) concentration in zones closest to the thermal anomaly and Zn, Mn(?), and MO(?) concentration in peripheral zones. Pb is more closely associated with As near the thermal anomaly, but may occupy an intermediate zone close to and possibly overlapping the periphery of the high As zone.

FINAL: Volume 77-15

(ESL No. IDO/77.3.1)

Three Dimensional Magnetotelluric Modeling

We have shown that three-dimensional (3D) models are required for interpreting MT data in the complex goethermal environment. One- and two-dimensional interpretations can be highly misleading. The three-dimensional integral equation solution developed will lend new insight to MT interpretation.

FINAL: ESL REPORT NO. IDO/77.5.6

Dipole-Dipole Resistivity Survey of a Portion of the
Coso Hot Springs KGRA, Inyo County, California

A 10 to 20 ohm-meter zone extends from near surface to a depth greater than 750 meters within the geothermal system. This zone is bordered to the north and west by bedrock resistivities greater than 200 ohm-meters and to the south by bedrock resistivities greater than 50 ohm-meters. The resistivity low is believed to be caused by 1) increased fracturing, 2) presence of hydrothermal alteration minerals, and 3) higher temperatures within the geothermal system.

FINAL: ESL REPORT NO. IDO/77.5.7

Low-Altitude Aeromagnetic Survey of a Portion of the

Coso Hot Springs KGRA, Inyo County, California

A magnetic low which has an areal extent of approximately 26 sq.km. occurs over the area of the known geothermal system. The boundaries of this magnetic low correlate with boundaries of an electrical resistivity low and of a high in measured shallow temperatures. At least part of the magnetic low is probably caused by alteration of magnetite to pyrite within the geothermal system.

4.0 Published Papers

The following manuscripts acknowledging the subject contract as a source of financial assistance appeared in the refereed literature.

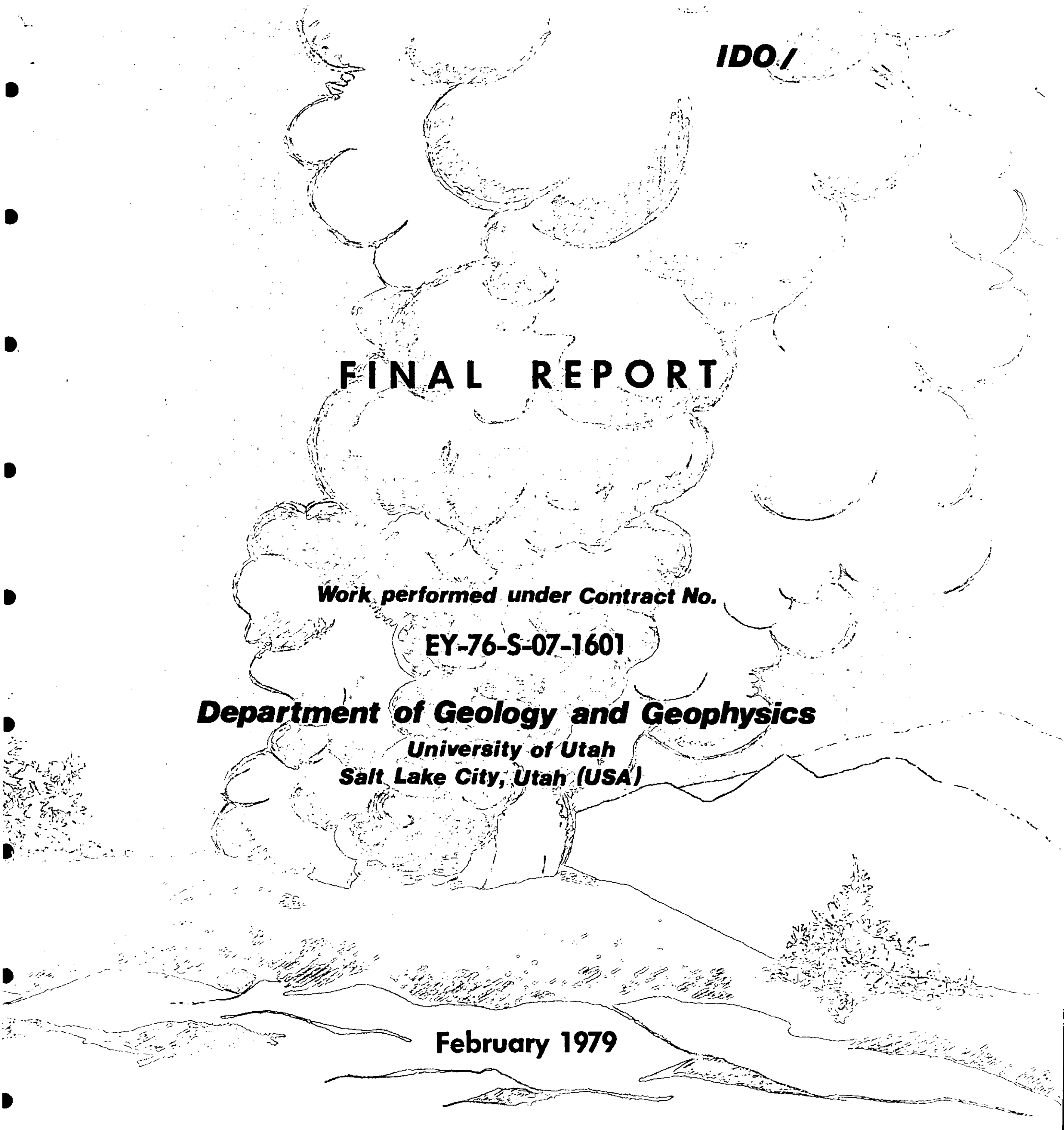
1. "From the Heat of the Earth," by Stanley H. Ward, 40th Ann. Frederick William Reynolds Lecture, Univ. of Utah Press, March 1977, 25 p.

2. "A Summary of the Geology, Geochemistry, and Geophysics of the Roosevelt Hot Springs Thermal Area, Utah," by S. H. Ward, W. T. Parry, W. P. Nash, W. R. Sill, K. L. Cook, R. B. Smith, D. S. Chapman, F. H. Brown, J. A. Whelan, and J. R. Bowman, Geophysics, v. 43, no. 7, December 1978, p. 1515-1542.

3. "Electromagnetic and Schlumberger resistivity sounding in the Roosevelt Hot Springs KGRA," by A. C. Tripp, S. H. Ward, W. R. Sill, C. M. Swift, Jr., and W. R. Petrick, Geophysics, v. 43, no. 7, December 1978, p. 1450-1464.

4. "Ridge Regression Inversion Applied to Crustal Resistivity Sounding Data from South Africa," by W. R. Petrick, W. H. Pelton, and S. H. Ward, Geophysics, v. 42, no. 5, August 1977, p. 945-1005.

5. "Pleistocene Rhyolite of the Mineral Mountains, Utah - Geothermal and Archeological Significance," by P. W. Lipman, P. D. Rowley, H. H. Mehnert, S. H. Evans, Jr., W. P. Nash, F. H. Brown, G. A. Izett, C. W. Naeser, and I. Friedman, Jour. Research U.S.G.S., v. 6, no. 1, Jan.-Feb. 1978, p. 133-147.



IDO/

FINAL REPORT

Work performed under Contract No.

EY-76-S-07-1601

Department of Geology and Geophysics

University of Utah
Salt Lake City, Utah (USA)

February 1979

Prepared for
DEPARTMENT OF ENERGY
Division of Geothermal Energy

Final Report

Contract No. EY-76-S-07-1601

Department of Energy

Part I: Technical

1.0 Introduction:

During the performance period of contract EY-76-S-07-1601, 15 volumes of topical reports and 21 volumes of final technical reports were issued. These reports are listed in Tables I and II, respectively. In this ultimate volume of the final technical report we include abstracts of all reports, a summary of the highlights of achievements under these reports, and copies of published papers which acknowledge financial support from the contract.

Table I

TOPICAL REPORTS

Contract EY-76-S-07-1601

A. Prime Contractor - University of Utah

1. "Dipole-Dipole Resistivity Delineation of the Near Surface Zone at the Roosevelt Hot Springs KGRA," Volume 76-1 by S. H. Ward and W. R. Sill, November 1976.

2. "A Thermodynamic Model of the Hydrolysis of Microcline in Acid Sulfate Solutions," Volume 76-2 by R. E. Dedolph and W. T. Parry, December 1976.

3. "Magnetotelluric Survey and Resistivity Maps, Roosevelt Hot Springs, Utah," Volume 76-3 by Geotronics Corporation, October 1976.

4. "Attempt at Paleomagnetic Dating of Opal, Roosevelt Hot Springs KGRA," Volume 77-1 by F. H. Brown, February 1977.

5. "Geothermal Exploration Architecture," Volume 77-2 by S. H. Ward, April 1977.

6. "Thermal Gradients and Heat Flow at Roosevelt Hot Springs," Volume 77-3 by W. R. Sill and J. Bodell, July 1977.

7. "Gravity Survey of the Cove Fort-Sulphurdale KGRA and the North Mineral Mountains Area, Millard and Beaver Counties, Utah," Volume 77-4 by William D. Brumbaugh and Kenneth L. Cook, August 1977.

8. "Hydrothermal Alteration at Roosevelt Hot Springs KGRA - DDH 1976-1," Volume 77-5 by Nancy Lee Bryant and W. T. Parry, August 1977.

9. "Gravity and Ground Magnetic Surveys of the Thermo Hot Springs KGRA Region, Beaver County, Utah," Volume 77-6 by Robert F. Sawyer and K. L. Cook, September 1977.

10. "Geologic Map of the Central and Northern Mineral Mountains, Utah," Volume 77-7 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.

11. "Geophysical Study of the Monroe-Red Hill Geothermal System," Volume 77-8 by Charles Mase, David S. Chapman and S. H. Ward, October 1978.

12. "Mineral Mountains Magmatism: Chemical and Thermal Evolution", Volume 77-9 by W.P. Nash and S.H. Evans, Jr., February 1979.

13. "Isotopic Studies, Roosevelt Hot Springs Thermal Area, Utah", Volume 77-10 by J.R. Bowman, January 1979.

14. "Escalante Desert Heat Flow", Volume 77-11, by D.S. Chapman.

15. "Electrical Properties of Core Samples", Volume 77-12, by W.R. Sill.

TABLE II

FINAL REPORTS

Contract EY-76-S-07-1601

A. Prime Contractor - University of Utah

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 KGRAs," 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 KGRAs 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.

* Indicates available for public distribution.

B. Sub Contractor - University of Utah Research Institute

1. "Geochemistry of Solid Materials from Two U.S. Geothermal Systems and Its Application to Exploration," Volume 77-14 (ESL No. IDO/77.3.2) by Robert W. Bamford, July, 1978.

2. "Three Dimensional Magnetotelluric Modeling," Volume 77-15 (ESL No. IDO/77.3.1) by Gerald W. Hohmann and Sam Ting, July, 1978.

3. "Dipole-Dipole Resistivity of a Portion of the Coso Hot Springs KGRA, Inyo County, California," Volume IDO/77.5.6 by Richard C. Fox, May, 1978.

4. "Low-Altitude Aeromagnetic Survey of a Portion of the Coso Hot Springs KGRA, Inyo County, California," Volume IDO/77.5.7 by Richard C. Fox, May, 1978.

5. "Geothermal Reservoir Assessment Case Study, Utah (CSU)," ESL Report No. 77-1 by Phillip M. Wright, July, 1977.

6. "Retrospective Case Studies," ESL Report No. 77-2 by Phillip M. Wright, September, 1977.

7. "State-Coupled Direct Heat Program, Western States," ESL Report No. 77-3 by Phillip M. Wright, September, 1977.

2.0 ABSTRACTS

2.1 TOPICAL

TECHNICAL: VOLUME 76-1

Dipole-Dipole Resistivity Delineation of the Near-Surface Zone at the Roosevelt Hot Springs Thermal Area, Utah

Recent dipole-dipole resistivity surveys using 100 m and 300 m dipoles at Roosevelt Hot Springs thermal area, near Milford, Utah have suggested that the north-south length of the convective hydrothermal system may be as great as 20 km. Tertiary granite of the Mineral Mountain pluton seems to be intensely fractured along a narrow (500 m?) sinuous zone trending north and coinciding in part with the Opal Mound Fault. This north-south fracture zone is crosscut by numerous east-west and some northwest-southeast faults. The brine in the fractures and alteration of feldspars to clay both result in lowered resistivities. Leakage of brine westward from the Opal Mound Fault fracture zone is still a realistic interpretation of low resistivity values several kilometers west of this Fault.

TECHNICAL: VOLUME 76-2

A Thermodynamic Model of the Hydrolysis of Microcline in Acid Sulfate Solutions

A theoretical model of the hydrolysis of microcline by a hydrothermal solution has been determined for a closed system at constant temperature.

Hypothetical solution compositions and temperatures were chosen to match the known geothermal system at Roosevelt Hot Springs thermal area, Utah. The calculated reaction paths indicate that the overall reaction process is an exchange of potassium from the reactant mineral, microcline, for hydrogen from the solution. Aluminum is nearly conserved among solid phases. The amount of microcline reacted per kilogram of solution before overall equilibrium is reached is a function of temperature and initial solution pH. Since the system is closed and at constant temperature, natural conditions are not reproduced well enough to apply the model as a geothermometer. The reaction paths suggest qualitative models of alteration mineral zoning patterns that are similar to zoning at Roosevelt Hot Springs thermal area, Utah; Steamboat Springs, Nevada, and Butte, Montana. The models presented view alteration zoning as a function of temperature and pH gradients within homogeneous host rocks where microcline and quartz are abundant.

TECHNICAL: Volume 76-3

Magnetotelluric Survey and Resistivity Maps,
Roosevelt Hot Springs Thermal Area, Utah

[DATA RELEASE ONLY]

TECHNICAL: Volume 77-1

Attempt at Paleomagnetic Dating of Opal,
Roosevelt Hot Springs Thermal Area, Utah

In an attempt at paleomagnetic dating of the opal and siliceous sinter at Roosevelt Hot Springs thermal area, a core was drilled on the Opal Mound to a depth of 16.8 meters. The first 7 meters consist dominantly of massive or banded opal with some clay interbeds, which become more abundant near the bottom of this section of the core. From 7 to 10 meters the core consists mainly of silicified sediment with minor opal layers. Below this to the bottom the core is made of cemented alluvium, either brown or light green, and varying considerably in its coherence.

Paleomagnetic measurements were made on each of the samples cut from the core. Because of the close sample spacing, measurements were averaged for each piece of core. Because it was not possible to control the declination of the core, and because the core was so badly fragmented, only inclinations were considered. There is a marked difference in the scatter of measurements above about 5 meters, and below that depth, the upper part of the core having greater scatter than the lower. This corresponds roughly to the lithologic transition from the part of the core mainly composed of opal (upper) to the part of the core which has a greater admixture of detrital sediment.

There is a difference in demagnetization behavior within the samples which are predominantly opal. Those above about 3 meters have more stable magnetism than those between 3 and 5 meters. NRM intensities for the opal samples range from 6.11×10^{-6} gauss to about 1×10^{-7} gauss, the mean and standard deviation for 31 samples being $1.63 \pm 1.53 \times 10^{-6}$ gauss. The mode lies below 1×10^{-6} gauss.

At first sight, the only bit of geochronologic data that would appear to be forthcoming from the paleomagnetic results is that the opal was all deposited during the Brunhes epoch, that is during the last 690,000 years.

This was expected, and may be considered confirmed by this study. It should also be noted that the alluvium underlying the opal is also of normal polarity, and as it is involved in the faulting along the Opal Mound Fault, this fault is believed to have been active more recently than 690,000 years.

One further bit of data regarding the time over which the opal was deposited is also present from the magnetic data without straining ones credulity too far. This is found in the great swing in both declination and inclination.

It is felt that because the opal is banded, deposition of the opal took place under surface conditions, and was sequentially deposited, rather than deposited by volume precipitation. Thus increasing depth is correlated with increasing age of the opal. The changes in declination and inclination observed with depth from the block samples of opal are thus thought to record a series of magnetic directions at the site distributed in time.

Were we to correlate the change in declination and inclination with one of the known excursions during the Brunhes Epoch, we could set a minimum time for the activity of the deposition of opal on the Opal Mound. The best known, recent, well documented excursion is called the Laschamp event, and supposing that the correlation be made with this event sets a minimum time of ca. 12,000 years on the activity of the Roosevelt Hot Springs thermal system. There is, of course, the possibility that a later excursion took place locally, in which case the minimum estimate for the length of activity would have to be correspondingly shortened.

The duration of magnetic excursions is short, being approximately

1000-2000 years. Using these rough estimates, and noting that the excursion which is believed to have been recorded is confined to about 20 cm. of opal leads to an estimate of the rate of deposition of opal of about 1m/5000 years or 1m/10,000 years. Applying the slower rate to the observed thickness of opal (ca. 7m) results in an estimate of ca. 70,000 years for opal deposition on this part of the Opal Mound, although it may have taken only half that long. Even if the excursion is to be correlated with the Biwa II event, of the Brunhes Epoch, the length of activity on the Opal Mound would thus be confined to the last 350,000 years or so. The estimate is gross, but better than no estimate at all.

TECHNICAL: Volume 77-2

Geothermal Exploration Architecture

A basic modular exploration sequence which includes a carefully balanced selection of geological, geochemical, and geophysical modules is developed for geothermal prospecting in the eastern Basin and Range. The cost per square mile for application of this exploration architecture is $461.00. If one were to expand this basic system to include virtually all techniques being routinely employed in geothermal prospecting today, then the cost per square mile would increase to $790.00. This latter expenditure rate is difficult to justify, but some increase above the $461.00 basic cost appears to be warranted to make exploration costs about equal to land acquisition costs and model-test drilling costs. Total costs per discovery appear to range from 6M to 27M depending upon assumptions, when the costs of exploring for "dry" prospects are included in the costs of the discoveries. Development and operating costs are not included in the analysis.

The basic exploration architecture described here is compared with others previously advanced in the literature. While differences in approach are abundant, there is a central core of exploration activities and an order to these activities to which most of us "architects" probably would subscribe. If a common basis is used for computing costs of individual exploration modules, then there is no great cost disparity between any of the architectures reviewed.

TECHNICAL: Volume 77-3

Thermal Gradients and Heat Flow at Roosevelt Hot Springs Thermal Area

Thermal gradient and electrical resistivity surveys both outline anomalous zones along the system of faults that control the near surface flow at Roosevelt Hot Springs thermal area. The source of both anomalies is the circulation of thermal water, which gives rise to the high heat flow and the lowered resistivity due to the hot brine and the associated hydrothermal alteration.

The nature of the temperature profiles and the asymmetry of the thermal gradient profile across the system are suggestive of a leakage and mixing of thermal water with the regional groundwater flow to the west. This interpretation is consistent with the resistivity data in which conductive regions to the west of the fault system have been interpreted in terms of brine-saturated sediments.

The maximum conductive heat flow over the anomaly is 40 HFU ($1.7 W/m^2$)

and the total conductive heat loss is estimated at 2 MW. Heat flow in the Mineral Mountains, to the east of the near-surface thermal anomaly, is low or near average for the Basin and Range. Recharge may be taking place in this region.

TECHNICAL: Volume 77-4

Gravity Survey of the Cove Fort - Sulphurdale KGRA and the North Mineral Mountains Area, Millard and Beaver Counties, Utah

During the summers of 1975 and 1976, a gravity survey was conducted in the Cove Fort - Sulphurdale KGRA and north Mineral Mountains area, Millard and Beaver counties, Utah. The survey consisted of 671 gravity stations covering an area of about 1300 km^2, and included two orthogonal gravity profiles traversing the area. The gravity data are presented as a terrain-corrected Bouguer gravity anomaly map with a contour interval of 1 mgal and as an isometric three-dimensional gravity anomaly surface. Selected anomaly separation techniques were applied to the hand-digitized gravity data (at 1-km intervals on the Universal Transverse Mercator grid) in both the frequency and space domains, including Fourier decomposition, second vertical derivative, strike-filter, and polynomial fitting analysis, respectively.

Residual gravity gradients of 0.5 to 8.0 mgal/km across north-trending gravity contours observed through the Cove Fort area, the Sulphurdale area, and the areas east of the East Mineral Mountains, along the west flanks of the Tushar Mountains, and on both the east and west flanks of the north Mineral Mountains, were attributed to north-trending Basin and Range high-angle faults. Gravity highs exist over the community of Black Rock area, the north Mineral Mountains, the Paleozoic outcrops in the east Cove Creek-Dog Valley-White Sage Flats areas, the sedimentary thrust zone of the southern Pavant Range, and the East Mineral Mountains. The gravity lows over north Milford Valley, southern Black Rock Desert, Cunningham Wash, and northern Beaver Valley are separated from the above gravity highs by steep gravity gradients attributed to a combination of crustal warping and faulting. A gravity low with a closure of 2 mgal corresponds with Sulphur Cove, a circular topographic feature containing sulphur deposits.

An extension of the Laramide overthrust sheet observed in the southern Pavant Range is indicated as extending westward under alluvial and volcanic cover by a southwest-trending gravity saddle that lies over the Paleozoic sedimentary exposures in the east Cove Creek area and the Pinnacle Pass igneous-sedimentary contact zone, and that separates the gravity low over north Milford Valley into northern and southern closures with a right-lateral offset. The possible buried, upwarped edge of this thrust sheet is indicated by a steep gravity gradient on the north-south gravity profile; Basin and Range high-angle faulting is indicated on the east-west gravity profile.

The gravity saddle over the Pinnacle Pass Contact zone overlies a possible east-west strike-slip fault zone between the Mineral Mountains pluton on the south and the Laramide overthrust on the north. The gravity highs lying north and south of Pinnacle Pass indicate a right-lateral offset along an east-west zone that continues eastward along an east-west geomorphic and structural feature to Clear Creek Canyon (which includes Sulphur Cove) in the Tushar Mountains outlining an inferred east-west strike-slip fault zone (supported also by aeromagnetic data).

TECHNICAL: Volume 77-5

Hydrothermal Alteration at Roosevelt Hot Springs Thermal Area - DDH 1976-1

Hot waters of the Roosevelt Hot Springs thermal area, Utah, have altered granitic rocks and detritus of the Mineral Range pluton, Utah. Alteration and mineral deposition recognized in a 200' drill core from DDH 1-76 is most intense in the upper 100 feet which consists of altered alluvium and opal deposits; the lower 100 feet is weakly altered quartz monzonite. Petrographic, X-ray, and chemical methods were used to characterize systematic changes in chemistry and mineralogy.

Major alteration zones include: 1) an advanced argillic zone in the upper 30 feet of altered detritus containing alunite, opal, vermiculite, and relic quartz; 2) an argillic zone from 30 feet to 105 feet containing kaolinite, muscovite, and minor alunite; and 3) a propylitic zone from 105 to 200 feet containing muscovite, pyrite, marcasite, montmorillonite, and chlorite in weakly altered quartz monzonite.

Comparison of the alteration mineral assemblages with known water chemistry and equilibrium activity diagrams suggests that a simple solution equilibrium model cannot account for the alteration. A model is proposed in which upward moving thermal water super-saturated with respect to quartz and a downward moving cool water undersaturated with respect to quartz produces the observed alteration.

An estimate of the heat flow contributions from hydrothermal alteration was made by calculating reaction enthalpies for alteration reactions at each depth. In calculating heat flow, the uncertain variables included: 1) depth of alteration, 2) duration of hydrothermal activity, 3) thermal gradient, and 4) amount of sulfide oxidized to sulfate. The estimated heat flow varied from .02 HFU (for 200' depth, 400,000 yr duration, and no sulfur oxidation) to 67 HFU (for 5,000' depth, 1,000 yr duration, and all sulfur oxidized from sulfide). Heat flow contributions from hydrothermal alteration may be comparable with those from a cooling granitic magma.

TECHNICAL: Volume 77-6

Gravity and Ground Magnetic Surveys of the Thermo Hot Springs KGRA Region Beaver County, Utah

During the period June to September 1976, gravity and ground magnetic surveys were made in the Thermo Hot Springs KGRA region which is located southwest of the town of Milford, Beaver County, Utah. The regional surveys comprised 273 new gravity and magnetic stations and incorporated 104 previous gravity stations over an area of approximately 620 km^2. The detailed surveys consisted of 9 east-west profiles in the immediate vicinity of the Thermo Hot Springs KGRA.

The gravity data were reduced and are presented as terrain-corrected Bouguer gravity anomaly maps. Terrain corrections were made to a distance of 18.8 km. The regional gravity map shows the following features: 1) a large north-south trend with total relief of 5 mgal extending through the central portion of the study area; 2) an east-west trend with relief of about 7-8 mgal south of the Star Range and Shauntie Hills; 3) a north-south trend with 5 mgal relief east of Blue Mountain; and 4) a broad low of approximately 5 mgal closure southwest of the Shauntie Hills. The trends are probably caused by major faults and the gravity low is probably caused by the southern end of the Wah Wah Valley graben.

The detailed gravity map indicates two possible east-west trending faults intersecting a major north-south trending fault in the immediate vicinity of the Thermo Hot Springs. The location of the hot springs appears to be fault controlled.

To facilitate interpretation of the gravity data, the following processing and modeling techniques were used: 1) high-pass frequency filtering; 2) polynomial fitting; 3) second derivative; 4) strike filtering; 5) two-dimensional modeling; and 6) three-dimensional modeling. These techniques proved helpful as they more clearly delineated features of interest. The residual maps outlined an elongate north-south graben that extends through the survey area. The strike - filtered maps emphasize the major north-south and east-west faults of the region. Modeling provided reasonable depth estimates for bedrock in the vicinity of the hot springs and supported the structural interpretation for the hot springs area.

The magnetic data are presented as total magnetic intensity anomaly maps for both the regional and detailed surveys. The regional map delineates a magnetic high with 60-gammas closure that corresponds to a Tertiary quartz monzonite intrusive in the northeast part of the survey area. An east-west trend with about 300-gammas relief is delineated south of the Shauntie Hills and Star Range and possibly corresponds to an east-west fault.

The detailed magnetic map outlines an anomalous low with nearly 100-gammas closure associated with the Thermo Hot Springs. This magnetic low may reflect an alteration zone which is structurally controlled.

The following processing and modeling techniques were applied to aid interpretation of the magnetic data: 1) low-pass frequency filtering; 2) strike-filtering; 3) pseudogravity; 4) two and one-half dimensional modeling; and 5) three-dimensional modeling. The low-pass filtering clearly delineates the intrusive and the east-west trend south of the Star Range. The strike-filtering outlines north-south and east-west trends which correlate with faults implied by gravity data. The pseudogravity map indicates that the magnetic and gravity anomalies are not caused by the same bodies. The two and one-half dimensional modeling in the hot springs area provides a possible model for an alteration zone which appears to be structurally controlled. The three-dimensional model of the Tertiary quartz monzonite intrusive indicates a relatively shallow, slightly elongate intrusion that continues to a depth of at least 1 km.

TECHNICAL: Volume 77-7

Geologic Map of the Central and Northern Mineral Mountains, Utah

[THIS TOPICAL REPORT WAS A GEOLOGIC MAP, WITHOUT A REPORT.]

TECHNICAL: Volume 77-8

Geophysical Study of the Monroe-Red Hill Geothermal System

A detailed geophysical study consisting of heat flow, dipole-dipole resistivity, ground magnetics and gravity was conducted in the vicinity of Monroe, Utah to assess the resource potential of an identified hydrothermal system. The detailed study covered a 40 km^2 area along the Sevier fault near the Monroe-Red Hill hot springs. Fourteen 100m dipole-dipole resistivity profiles across the system were used to construct a first separation apparent resistivity contour map. The map effectively outlines the trace of the Sevier fault and reveals an elongate zone of low resistivity (<10 Ω-m) associated with the hydrothermal system. Similar features are evident on the total magnetic intensity anomaly map. Gravity modeling across the system indicates that the Sevier fault is comprised of three or more nearly vertical en echelon faults. On the basis of geological mapping and surface geophysical surveys a series of eleven shallow boreholes (40-90m) was drilled on two profiles across the system. Surface geothermal gradients vary from 240°C km^{-1} to over 1000°C km^{-1} along the profiles. Heat flow values vary smoothly from 550 mW m^{-2} to over 3000 mW m^{-2}, a significant enhancement over background Basin and Range heat flow of 80 mW m^{-2}. Heat budget calculations based on conductive heat loss and enthalpy of the discharge waters indicate a net power loss of 7.8 MW.

Models of the system picture deep circulation and heating of groundwater and subsequent discharge to the surface through the Sevier fault zone. The lack of Pleistocene and Quaternary volcanism in the area suggests that the system is a stable stationary phase supported by high regional heat flow and forced convection.

TOPICAL: Volume 77-9

Mineral Mountains Magmatism: Chemical and Thermal Evolution

Results are presented for X-ray fluorescence and instrumental neutron activation analyses of rhyolites from the Roosevelt Hot Springs thermal area and adjoining regions. Obsidians from the two rhyolite flows of

Bailey Ridge and Wildhorse Canyon are extremely homogeneous. The average error for 16 elements measured with high precision on five samples is ±1.20% of the amount present. Younger rhyolites display systematic shifts in elemental concentrations from earlier rhyolites similar to those observed at Long Valley and the Jemez Mountains. Elements that are enriched in later lavas include Li, Be, F, Na, Mg, Al, Cl, Sc, Mn, Zn, Rb, Y, Nb, Mo, Sb, Cs, Tm, Yb, Lu, Hf, Ta, W, Th and U. Relatively depleted elements are P, K, Ca, T, Fe, Co, Sr, Zr, Ba, La, Ce, Pr, Nd, Sm, Eu, Gd, Th, and Dy. The chemical evolution of the rhyolites is consistent with a derivation of all lavas from a single magma body whose composition had been modified systematically over the period from 800,000 to 500,000 years ago. If so, this requires either a sizeable magma body in order to remain molten over this interval, or there must have been periodic reinjections of heat into a smaller system to sustain the magmatic system.

TOPICAL: Volume 77-10

Isotopic Studies, Roosevelt Hot Springs Thermal Area, Utah

Carbon-hydrogen-oxygen isotope compositions have been measured in regional cold waters, geothermal fluids, and hydrothermally altered rocks from the Roosevelt Hot Springs thermal area. These data have been used, in conjunction with other geological and geochemical data from this geothermal system, to place some limits on the origin of geothermal fluids and the reservoir carbon, the fluid recharge area, the physical-chemical environment of hydrothermal alteration, and the relative permeability of the geothermal system. The similarity of hydrogen isotope compositions of local meteoric water and geothermal reservoir fluid indicate that the geothermal fluids are almost entirely of surface derivation. An isotopically reasonable source area would be the Mineral Mountains directly to the east of the Roosevelt Hot Springs system. Hydrothermal calcite appears to be in isotopic equilibrium with the deep reservoir fluid. The C^{13} values of deep calcites and T- pH-fO_2 conditions of the reservoir defined by measured temperature, fluid chemistry, and alteration mineralogy fix the ^{13}C value of the geothermal system to -5 to -6.5 °/°° (PDB). These values do not unambiguously define any one source or process, however. There is a relatively small increase in ^{18}O of geothermal fluids relative to their cold surface water precursors and significant ^{18}O depletion accompanying hydrothermal alteration of the granitic host rock. These isotopic shifts indicate a high ratio of geothermal fluid to altered rock for the geothermal system, implying relatively rapid (geologically) recirculation rates and significant permeability of the geothermal system.

TOPICAL: Volume 77-11

Escalante Desert Heat Flow

Heat flow results at ten new sites surrounding the Escalante Desert (ED) in southwest Utah range from 79 to 148 mW m^{-2} (1.9 to 3.5 HFU) with a mean of 114 mW m^{-2} (2.7 HFU). High heat flow occurs near Keel Spring and

Lund to the north of the ED, and between Beryl Junction and Uvada towards the western margin of the ED. Three new sites along a northwest-southeast axis through the Antelope range have a mean of 100 mW m^{-2} (2.4 HFU) consistent with a published value of 96 mW m^{-2} (2.3 HFU) for nearby Iron Mountain.

All the sites above are located in Tertiary age rhyolites and it is possible that the relatively high heat flow is a result of a widespread magmatic event which produced the Tertiary volcanic belt of southwest Utah. The geothermal significance of these results is twofold: (1) the two regions of heat flow greater than 120 mW m^{-2} (2.9 HFU) have been delineated within which the possibility of locating a blind high temperature system is enhanced and (2) a broader area of high heat flow and high geothermal gradients, locally up to 70°C/km, indicates a widespread potential for lower temperature resources.

TOPICAL: Volume 77-12

Electrical Properties of Core Samples

Complex resistivity (amplitude and phase) measurements were made on fifteen core samples from Roosevelt Hot Springs, at frequencies from 10^{-2} to 10^{5} Hz. These samples included altered granite alluvium, altered gneiss, unaltered gneiss as well as two synthetic samples composed of clay and quartz sand grains. The unaltered gneiss samples were sampled on the surface and the core samples came from two thermal gradient holes and represent materials from depths of 70 ft to 226 ft.

At salinities appropriate for the geothermal fluids (.1n) the unaltered material has a resistivity of about 500 Ω-m. The altered materials have resistivities in the range from 5 Ω-m to 50 Ω-m. The lowest resistivity samples have the highest porosities and clay contents. All of the altered material (high clay content) show phase angles in the range of 10 mrad to 100 mrad. The high frequency portion of the dispersion curves, due to the clays, increases from phase angles of 5-10 mrad around 1-10 Hz to 50-100 mrad at 10^5 Hz. Some of the samples containing pyrite (<5%) show an additional dispersion region (maximum phase angles around 10 mrad) at frequencies below 10 Hz.

A simple model for the conductive effects of clays has been developed by Waxman and Smits (1968, 1974). This model is in reasonable agreement with measured clay contents and the electrical measurements. The model indicates that in most of the low resistivity altered material the clay conduction carries 2 to 3 times more current than the pore water. Therefore, the near surface electrical properties are largely dominated by the clay alteration, with only small contributions due to the higher salinities and temperatures.

2.2 FINAL TECHNICAL REPORTS

FINAL: Volume 77-0

[SUMMARY MANAGEMENT DOCUMENT ONLY, NO TECHNICAL INFORMATION OTHER THAN AN MT DATA RELEASE.]

FINAL: Volume 77-1

The Barringer AIRTRACE Airborne Geochemical Exploration System and its Performance in Metal and Geothermal Resource Areas

1. The Barringer Research Ltd. AIRTRACE system uses a novel, complex method to sample coarse airborne particulate matter from a helicopter. The discrete samples obtained are analyzed for 25 major and trace elements. There are many variables introduced by nature and the system. Many of these need careful study.

2. During a test in southwestern Utah, 750 line miles of AIRTRACE survey were flown over known geothermal and base metal occurrences in six areas, with widely different conditions of vegetation, ambient dust, rock outcrop, geology, and cultural pollution. The system performed well under production conditions. Down time and the need to refly lines were minimal.

3. Laboratory analysis of the samples raised several problems and questions. Barringer personnel stated that the particles collected were coarser than usual, requiring development of a system to "crush" them prior to laser volatilization (the first step in the 25 element analysis). Ambient calcium levels were so high as to cause interferences. Fine, wind-blown dust was abundant, and may have decreased the sensitivity of the system in at least some of the areas.

4. Because of these problems, Barringer personnel recommended that analysis cease after preliminary values were calculated for the Rocky Range Copper district and the central one-third of the Mineral Range-Roosevelt Hot Springs thermal area. No further analysis, and no statistical data treatment, has been done.

5. In the Rocky Range Copper district, analysis showed strong copper and zinc anomalies over the old copper-rich tailings ponds at the

southernmost end of the Rocky Range. Smaller anomalies were detected in the vicinity of open pit copper mines and copper mineralization concealed beneath alluvium. Lead anomalies approximately flank the copper anomalies. Parts of this test area are far too contaminated with metal-rich mine wastes to allow a realistic test of the system. But the test did detect hidden mineralization.

Despite the reported adverse conditions, the system did generate a reasonable-appearing geochemical map of the area. No ground samples were analyzed, so only very general comparisons between airborne and ground geochemical patterns can be made. A general, though poor, correspondence between rock type and major elements was evident.

6. Analysis of the central one-third of the samples collected over the encompassing east-west flight lines over the Roosevelt Hot Springs thermal area and the adjacent Mineral Range and Escalante Desert yielded few distinct "anomalies", and apparently random patterns of element distribution. Some indication of non-random system noise (i.e. single data lines showing very high and very low values for one element) was noted. Possible small multi-metal anomalies over at least one geologic feature were noted.

7. During the survey, Barringer personnel conducted local soil sampling, and reported uranium, mercury and arsenic anomalies in coarse (40-80 mesh) surface soil fractions associated with faults and opaline sinter above the geothermal area. Finer fractions reportedly yielded no anomalies. Because of this, Barringer recommended re-flying all of the areas with the AIRTRACE system adjusted to collect coarser particles than were obtained in the initial six flights.

8. The argument that coarse particles will have to be sampled to obtain meaningful results over any of the areas may be fallacious. Particles in the 40-80 mesh range are extremely large, and may not even exist in any abundance in air over the test areas. The geochemistry and size distribution of airborne particulate matter over the other areas remains unknown. To refly these other areas, at a large cost, simply because of lack of results over a part of Roosevelt Hot Springs thermal area, is unrealistic. Each area was selected as having unique characteristics. Most of the other areas apparently contain far less ambient (wind blown) dust.

9. The AIRTRACE system, a new concept in airborne exploration, is technically almost operational. It should never be expected to detect every known geothermal or metal occurrence. If it can detect a significant percentage of them on a cost-effective basis, it is a useful exploration tool. However, serious questions exist as to whether the system can reliably detect geochemical differences over known geologic and concealed economic features. Costs of performing surveys with it are excessive.

FINAL: Volume 77-2

A Summary of the Geology, Geochemistry, and Geophysics of the Roosevelt Hot Springs Thermal Area, Utah

The Roosevelt Hot Springs thermal area is a newly discovered geothermal power prospect in Utah. Seven production wells have been drilled with a maximum per well flow capability averaging 4.5×10^5 kg of combined vapor and liquid per hour at a shut-in bottom hole temperature near 260°C.

The thermal area is located on the western margin of the Mineral Mountains, which consist dominantly of a Tertiary granitic pluton 32 km long by 8 km wide. Rhyolitic tuffs, flows, and domes cover about 25 km^2 of the crest and west side of the Mineral Mountains within 5 km of the thermal area. The rhyolitic volcanism occurred between 0.8 and 0.5 m.y. ago and constitutes a major Pleistocene thermal event believed to be significant to the evaluation of the Roosevelt Hot Springs thermal area. Thermal waters of the (now) dry spring, a seep, and the deep reservoir are dilute (ionic strength 0.1 to 0.2) sodium chloride brines.

Spring deposits consist of siliceous sinter and minor sulfur. Alluvium is cemented by sinter and altered in varying degrees by hot, acid-sulfate water to opal and alunite at the surface, grading successively to alunite-kaolinite, alunite-kaolinite-montmorillonite, and muscovite-pyrite within 60 m of the surface. Observed alteration and water chemistry are consistent with a model in which hot aqueous solutions containing H_2S and sulfate convectively rise along major fractures. Hydrogen sulfide oxidizes to sulfate near the surface decreasing the pH and causes alunite to form. Opal precipitates as the solutions cool. Kaolinite, muscovite, and K-feldspar are formed in sequence, as the thermal water percolates downward and hydrogen ion and sulfate are consumed.

Major swarms of earthquakes occur 30 km to the east-northeast near Cove Fort, Utah, but only minor earthquake activity occurs near the Roosevelt Hot Springs thermal area. Delayed P-wave traveltimes generated from the Cove Fort microearthquakes, and observed west of the northern Mineral Mountains, are suggestive of a low velocity zone beneath the Mineral Mountains; the vertical and lateral resolution of the data is inadequate to delineate the zone. Gravity and magnetic surveys are useful in determining the structure and depth of valley fill of the area of the northern Mineral Mountains, but neither one has detected an igneous intrusive source of heat. Thermal gradient measurements that range up to 960°C/km in 30 to 60 m deep holes outline a 6 by 12 km thermal field. Heat flow and resistivity data both outline anomalous zones along a system of faults that controls the near-surface fluid flow. The source of heat is interpreted to be the convective circulation of thermal water. The lowered resistivity is due to the hot brine and the associated hydrothermal alteration. Magnetotelluric data are highly anomalous over the field but means for their quantitative interpretation are unavailable at present; the anomalous data could as readily be interpreted as due to surface conductors as deep conductors which one might like to associate with a source of heat.

Any current model of the subsurface is highly speculative but can be expected to improve once existing seismic refraction and magnetotelluric data are fully interpreted. Then multiple-data-set modeling, combined with subsurface control from existing wells, should result in a reasonable model of the geothermal system. This modeling will be aided also by hydrologic, isotopic, structural, and additional P-wave delay studies currently in progress.

Based upon this case history, an exploration sequence appropriate to the eastern Basin and Range province should consist of phase 0, a digest and synthesis of available data; phase 1, a regional airphoto accumulation and analysis; phase 2, regional geologic mapping, regional radiometric dating of all intrusive and extrusive rocks, regional isotopic and chemical analysis of waters, regional aeromagnetic and gravity surveys, and regional collection of thermal gradients in available holes; phase 3, heat flow measurements in strategically located holes; phase 4, dipole-dipole resistivity surveys; phase 5, petrological, mineralogical, and geochemical studies on cuttings and cores from heat flow drill holes; phase 6, model test drilling accompanied by petrological, chemical, and isotopic analyses of cuttings and cores plus chemical and isotopic analyses of fluids; phase 7, detailed seismic refraction and reflection surveys; and phase 8; modeling and synthesis of all available data.

FINAL: Volume 77-3

Long-Term Seismic Monitoring of the Roosevelt - Cove Fort KGRA's

Earthquake monitoring of the Roosevelt Hot Springs and Cove Fort-Sulphurdale KGRA's was implemented by the installation of three RF telemetered, vertical component seismograph stations. The signals from the stations were FM-transmitted to a collecting site near Milford where they were telephone-transmitted to the University of Utah campus for recording. The limitations of only three stations precluded accurate hypocenter determinations but allowed detection to a minimum threshold of about M -0.5 for close-in events. Locations were determined for earthquakes of about M 0.7 or greater. Regional earthquake coverage of the south-central Utah KGRA's was supplemented by the use of other existing University of Utah stations to the east. During the period of 1 January 1977 to 30 June 1977 over 70 earthquakes were located in the south-central Utah area. Persistent activity continued throughout the Cove Fort-Sulphurdale KGRA.

Only two earthquakes were located north of Roosevelt Hot Springs during the report period of January 1977 to 30 June 1977. The close proximity of one earthquake to the Roosevelt Hot Springs thermal area suggests that although the seismicity is low, there is sufficient brittle strain release to warrant consideration as a potential area of earthquake inducement.

In conclusion, this period of earthquake locations shows continuing swarm activity near Cove Fort-Sulphurdale KGRA with relatively little activity at the Roosevelt Hot Springs KGRA.

FINAL: Volume 77-4

[DATA RELEASE ONLY]

FINAL: Volume 77-5a

Electromagnetic and Schlumberger resistivity

One- and two-dimensional modeling of the Schlumberger soundings at the Roosevelt Hot Springs thermal area have indicated a low-resistivity zone of approximately 5 Ω-m paralleling the Opal Mound fault. The low resistivity of this zone is probably due to intensely fractured and altered water-saturated rock. A zone of resistivity 12 Ω-m extending to the west of the fault is probably due to leakage of brine away from the geothermal system through alluvium or moderately altered rock. A resistive basement underlies the conductive zones and is believed to be essentially nonporous and unaltered rock.

A major problem in the application of one-dimensional (1-D) modeling of Schlumberger data in the Roosevelt Hot Springs thermal area is poor resolution of the 1-D parameters. The joint inversion of Schlumberger and electromagnetic sounding data gives a least-squares 1-D conductivity model in which parameters are much better resolved than are the model parameters estimated by the inversion of Schlumberger data alone.

One-dimensional modeling of Schlumberger soundings along a traverse does indicate the presence of a 2-D inhomogeneity but it gives no hint of the possible complexity of that inhomogeneity even though the parameters of the models fitting each sounding have acceptable standard deviations when constrained by electromagnetic sounding data. Since the model parameter standard deviations are model dependent, good resolution of 1-D model parameters does not indicate that the assumption of a 1-D model is valid. On the other hand, the possible complexities of structure is brought out by 2-D modeling of the same data, but since the degrees of freedom for complex 2-D models is large, a thorough study of the resolution of such models is prohibitively costly at present. In these circumstances, we must constrain the 2-D models with independent geological or geophysical data and then accept the subsequent best-fit model as semiquantitative.

FINAL: Volume 77-5b

Cost Analysis and Drilling Data Thermal Gradient and Heat Flow Holes, 1976

Ten heat flow holes were drilled in 1976 totaling 2732 feet. Total funds expended, not including University of Utah supervision, nor supplies, chiefly black-iron pipe, were $29,320. Cost per foot for NX-core drilling, on holes was $15.08. Cost per foot for rotary drilling in alluvium was $4.98 per foot.

FINAL: Volume 77-5c

[DATA RELEASE ONLY]

FINAL: Volume 77-5d

Ridge Regression Inversion Applied to Crustal Resistivity Sounding Data from South Africa

Ridge regression inversion has been used to test the applicability of various one-dimensional crustal models to the interpretation of deep Schlumberger sounding data from southern Africa (Van Zijl and Joubert, 1975). Four main models were investigated: a simple three-layered earth, a layered earth with a transition zone exhibiting a linear decrease in log resistivity with depth, a similar earth with the transition zone determined by cubic splines, and a model having exponential resistivity behavior at depth. The last model corresponds to temperature-dependent semiconduction through solid mineral grains (Brace, 1971). It was found that all of these models are capable of fitting the sounding data from south-western Africa, while all except the semiconduction model fit the data from southeastern Africa. One is, thereby, immediately alerted to the problem of lack of resolution in Schlumberger sounding data where geologic control is not available.

A major problem with the inversion of Schlumberger data alone is that accurate information is obtainable only for the resistivity-thickness product of the resistive portion of the crust. On the other hand, magnetotelluric data, when available, tends to provide information on the thickness, but very little information on the true resistivity of a resistive crust. In order to resolve both resistivity and thickness it is possible to invert simultaneously Schlumberger and magnetotelluric (MT) data. Results obtained from the combined inversion of the African resistivity data and hypothetical MT data show that a considerable improvement in model resolution can be achieved using MT amplitude data even of poor accuracy from a relatively limited frequency range (0.1 to 100 Hz), whereas inclusion of MT phase information is of negligible additional benefit.

Unfortunately, no significant test can be made, from data available at the time of our analysis, of the applicability of one-dimensional inversion in a geologic circumstance which probably demands more dimension.

FINAL: Volume 77-6

The Analysis of Sodium and Potassium in Silicate Rocks by a Lithium Metaborate Fusion Method

The lithium tetraborate fusion method for emission spectroscopy and flame photometry analysis of silicates has been modified slightly to produce rapid and precise analyses of sodium and potassium contents in silicate rocks. The analytical method we previously employed yields precise sodium and potassium values in the hands of a skilled analyst. However, the procedure requires considerable manipulation and is time consuming, taking about three days per batch of 6 to 12 samples. The new method makes it possible for a relatively unskilled analyst to analyze a dozen samples in half a day.

FINAL: Volume 77-7

Gravity and Ground Magnetic Surveys in the Monroe and Joseph KGRA's and Surrounding Region, South Central Utah

During the summer of 1977, regional gravity data were collected in portions of the Pavant Range, Tushar Mountains, northern Sevier Plateau, the Antelope Range, and throughout Sevier Valley approximately between the towns of Richfield and Junction, Utah. Additionally, detailed gravity and ground magnetic data were collected in the vicinity of hot springs in both the Monroe and Joseph Known Geothermal Resource Areas (KGRA's).

The regional gravity data were terrain corrected out to a distance of 167 km from the station and 948 gravity station values were compiled into a complete Bouguer gravity anomaly map of the survey area. Major features of this map include: 1) a pronounced regional gravity gradient associated with the Pavant thrust along which dense Paleozoic carbonate rocks structurally emplaced over Mesozoic sedimentary rocks are exposed not far from low-density volcanic rocks of the Marysvale volcanic field; 2) gravity lows over the alluvial-filled grabens of Sevier Valley and Marysvale Valley; 3) strong gravity gradients associated with the Sevier, Elsinore, Dry Wash, and Tushar faults; 4) gravity lows over the Mount Belknap, Red Hills, and Big John calderas; and 5) east-northeast-trending gravity contours in alignment with a belt of Tertiary intrusive rocks and the Wah-Wah-Tushar mineral belt of southern Utah.

Modeling of four regional gravity profiles throughout the survey area indicates that: 1) the Sevier Valley graben has an alluvial-fill about 1300 m in depth and Marysvale Valley graben has an alluvial-fill about 1200 m in depth; 2) the regional gravity gradient in the southern Pavant Range may be largely due to changes in densities of sedimentary rocks across the Cordilleran hingeline, and only partly the result of changes in the depth to the Moho across the Basin and Range-Colorado Plateau transition; and 3) the Mount Belknap caldera gravity low may be due to low-density Tertiary volcanic fill in the caldera surrounded by sedimentary and intrusive rocks. Polynomial residual gravity anomaly maps were helpful in delineating a closed gravity low in the Pavant Range which may be related to a volcanic source area.

A total of 840 ground magnetic stations established along 19 profiles in the Monroe KGRA were compiled into a diurnal-corrected total magnetic intensity anomaly map. Major features of this map include: 1) a magnetic anomaly of about 700 gammas relief across the Red Hill Hot Spring with the magnetic high on the Sevier Valley side of the hot spring; and 2) a linear magnetic low along the Monroe Hot Springs area. These magnetic features are believed to be due to alteration of magnetite in the alluvium by thermal waters rising along the Sevier fault zone. Modeling of gravity and magnetic profiles in the Monroe KGRA shows the faulting to consist of many individual en echelon faults along the Sevier fault zone instead of one large fault.

Detailed gravity and ground magnetic data were also collected along two profiles in the Joseph KGRA. Modeling of gravity and magnetic data along one of these profiles indicates: 1) relatively little throw along the Dry Wash fault, which controls the Joseph Hot Springs; and 2) the existence of a larger fault of about 800 m throw down on the east farther west in the valley near the Sevier River.

FINAL: Volume 77-8

Electrical Energizing of Well Casings

Electrical measurements of several kinds were made at Roosevelt Hot Springs KGRA using the casings of two production wells as electrodes. One purpose of these measurements was to determine if a "mise a la masse" measurement could provide useful information on the fault system which controls the near surface and deeper circulation. A second purpose was to determine if the introduction of the current deep into the conductive part of the system, via the well casing, would provide any additional information about the conductivity at depths below the near surface conductor.

The current excitation was a square wave with an amplitude of 20 amps and a frequency of 0.3 Hz. The current electrodes were the well casings of Phillips Petroleum Company wells numbers 13-10 and 12-35. The depth of the casing in these wells are 522 m (13-10) and 1340 m (12-35). The distance between the wells is about 4 km giving a bipole oriented at N25E°, which is situated over the near surface zone of low resistivity.

The equipotentials are highly distorted from the regular circular shape that would be observed in a homogeneous earth. The equipotentials around the southern electrode roughly parallel the mountain front in the east, except for a pronounced bulge to the southeast into Big Cedar Cove. The flattening of the contours parallel to the mountain front are caused in part by the strong resistivity contrast between the conductive alluvium and the resistive granite of the mountains. The bulge of the contours into Big Cedar Cove could be due to the extension of a conductor into this region or perhaps just a greater thickness of alluvium in the cove.

The potential difference measurements were also used to calculate apparent resistivities. In the vicinity of the electrodes, such apparent resistivities ranged from 10 to 50 ohm-meter, in general agreement with other surface measurements. These apparent resistivities were also used to look for conductive zones where the profiles crossed certain of the faults, without much success.

At distances between 2 and 15 km, potential measurements were made with an orthogonal set of 300 m dipoles. This set up is essentially the same as that used in the roving bipole-dipole scheme, except that vertical line source electrodes were used.

The apparent resistivities calculated from the magnitude of the observed electric field are about what might be anticipated from other resistivity surveys. Values from 10 to 50 ohm-meter are observed to the west in the alluvial valley fill and in the near vicinity of the electrodes which are in the near surface conductive region. The values in the Mineral Range and to east of the range are generally greater than 150 ohm-meter. There is some slight indication that the resistivity may be generally lower towards the northeast from the dipole. Toward the southeast the apparent resistivities generally increase with distance.

FINAL: Volume 77-9

Precision Leveling and Gravity Studies at Roosevelt Hot Springs Thermal Area, Utah

The objective of the precision gravity and precision leveling studies in the Roosevelt Hot Springs thermal area, Utah was to provide a baseline for detecting mass reduction or movement (displacement) related to injection or withdrawal of geofluids or to changes in tectonic strain, or both of these effects. In this project, the University of Utah obtained precision gravity and precision leveling data in the Roosevelt Hot Springs thermal area during the period September 1975 through October 31, 1977, and interpretations of these data were made (Cook and Carter, 1978). The project was conducted with the informal cooperation of the Phillips Petroleum Company, which authorized the inclusion of some of its data in this report, and the U.S. Geological Survey.

Two networks of benchmarks and/or monuments have been established in the Roosevelt Hot Springs thermal area: 1) a network of about 22 monuments by the Phillips Petroleum Company, for which precision leveling was done by Bulloch Bros. Engineering, Inc., in September to December 1975; and 2) a network of about 35 benchmarks, for which precision leveling was done by the USGS in May 1955 and for which precision horizontal control (not yet available) was done by the USGS during August 1976 and July 1977. The USGS precision leveling survey in may 1977 reoccupied only three of the Phillips monuments (E, G, and I), which were found to be about 0.7 to 0.8 feet <u>lower</u> in elevation than the precision leveling survey by Bulloch Bros. Engineering, Inc. in 1975. Because this difference is about the same for all three stations, it appears unreasonable and is attributed to a possible error in leveling along the 8-mile line between the datum and the Roosevelt Hot Springs thermal area.

Throughout the 4-day withdrawal test by the Phillips Petroleum Company in well #54-3 during February 12-16,, 1976, precision gravity readings taken at 1-hr intervals with two gravity meters at monument B (54-3) near the well showed no variation in gravity that could be attributed to mass reduction or ground movement (displacement) related to either withdrawal of geofluids or changes in tectonic strain.

During the period February 1976 to July 1977, four separate precision gravity surveys were conducted by the University of Utah on about 22 Phillips monuments and 8 USGS benchmarks in the Roosevelt Hot Springs thermal area. No changes in gravity at these stations were observed that can be attributed to either mass reduction or ground movement (displacement) associated with the withdrawal of geothermal fluids. An apparent decrease in observed gravity of about 0.106 mgal at station E during a 17-month period is believed unrealistic, and was probably caused by a fortuitous accumulation of errors involving both reading errors and insufficiently precise field techniques. These techniques have now been improved to assure greater accuracy in the future.

The precision gravity surveys made to date indicate that long-term changes in mass and/or elevation effects on the order of 0.1 mgal (corresponding to an elevation change of more than 1 foot) are detectable. Anticipated improvements in procedure, data reduction, and instrumentation should allow detection of smaller gravity changes.

FINAL: Volume 77-10

Quaternary Rhyolite from the Mineral Mountains, Utah, U.S.A.

A suite of silicic volcanic rocks is associated with the Roosevelt Hot Springs thermal area in southwestern Utah. The volcanic sequence includes

Tertiary rhyolite 8 m.y. old and obsidian, ash and rhyolite of Quaternary age.

The Quaternary lavas are characterized by high silica content (76.5% SiO_2) and total alkalies in excess of 9 percent. Obsidians commonly contain greater amounts of fluorine than water. Two older flows (0.8 m.y.) can be distinguished from younger dome and pyroclastic material (approximately 0.5 m.y.) by subtle differences in their chemistry. The mineralogy of the rhyolites consists of alkali feldspar, plagioclase, and small amounts of Fe-Ti oxides, biotite, hornblende and rare allanite. Fe-Ti oxide temperatures are 740-785°C for the flows and 635-665°C for the domes; two feldspar temperatures give similar results.

The phase relationships of bulk rock, glass and feldspar compositions demonstrate that the younger Quaternary rhyolites could have been derived from the earlier magma type, represented by the obsidian flows, by a process of crystal fractionation. The major phases which must fractionate are alkali feldspar, plagioclase and quartz with minor amounts of biotite, magnetite and ilmenite participating also. Trace element patterns support this scheme as well. The Tertiary lavas cannot be related to the Quaternary rhyolites and are thought to represent a separate event.

FINAL: Volume 77-11

Regional Gravity and Aeromagnetic Surveys of the Mineral Mountains and Vicinity, Millard and Beaver Counties, Utah

The results of gravity and aeromagnetic surveys of the Mineral Mountains and vicinity are presented as a terrain-corrected Bouguer gravity anomaly map (about 1450 stations with 1-mgal contour interval) and a total magnetic field intensity residual anomaly map (with contour interval 50 gammas), respectively. Combined interpretation of the gravity and aeromagnetic data was conducted based on comparing and contrasting various processed maps and interpretative geologic cross sections produced from each survey. Processing and modeling techniques which were used to facilitate the interpretation include:

1) Gravity -- a) a high-pass frequency filtering, b) polynomial fitting, c) pseudomagnetic filtering, d) strike filtering, e) upward continuation filtering, and f) two and one-half dimensional profile modeling.

2) Aeromagnetics -- a) low-pass frequency filtering, b) polynomial fitting, c) pseudogravity filtering, d) strike filtering, and e) two and one-half dimensional profile modeling.

Broad structural features apparent from the interpretation include: 1) Basin and Range normal faults which strike generally north-south and lie along the eastern and western margins of the Mineral Mountains; 2) the grabens of Milford and Beaver valleys which border the Mineral Mountains horst on the west and east, respectively; and 3) an east-northeastward-trending lineation which corresponds with the Black Rock offset and passes through the County line fault in the northern Mineral Mountains. This lineation probably corresponds to a major structural feature along which intrusive bodies have been emplaced. Modeling of the reduced gravity data using an assumed density contrast of 0.5 g/cc between the bedrock and valley fill resulted in a depth of alluvial fill of about 1.5 km at the deepest point in Milford Valley graben.

Quaternary rhyolite domes and flows are exposed along the crest of the Mineral Mountains. These volcanics are thought to be related to the heat source for the geothermal reservoir at Roosevelt Hot Springs thermal area. Roughly corresponding magnetic and gravity lows overlie the exposed volcanic domes which include Bearskin, Little Bearskin and North and South Twin Flat Mountains. These lows may be caused by a magma chamber at rather shallow depth, but are more likely caused by the lower density and magnetic susceptibility of the rhyolite. A gravity saddle in the area of Ranch Canyon and a roughly corresponding magnetic susceptibility body, but modeling has indicated that the gravity saddle may be caused by overlap of the gravity lows associated with Milford Valley and Beaver Valley grabens and the silicic volcanics. Removal of a different regional gravity could, however, alter this conclusion.

Over the known geothermal reservoir, possible expressions of hydrothermal magnetite alteration (a magnetic low area) and sediment densification (a gravity high area) have been observed. A north-south-trending magnetic high, which overlies alluvium, corresponds with the Opal Mound fault, which marks the westward extent of the reservoir. A pronounced magnetic low, which may represent a sedimentary or metamorphic rock unit, is located just south of the high thermal gradient anomaly area and corresponds with the southern boundary of the resevoir.

FINAL: Volume 77-13

Fluid Dynamic Properties of Rhyolitic Magmas, Mineral Mountains, Utah

Rhyolites from southwestern Utah display striking dissimilarities in morphology which are attributed to viscosity differences due to variations in water content. Temperature effects and fluorine concentrations are unable to account for the observed differences in morphology. Fluid dynamic calculations indicate that rhyolite flows of fluid aspect contained between 1 and 3 percent water upon eruption. More viscous domes contained less water which was expelled in pyroclastic eruptions preceding emplacement of the domal rhyolite magma.

Calculations that determine the physical properties of rhyolite magmas in the Mineral Mountains have been made. Data are presented on density, molar volume, heat capacity, gram formula mass, dynamic viscosity, thermal conductivity, thermal diffusivity, kinematic viscosity, and coefficient of thermal expansion.

FINAL: Volume 77-14

(ESL REPORT IDO/77.3.2)

Geochemistry of Solid Materials From Two U.S. Geothermal Systems and its Application to Exploration

This paper describes initial development of geochemical techniques for exploration and exploitation of geothermal systems. The techniques are based on analysis of solid materials. Distribution of Cu, Mo, Pb, Zn, Ag, As, Sb, Co, Ni, Mn, Fe, Bi, B, Te, In, Sn, and W are determined and evaluated for several sample types in a hot water system (Roosevelt Hot Springs thermal area, Utah) and a vapor dominated system (Geysers, California). The sample types analyzed are magnetic fractions, whole rock samples, and two different heavy liquid separates derived from cuttings composites from geothermal wells and shallow rotary drill holes. The results show that multi-element geochemical zoning is developed at both a relatively small scale of over hundreds of feet around individual steam entries (Se's) and hot water entries (HWE's) in geothermal wells, and at a larger scale of over thousands of feet both vertically and laterally in geothermal systems. Zoning is surprisingly similar for both hot-water and vapor-dominated systems. Trace elements which display the most consistent and useful zoning characteristics are As, Sb, Pb, Zn, Mn, B and W. Optimum delineation of the zoning is provided by +3.3 heavy liquid (HL) samples compared to the other sample types evaluated. Utilization of +3.3 samples maximizes detection of hydrothermal trace elements and markedly reduces or eliminates chemical signatures specifically related to rock type.

In small-scale zoning around HWE's and SE's, As, Sb, B(?), and W(?) are concentrated at or very close to the entries and Pb and Mn are concentrated between entries or for Pb at least, near cold water entries (CWEs). Pyrite abundance is generally greatest at or near HWE's and SE's and has a roughly antithetical relationship to overall magnetite distribution. Much Fe in the pyrite has probably been derived from magnetite which presumably is mainly non-hydrothermal in origin.

Large scale zoning, both vertical and lateral, is apparently characterized by As, Sb, B(?), and W(?) concentration in zones closest to the thermal anomaly and Zn, Mn(?), and Mo(?) concentration in peripheral zones. Pb is more closely associated with As near the thermal anomaly, but may occupy an intermediate zone close to and possibly overlapping the periphery of the high As zone. Comparison of large-scale lateral zoning results for Roosevelt Hot Springs thermal area with thermal gradient data shows a good correlation of high As anomalies with high thermal gradients (>100°C/km) and of high Zn anomalies with lower thermal gradients (<100°C/km).

Several important applications of these geochemical results to problems of exploration and exploitation of geothermal systems could be attempted during the FY 1978 and 1979 period. These include use for

1) location of steam or hot water entries in newly drilled geothermal wells,
2) definition of general and possibly specific drilling targets, and
3) prediction of approach to steam or hot water entries especially in order to facilitate decisions on additional drilling in sub-commercial wells as planned total depth is approached. Such applications could significantly contribute to power on stream in 1985 and to cost effectiveness in achieving this goal.

A considerable amount of additional work is required to optimize methods, corroborate results, and make some of these applications routine. Information to be obtained on depositional processes to aid understanding of the geochemical results should be of significant value in dealing with reservoir engineering problems. Work of this description could be expanded to deal specifically with such problems.

FINAL: Volume 77-15

(ESL REPORT IDO/77.3.1)

Three Dimensional Magnetotelluric Modeling

We have refined a three-dimensional (3D) volume integral equation solution, and have adapted it to magnetotelluric (MT) modeling. The refinement, incorporating an integro-difference scheme, increases the accuracy somewhat without increasing the computer time. Utilizing the two symmetry planes for a plane wave source decreases the computer storage by a factor of 8 and greatly reduces the computer time.

Convergence checks and comparisons with other solutions show that our results are valid. Because of space charges at resistivity boundaries, low-frequency 3D responses are much different from 1D and 2D responses. Hence 3D models are required for interpreting MT data in the complex geothermal environment.

FINAL: ESL REPORT NO. IDO/77.5.6

Dipole-Dipole Resistivity Survey of a Portion of the
Coso Hot Springs KGRA, Inyo County, California

A detailed electrical resistivity survey of 54 line-km was completed at the Coso Hot Springs KGRA in September 1977. This survey has defined a bedrock resistivity low at least 4 sq mi (10 sq km) in extent associated with the geothermal system at Coso. The boundaries of this low are generally well defined to the north and west but not as well to the south where an approximate southern limit has been determined. The bedrock resistivity low merges with an observed resistivity low over gravel fill east of Coso Hot Springs.

A complex horizontal and vertical resistivity structure of the surveyed area has been defined which precludes the use of layered-earth or two-dimensional interpretative models for much of the surveyed area. In general the survey data indicate that a 10 to 20 ohm-meter zone extends from near surface to a depth greater than 750 meters within the geothermal system. This zone is bordered on the north and west by bedrock resistivities greater than 200 ohm-meters and to the south by bedrock resistivities greater than 50 ohm-meters. A combination of observed increases in: 1) fracture density (higher permeability), 2) alteration (high clay content), and 3) temperature (higher ion activity of salts of ground water) within the bedrock low explain its presence.

FINAL: ESL REPORT NO. IDO/77.5.7

Low-Altitude Aeromagnetic Survey of a Portion of the Coso Hot Springs KGRA, Inyo County, California

A detailed low-altitude aeromagnetic survey of 576 line-mi (927 line-km) was completed over a portion of the Coso Hot Springs KGRA in September 1977. The survey has defined a pronounced magnetic low that could help delineate the geothermal system. The magnetic low has an areal extent of approximately 10 sq mi (26 sq km). Direct and indirect evidence indicates that this anomaly is due, in part, to magnetite destruction by hydrothermal solutions associated with the geothermal system. The anomaly generally coincides with two other geophysical anomalies which are directly associated with the system: 1) a bedrock electrical resistivity low, and 2) an area of relatively high near-surface temperatures. The highest measured heat flow, 18 HFU, also occurs within its boundary.

The magnetic low occurs at the intersection of two major structural zones which coincide with a complementary set of strike-slip fault zones determined from seismic activity. The intersection of these two zones of active tectonism probably served as the locus for emplacement of a pluton at depth, above which are observed the coincidental geophysical anomalies and surface manifestations related to the geothermal system.

2.3 Management Task Reports

ESL REPORT NO. 77-1

Geothermal Reservoir Assessment Case Study, Utah (CSU)

The purpose of this report is to list the tasks which comprise the program of the above title. The tasks below were agreed upon with DOE.

Task 1. Phase Zero Study - to define objectives, tasks and milestones of this project and to assign priorities.

Task 2. Establish Internal Management Scheme.

Task 3. Establish Information Documentation Scheme.

Task 4. Assemble Background Technical Information and Worldwide Case History Reference Base.

Task 5. Establish Core and Cuttings Sample Library.

Task 6. Convert Information Control to In-House Computer Retrieval Format.

Task 7. Develop Standard Interpretation Procedures.

Task 8. Effect Standard Interpretation Procedures.

Task 9. Write and Distribute Case Histories.

Task 10. Provide Advisory Services.

Task 11. Gravity and Magnetic Data.

ESL REPORT NO. 77-2

Retrospective Case Studies

The purpose of this report is to list the tasks which comprise the program of the above title. The tasks below were agreed upon with DOE.

<u>Task 1.</u> Phase Zero Study - to define objectives, tasks and milestones of this project and to assign priorities.

<u>Task 2.</u> Establish Internal Management Scheme.

<u>Task 3.</u> Establish Information Documentation Scheme.

<u>Task 4.</u> Assemble Background Technical Information and Worldwide Case History Reference Base.

<u>Task 5.</u> Establish Core and Cuttings Sample Library.

<u>Task 6.</u> Convert Information Control to In-House Computer Retrieval Format.

<u>Task 7.</u> Develop Standard Interpretation Procedures.

<u>Task 8.</u> Develop and Pursue Strategies for Obtaining Data from Industry.

<u>Task 9.</u> Effect Standard Interpretation Procedures.

<u>Task 10.</u> Write and Distribute Case Histories.

ESL REPORT NO. 77-3

State-Coupled Direct Heat Program, Western States

The purpose of this report is to list the tasks which will comprise the program of the above title. The tasks below were agreed upon with DOE.

<u>Task 1.</u> Phase Zero Study - to define objectives, tasks and milestones of this project and to assign priorities.

<u>Task 2.</u> Establish Internal Management Scheme.

<u>Task 3.</u> Establish Information Documentation Scheme.

<u>Task 4.</u> Assemble Background Technical Information and Worldwide Case History Reference Base.

<u>Task 5.</u> Establish Core and Cuttings Sample Library.

<u>Task 6.</u> Convert Information Control to In-House Computer Retrieval Format.

<u>Task 7.</u> Aid DGE in Establishing Cooperative State Programs.

<u>Task 8.</u> Provide Consulting Expertise to Cooperative State Programs.

<u>Task 9.</u> Provide Advice to Developers of Low Temperature Geothermal Resources.

<u>Task 10.</u> Write and Distribute Reports.

3.0 HIGHLIGHTS

3.1 Topical Reports

TOPICAL: Volume 76-1

Dipole-Dipole Resistivity Delineation of the Near Surface Zone at the Roosevelt Hot Springs Thermal Area

The dipole-dipole resistivity method is useful in mapping shallow (<500m) hydrothermal alteration and fractures in a convective hydrothermal system. It can also detect leakage of brine from such a system.

TOPICAL: Volume 76-2

A Thermodynamic Model of the Hydrolysis of Microcline in Acid Sulfate Solutions

Theoretical modeling of the hydrothermal alteration zoning at Roosevelt Hot Springs thermal area, Utah, leads to the conclusion that this zoning is a function of temperature and pH gradients within homogeneous host rocks where microcline and quartz are abundant.

TOPICAL: Volume 76-3

Magnetotelluric Survey and Resistivity Maps, Roosevelt Hot Springs Thermal Area, Utah

The first MT data for Roosevelt Hot Springs thermal area was placed in the public domain by this data release. Some unexplained exceptionally low values of resistivity were observed.

TOPICAL: Volume 77-1

Attempt at Paleomagnetic Dating of Opal, Roosevelt Hot Springs Thermal Area

Paleomagnetic dating of the opal and siliceous sinter at Roosevelt Hot Springs thermal area has established that the main depositional activity at the area took place between 12,000 and 350,000 years ago.

TOPICAL: Volume 77-2

Geothermal Exploration Architecture

Several different strategies to be used in exploration for convective hydrothermal systems are described and costs for them computed.

TOPICAL: Volume 77-3

Thermal Gradients and Heat Flow at Roosevelt Hot Springs Thermal Area

Heat flow, as opposed to thermal gradients, can best delineate the near-surface thermal regime at Roosevelt Hot Springs thermal area. Heat flow and resistivity, when combined, can provide the best geophysical targets for drilling.

TOPICAL: Volume 77-4

Gravity Survey of the Cove Fort-Sulphurdale KGRA and the North Mineral Mountains Area, Millard and Beaver Counties, Utah

The principal occurrences of hydrothermal alteration, hot spring deposits, and flowing hot springs and hot-water wells in the Cove Fort-Sulphurdale and north Mineral Mountains area apparently coincide with the inferred intersections of: 1) east-west, and 2) north-south and/or north-northeastward trending fault zones. These occurrences include Sulphurdale Hot Springs, Sulphur Cove, and the Dog Valley area.

TOPICAL: Volume 77-5

Hydrothermal Alteration at Roosevelt Hot Springs
Thermal Area - DDH 1976-1

Major near-surface hydrothermal alteration zones at the Roosevelt Hot Springs thermal area include a 30 foot advanced argillic zone overlying a 75 foot argillic zone which in turn overlies a 95 foot propylitic zone. Upward moving thermal waters supersaturated with quartz and downward moving meteoric waters undersaturated with quartz both appear necessary to produce the observed alteration zones which are responsible for low electrical resistivities observed in the area.

TOPICAL: Volume 77-6

Gravity and Ground Magnetic Surveys of the Thermo Hot Springs KGRA
Region Beaver County, Utah

Detailed gravity surveying of the Thermo Hot Springs KGRA and vicinity indicates two possible east-west trending faults intersecting a major north-south trending fault in the immediate vicinity of Thermo Hot Springs. The locations of the springs appears to be controlled by faults.

TOPICAL: Volume 77-7

Geologic Map of the Central and Northern Mineral Mountains, Utah

The geologic map of the Mineral Mountains includes areas mapped by various researchers at the University of Utah. Map units include Precambrian basement, Paleozoic sediments, Tertiary intrusive stocks and dikes, Tertiary volcanics, Quaternary acid volcanics and Quaternary hot spring deposits and alluvium.

Significant features displayed by the map relating to the geothermal potential of the area include an East-West, North-South fault system which may be a significant structural control for the hot water system. Mapping has also shown the presence of significant amounts of Quaternary rhyolite flows and domes, active from 0.8 to 0.5 m.y. B.P. This igneous episode probably represents the eruption of magma from a chamber that may be the source of heat for the geothermal area.

TOPICAL: Volume 77-8

Geophysical Study of the Monroe-Red Hill Geothermal System

Resistivity, gravity, and magnetic surveys were interpreted to map the Sevier Fault; both the resistivity and magnetic surveys mapped hydrothermal alteration associated with hot fluids convecting up the Fault. Eleven shallow boreholes confirmed and constrained the geophysical interpretation and permitted heat flow measurements of 550 mWm^{-2} to over 3000 mWm^{-2}, a significant enhancement over background Basin and Range heat flow of 80mWm^{-2}. A target worthy of exploration as a source of direct heat has been delineated.

TOPICAL: Volume 77-9

Mineral Mountains Magmatism: Chemical and Thermal Evolution

Detailed analyses of rhyolites from the Roosevelt Hot Springs Thermal Area for 46 elements demonstrate that the initial eruption of two flows 800,000 years ago were from the same magma batch. Subsequent eruptions over the next 300,000 years produced lavas which exhibit a systematic evolution in their chemical composition which is consistent with the derivation of the younger lavas from the original magma source. The chemical patterns observed, such as depletion in the light rare earths and enrichment in the heavy rare earths, are virtually identical to those observed in the eruption products of Long Valley Caldera, California, and the Jemez Mountains, New Mexico.

If the volcanic activity is derived from a single magma source, the magma body must have been extremely large, or more likely, it was resupplied with heat periodically which sustained the molten mass for a period of at least 300,000 years.

TOPICAL: Volume 77-10

Isotopic Studies, Roosevelt Hot Springs Thermal Area, Utah

The Mineral Mountains are a logical recharge area for the geothermal system of the Roosevelt Hot Springs thermal area. The system exhibits rapid circulation rates and high permeability if the isotopic data is accepted.

TOPICAL: Volume 77-11

Escalante Desert Heat Flow

New heat flow results at ten sites surrounding the Escalante Desert greatly assists the regional geothermal resource assessment in southern Utah. Heat flow values are higher than normal Basin and Range values with two areas considered to have enhanced geothermal potential.

TOPICAL: Volume 77-12

Electrical Properties of Core Samples

Conduction of electricity along the surface of clay minerals carries 2 to 3 times more current than conduction through the pore water for rocks from the Roosevelt Hot Springs thermal area. Therefore, the near-surface electrical properties are largely dominated by the clay alteration, with only small contributions due to the higher salinities and temperatures.

3.2 Final Technical Reports

FINAL: Volume 77-1

An Evaluation of AIRTRACE in the Geothermal Environment

The probability of successfully delineating geothermal reservoirs by AIRTRACE was accepted to be a long shot from the outset. however, the predicted low cost of exploration using the method warranted a test of it. When the costs and uncetainties of AIRTRACE in practice turned out to be excessive, further testing of it was cancelled.

FINAL: Volume 77-2

A Summary of the Geology, Geochemistry, and Geophysics of the Roosevelt Hot Springs Thermal Area, Utah

A summary documentation of the geology, geochemistry, and geophysics of the Roosevelt Hot Springs thermal area, Utah, as of December, 1978, has been provided. Despite the amount of work carried out at the site, any model of the subsurface is highly conjectural. Work in progress is expected to aid materially in developing conceptual models.

FINAL: Volume 77-3

Long-Term Seismic Monitoring of the Roosevelt - Cove Fort KGRA's

Microearthquake swarm activity is common at Cove Fort-Sulphurdale, but is uncommon at Roosevelt Hot Springs thermal area.

FINAL: Volume 77-5a

Electromagnetic and Schlumberger Resistivity

One-dimensional interpretation of electromagnetic or Schlumberger survey data in the typically complex convective hydrothermal setting should be replaced by two- and three-dimensional modeling.

FINAL: Volume 77-5b

Cost Analysis and Drilling Data Thermal Gradient and Heat Flow Holes, 1976

Costs for drilling 100 m thermal gradient holes range from $5.00 per foot for rotary drilling in alluvium to $15.00 per foot for NX-core drilling in Tertiary granite.

FINAL: Volume 77-5d

Ridge Regression Inversion Applied to Crystal Resistivity Sounding Data from South Africa

It has been demonstrated that joint inversion of MT and Schlumberger resistivity data yields earth models of lower parameter uncertainty than inversion of either data set separately.

FINAL: Volume 77-6

The Analysis of Sodium and Potassium in Silicate Rocks by a Lithium Metaborate Fusion Method

The lithium metaborate fusion technique for alkali analyses in rocks and minerals produces rapid and precise analyses both for potassium argon dating and for general whole rock chemical analyses.

FINAL: Volume 77-7

Gravity and Ground Magnetic Surveys in the Monroe and Joseph KGRA's and Surrounding Region, South Central Utah

The results of this work have provided valuable information regarding large-scale faults throughout the survey area and particularly about faults which control hot springs in the Monroe and Joseph KGRA's. Such information should be of significant help in properly locating future test or production drill holes designed to tap the geothermal energy resources of this region.

FINAL: Volume 77-8

Electrical Energizing of Well Casings

The mise-a-la-masse method, as employed at Roosevelt Hot Springs thermal area, did not aid in delineating fractures nor did it detect a hypothesized highly conductive heat source at depth. The experiment, however, was not optimally designed due to logistical constraints.

FINAL: Volume 77-9

Precision Leveling and Gravity Studies at Roosevelt Hot Springs Thermal Area, Utah

A network of benchmarks and monuments has been established in the Roosevelt Hot Springs thermal area, and precision leveling data and precision gravity data have been taken to provide an initial baseline to detect mass reduction or changes in ground movement (displacement) related to the withdrawal of geothermal fluid. However, insofar as the precision gravity data are concerned, the baseline is considered to be inadequate until concrete monuments adjacent to the 30 new USGS benchmarks have been erected and precision gravity measurements taken at these monuments.

FINAL: Volume 77-10

Quaternary Rhyolite from the Mineral Mountains, Utah, U.S.A.

Although volcanic activity in the Mineral Mountain area extends as far back as 20 million years; activity in the Roosevelt Hot Springs thermal area is confined to the last 800,000 years. The rhyolite erupted during the period of 0.8 to 0.5 million years ago are chemically similar to Quaternary rhyolites of other geothermal areas in the western U.S. such as the Valles Caldera, Long Valley, Coso Mountains, and Yellowstone National Park.

Chemical and mineralogical evidence demonstrate that the youngest rhyolites were erupted from the same magma batch. That magma may have been derived from the earlier magma through a complex process of differentiation over a period of 300,000 years.

FINAL: Volume 77-11

Regional Gravity and Aeromagnetic Surveys of the Mineral Mountains and Vicinity, Millard and Beaver Counties, Utah

Gravity data at Roosevelt Hot Springs thermal area suggests normal range-front faulting west of the Opal Mound Fault. The depth of alluvium in Milford Valley is indicated to be 1400 m. No low-density rock, indicative of a high-temperature source rock, has yet been found. Aeromagnetic data is particularly useful for mapping magnetic phases within the Tertiary granite, for inferring the presence of Precambrian gneisses and schists beneath deep alluvium of the Milford Valley, and in mapping east-west faults.

FINAL: Volume 77-12

[DATA RELEASE ONLY]

FINAL: Volume 77-13

Fluid Dynamic Properties of Rhyolitic Magmas, Mineral Mountains, Utah

The morphological differences in rhyolite occurrences in the Roosevelt Hot Springs thermal area are due to differing water contents of the magmas at the time of extrusion. The more viscous dome lavas contained less water than the flow magmas. Water was lost from the magmas through pyroclastic eruptions which preceded eruption of the dome magmas. Water contents of the pre-eruptive magmas could have been in excess of 4 weight percent; however, water saturation of the magmas would be reached only within one or two kilometers from the earth's surface.

FINAL: Volume 77-14

ESL No. 77.3.2

Geochemistry of Solid Materials From Two U.S. Geothermal Systems and its Application to Exploration

Small-scale zoning was found around hot water entries (HWE's) and steam entries (SE's) in drill holes for As, Sb, B(?), and W(?) which are concentrated at or very close to the entries, and Pb and Mn, which are concentrated between entries. Large scale zoning, both vertical and lateral, is apparently characterized by As, Sb, B(?), and W(?) concentration in zones closest to the thermal anomaly and Zn, Mn(?), and MO(?) concentration in peripheral zones. Pb is more closely associated with As near the thermal anomaly, but may occupy an intermediate zone close to and possibly overlapping the periphery of the high As zone.

FINAL: Volume 77-15

(ESL No. IDO/77.3.1)

Three Dimensional Magnetotelluric Modeling

We have shown that three-dimensional (3D) models are required for interpreting MT data in the complex goethermal environment. One- and two-dimensional interpretations can be highly misleading. The three-dimensional integral equation solution developed will lend new insight to MT interpretation.

FINAL: ESL REPORT NO. IDO/77.5.6

Dipole-Dipole Resistivity Survey of a Portion of the
Coso Hot Springs KGRA, Inyo County, California

A 10 to 20 ohm-meter zone extends from near surface to a depth greater than 750 meters within the geothermal system. This zone is bordered to the north and west by bedrock resistivities greater than 200 ohm-meters and to the south by bedrock resistivities greater than 50 ohm-meters. The resistivity low is believed to be caused by 1) increased fracturing, 2) presence of hydrothermal alteration minerals, and 3) higher temperatures within the geothermal system.

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Low-Altitude Aeromagnetic Survey of a Portion of the

Coso Hot Springs KGRA, Inyo County, California

A magnetic low which has an areal extent of approximately 26 sq.km. occurs over the area of the known geothermal system. The boundaries of this magnetic low correlate with boundaries of an electrical resistivity low and of a high in measured shallow temperatures. At least part of the magnetic low is probably caused by alteration of magnetite to pyrite within the geothermal system.

4.0 Published Papers

The following manuscripts acknowledging the subject contract as a source of financial assistance appeared in the refereed literature.

1. "From the Heat of the Earth," by Stanley H. Ward, 40th Ann. Frederick William Reynolds Lecture, Univ. of Utah Press, March 1977, 25 p.

2. "A Summary of the Geology, Geochemistry, and Geophysics of the Roosevelt Hot Springs Thermal Area, Utah," by S. H. Ward, W. T. Parry, W. P. Nash, W. R. Sill, K. L. Cook, R. B. Smith, D. S. Chapman, F. H. Brown, J. A. Whelan, and J. R. Bowman, Geophysics, v. 43, no. 7, December 1978, p. 1515-1542.

3. "Electromagnetic and Schlumberger resistivity sounding in the Roosevelt Hot Springs KGRA," by A. C. Tripp, S. H. Ward, W. R. Sill, C. M. Swift, Jr., and W. R. Petrick, Geophysics, v. 43, no. 7, December 1978, p. 1450-1464.

4. "Ridge Regression Inversion Applied to Crustal Resistivity Sounding Data from South Africa," by W. R. Petrick, W. H. Pelton, and S. H. Ward, Geophysics, v. 42, no. 5, August 1977, p. 945-1005.

5. "Pleistocene Rhyolite of the Mineral Mountains, Utah - Geothermal and Archeological Significance," by P. W. Lipman, P. D. Rowley, H. H. Mehnert, S. H. Evans, Jr., W. P. Nash, F. H. Brown, G. A. Izett, C. W. Naeser, and I. Friedman, Jour. Research U.S.G.S., v. 6, no. 1, Jan.-Feb. 1978, p. 133-147.