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FINAL REPORT

SUPPLEMENT TO THE TECHNICAL ASSESSMENT OF
GEOSCIENCE-RELATED RESEARCH FOR GEOTHERMAL
ENERGY TECHNOLOGY

SEPTEMBER 1983

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Introduction

The information contained in this report is a supplement to a report entitled "Technical Assessment of Geoscience-Related Research For Geothermal Energy Technology" (September 1983) which has been published by the U.S. Department of Energy. This supplement has been published under separate cover due to its large size. The purpose of that study was to identify and prioritize geoscience-related research needed to permit and promote the expanded development of geothermal energy resources in the United States. In addition, potential performers to conduct the research were identified and estimates made of the level-of-effort required to undertake the research. This was accomplished through the formation of a special panel of recognized technical experts with long-standing experience in geoscience-oriented research and/or geothermal energy exploration/development.

In order to supplement the expertise of the panel, information on recently-completed and on-going relevant research sponsored or conducted by the Federal Government and other parties was collected and documented. This report is the culmination of that effort.

Section I of this supplement presents detailed information (e.g., project title, sponsoring organization, research area, objective status, etc.) for 338 geoscience/geothermal related projects.⁽¹⁾ Table 1-1 presents a summary of the projects conducted by sponsoring organization and provides an easy reference to obtain

¹The project reference number appears at the bottom-center of the page.

detailed information on the number and type of efforts being sponsored.

Table 1-2 summarizes the projects by research area (e.g., volcanology, fluid inclusions, etc.) and also provides an additional project cross-reference mechanism.

Subsequent to the collection of the project information, a geosciences classification system was developed to categorize each project by research area (e.g., isotope geochemistry, heat flow studies) and by type of research conducted (e.g., theoretical research, modeling/simulation). Section 2 of this supplement contains a series of matrices (Table 2-1) that summarize, on a project-by-project basis, the research area addressed and the type of R&D conducted. In addition, Table 2-2 presents a summary of the total number of projects by research area and R&D type.

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Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Hawaiian Magma Reservoirs

Sponsoring Organization: USGS

Research Area(s):

Volcanology

Heat Flow Studies

Physical Properties Rocks/Liquids

Contract/Grant Number: NA

Type of Research Activities:

Performing Organization:

Field Research

Modeling/Simulation

USGS

Principal Investigators:

Robert W. Decker

Objective:

To determine the surface and subsurface characteristics of areas of magma occurrence. To establish the in situ physical properties of magma and its host rocks. To determine the heat transfer budget and mechanisms between magma bodies and adjacent groundwater systems. To determine other significant parameters of magma bodies to aid in the exploration for geothermal energy resources by collecting and synthesizing a variety of geologic, seismic, geoelectric, geophysical and geochemical data.

Information/Status:

This is a long-term ongoing project that is part of the research program at the Hawaiian Volcano Observatory. Several topical papers concerning magma-related electro-magnetic sounding surveys on Kilauea, fumarole inventory of Hawaiian volcanoes, and volatile budget on Hawaiian volcanoes are published or in press.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Volcanic Evolution of the Crater Lake Region

Sponsoring Organization: USGS

Research Area(s):

Volcanology
Geochronology/Stratigraphy

Contract/Grant Number: NA

Type of Research Activities:

Field Research
Modeling/Simulation

Performing Organization:

USGS

Principal Investigators:

Charles R. Bacon

Objective:

To study the geology and petrology of Mt. Mazama and the Crater Lake area of Oregon, with emphasis on developing an understanding of processes that lead to the emplacement of shallow silicic magma bodies. To document the chronology of eruption, chemical variation of eruptive products, and tectonic deformation through detailed geologic mapping supported by ^{14}C and potassium-argon dating, paleomagnetic studies, and chemical analyses. To develop a model of volcanic and tectonic evolution of the Crater Lake area that may be used to recognize similar volcanic systems that possess shallow silicic magma reservoirs but have not progressed to the climactic stage of eruption exemplified by Mt. Mazama. To examine relations among silicic magma bodies, high-temperature geothermal systems, and processes of ore deposition.

Information/Status:

Detailed geologic mapping of the walls of Crater Lake caldera and extensive sampling of eruptive products have provided evidence for a new interpretation of events immediately prior to and during the climactic eruption of Mt. Mazama. Many deposits previously thought to be of glacial origin are now recognized as the products of pyroclastic flows. As a result of this first phase of work the volcanic stratigraphy of much of Mt. Mazama has been established. Hydrothermally-altered volcanic rocks exposed in the caldera walls provide evidence of a fossil geothermal system that may have overlain the shallow silicic magma chamber that fed the climactic eruption. Related studies by C.H. Nelson and D.L. Williams have revealed the presence of as much as 100 m of sediment and the probable emission of geothermal fluids on the floor of the lake.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Geology of Long Valley-Mono Basin Geothermal Area

Sponsoring Organization: USGS

Research Area(s):

Volcanology
Petrology
Structural Geology

Contract/Grant Number: NA

Type of Research Activities:

Performing Organization:

Field Research
Laboratory Research-Analytical

USGS

Principal Investigators:

Roy A. Bailey

Objective:

To provide, primarily by means of detailed geologic mapping and petrochemical studies, basic volcanologic petrologic, and structural information needed to understand the physical, chemical, and thermal evolution of the magma chambers and geothermal systems associated with Long Valley Caldera and the Mono Craters ring-fracture system of California.

Information/Status:

Since initiation of the project in 1972, a preliminary paper on the geology of Long Valley Caldera has been published, and two open-file maps, one of the Casa Diablo geothermal area (scale 1:20,000) and another of Long Valley caldera (scale 1:62,500), have been made available. Both maps were prepared for publication in full color. A third map of the entire Long Valley - Mono Basin Known Geothermal Resource Area (scale 1:125,000) is planned. Petrologic (microprobe and major - and trace-element) studies are in progress on several volcanic rock groups associated with the caldera: 1) precaldern basalts and quartz latites; 2) rhyolites of Glass Mountain; 3) postcaldern rhyolites; 4) postcaldern basalts and quartz latites; and 5) the rhyolites of the Inyo-Mono craters. Separate petrologic reports on each group are planned. A more general, comprehensive report on the volcanism, structure, and general petrology of the Long Valley Caldera is in preparation.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Petrology of the Yellowstone Plateau Volcanic Field

Sponsoring Organization: USGS

Research Area(s):

Petrology
Isotope Geochemistry

Contract/Grant Number: NA

Type of Research Activities:

Performing Organization:

Laboratory Research-Analytical

USGS

Principal Investigators:

Robert L. Christiansen

Objective:

To study in detail the mineralogy, geochemistry, and petrology of the voluminous rhyolite-basalt association of the Yellowstone Plateau and Island Park region in order to interpret origin and evolution of the magmas and their relation to regional evolution of the crust and upper mantle, possible future volcanism, and existing high-temperature hydrothermal systems. To study aspects of the petrology of other voluminous silicic volcanic systems for comparative analysis and to do experimental studies of differentiation mechanisms in silicic magmas.

Information/Status:

A large suite of samples has been collected that represents most recognized emplacement units of the Yellowstone Plateau volcanic field. Systematic major- and trace-element and isotopic analyses have been started for most of the rhyolitic units, and a first data set has been nearly completed for the voluminous rhyolitic ash-flow tuffs of the field. Detailed electron-microprobe analyses have been started on minerals and glasses for many of these same units. At this point, only reconnaissance studies have been done on the basalts. Field and petrologic studies of the Bishop Tuff of eastern California and of the Katmai-Valley of Ten Thousand Smokes system in Alaska have also been completed as parts of the comparative study.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Volcanology and Petrology of the Mount Shasta Region

Sponsoring Organization: USGS

Research Area(s):

Volcanology
Petrology
Minerology/Alterations

Contract/Grant Number: NA

Type of Research Activities:**Performing Organization:**

USGS

Field Research
Laboratory Research-Analytical
Modeling/Simulation

Principal Investigators:Robert L. Christiansen

Objective:

To study the volcanic evolution and the mineralogy, geochemistry, and petrology of the calc-alkalic volcanic association of Mount Shasta, California and surrounding parts of the Cascade volcanic chain in order to interpret origin and magmatic evolution of the late Cenozoic magmatic system and its relation to regional evolution of the crust and upper mantle, possible future volcanism, and geothermal potential of the Cascade Range in northernmost California.

Information/Status:

The project grew out of the evaluation of a Wilderness Area in 1976, but only a small amount of geologic mapping has been done since that time because of administrative assignments of the project chief. A detailed geologic map of Mount Shasta has been compiled, and brief reconnaissance field studies have been carried out in the Cascade chain between the Klamath and McCloud Rivers. Work is now resuming on the study.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Volcanic Hazards

Sponsoring Organization: USGS

Research Area(s):

Volcanology
Geochronology/Stratigraphy

Contract/Grant Number: NA

Type of Research Activities:

Performing Organization:

Field Research

USGS

Principal Investigators:

Dwight R. Crandell

Objective:

To study late-Quaternary volcanic rocks in order to infer the kinds and frequency of eruptive events they represent. To provide information needed for evaluating potential hazards to communities, reservoirs, recreation facilities, and proposed nuclear power plants which could be affected by future eruptions. To provide data to help evaluate the geothermal potential of volcanic regions in the Western United States.

Information/Status:

During 1980, USGS Bulletins were completed on recent eruptive histories and potential hazards at Mount Hood, Oregon, and Mount Shasta, Oregon. A manuscript was completed on Holocene eruptive history and potential hazards from future eruptions of Glacier Peak, Washington. A manuscript was completed for a USGS Bulletin on pyroclastic flows and lahars from Mount St. Helens, Washington. Detailed stratigraphic and paleomagnetic investigations of the eruptive activity of Mount St. Helens during the last 450 years are continuing in order to evaluate evidence for eruptive cycles. Detailed stratigraphic investigations were started in the Mono Craters-Inyo Craters volcanic chain, California, to determine the kinds, frequency, and extent of eruptive activity during the Holocene in that region. Studies are also in progress to assess the state of evolution of Mount St. Helens and Mount Shasta (with R.L. Christiansen) to attempt to predict the nature of future eruptions. These studies will review temporal chemical variations in eruptive products, evaluate past eruptive behavior, and examine evidence for possible evolutionary or cyclic trends.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Medicine Lake Volcano

Sponsoring Organization: USGS**Research Area(s):**Volcanology
Geochronology/Stratigraphy
Mineralogy/Alteration**Contract/Grant Number:** NA**Type of Research Activities:****Performing Organization:**Field Research
Laboratory Research-Analytical

USGS

Principal Investigators:Julie Donnelly-Nolan

Objective:

To assess the geothermal potential of Medicine Lake Volcano, California through detailed geologic mapping, isotopic dating, and chemical analysis of lavas. To interpret the volcanic history and tectonic setting, together with geophysical information from other projects in terms of magmatic source regions and shallow magma reservoirs that may serve as a heat source for geothermal resources.

Information/Status:

At least 5 late Holocene silicic flows and numerous late Holocene basaltic flows are present, making Medicine Lake volcano a prime target for geothermal exploration. Since June 1979, an area of nearly 200 km² on the north-western and eastern sides of Medicine Lake Volcano has been mapped in detail. The mapping has revealed a complex volcanic stratigraphy, significantly revised from earlier studies. An undated andesite ignimbrite previously thought to be the volcano's basal unit, is normally polarized and is actually in the upper 20 percent of the volcanic pile. Significant volumes of silicic lavas predated the andesite ignimbrite, notably a previously unrecognized rhyolitic ash flow that is thicker and more widespread than the later andesitic one. A complex sequence including basalt, andesite, dacite and rhyolite flows was erupted between the two ignimbrites. A similar complex sequence postdates the andesitic ash flow. Thus, the volcano is not a basaltic shield as thought by some previous workers.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Coso Mountains

Sponsoring Organization: USGS

Research Area(s):

Geochronology/Stratigraphy
Gravity/Magnetic Studies
Heat Flow Studies

Contract/Grant Number: NA

Type of Research Activities:

Performing Organization:

Field Research
Laboratory Research-Analytical

USGS

Principal Investigators:

Wendell A. Duffield

Objective:

To evaluate the geothermal potential of the Coso Range area of California through geologic mapping, geochronology and chemical studies of the Coso volcanic field, in conjunction with complementary studies such as aeromagnetics, gravity, electromagnetics, seismicity, heat flow, ground deformation, hydrology, and drilling.

Information/Status:

Many of the original goals of the Coso project have been achieved with the publication of a colored geologic map and 11 papers in the May 1980 issue of the Journal of Geophysical Research. Two of the JGR papers are direct products of this project and document geologic evidence for the nature and extent of volcanic, tectonic, and geothermal activity in the area. The other papers present geophysical and geochemical data from related studies. Isotopic, geochemical, and mineralogic studies of Coso volcanic rocks are continuing.

The drilling of a 1477 m-deep test hole at the Coso geothermal field, California suggests that partially-molten rock may be present several kilometers beneath the hydrothermal system penetrated by this drill hole.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Geothermal Paleomagnetic Studies

Sponsoring Organization: USGS

Research Area(s):

Geochronology/Stratigraphy
Gravity/Magnetic Studies

Contract/Grant Number: NA

Type of Research Activities:

Performing Organization:

Field Research

USGS

Principal Investigators:

Sherman Gromme

Objective:

To use paleomagnetic measurements on volcanic rocks as an aid in geologic studies of volcanoes. To measure secular variation and polarity reversals of the geomagnetic field as a way to date and correlate volcanic events in individual volcanic fields.

Information/Status:

The areas of principal investigation to date have been the Snake River Plain of Idaho and Wyoming, the Cascade Range of California, Oregon, and Washington, and the island of Hawaii. Secular variation has proved to be a remarkably strong tool for assigning ages to many otherwise undated lavas at Kilauea Volcano. Future work will concentrate on the Cascade Range at Newberry Caldera, Oregon, the Three Sisters area, Oregon, Mt. Mazama, Oregon, and the Medicine Lake Highlands-Modoc Plateau area, California.

Program/Project Title: Geology of The Geysers-Clear Lake Area, California

Sponsoring Organization: USGS

Research Area(s):

Contract/Grant Number: NA

Structural Geology
Geochronology/Stratigraphy
Petrology
Isotope Geochemistry

Performing Organization:
USGS

Type of Research Activities:
Field Research
Laboratory Research-Analytical

Principal Investigators:

B. Carter Hearn, Jr.

Objective:

To map, isotopically date, chemically analyze, and determine remanent magnetism of the Clear Lake Volcanics of California to determine the age, eruptive sequence, structure and petrology of the magmatic system and evaluate its potential for geothermal resources beyond the present production area of The Geysers steam field. To locate active faults and document ongoing deformation in the area. To coordinate with ground-based and airborne geophysical studies to determine sub-surface structure, tectonic activity, the presence of a magma chamber, and potential for future eruptive activity. To sample springs and wells for chemical analysis and interpretation of subsurface geothermal reservoirs.

Information/Status:

Field work is completed and the project is in the writing and laboratory-work stages. Prof. Paper 1141, Compendium of Geysers-Clear Lake Studies, is in press. Compilation of a 1:24,000-scale geologic map is in progress. Most of the mapping has already been open-filed. A map showing springs and faults is nearly completed. Coordination with on-going geophysical studies such as measurement of ground deformation, detection of a magma chamber and the analysis of thermal fluids is continuing, as is the interpretation of cuttings from geothermal exploration holes to correlate subsurface units with mapped units and to determine patterns of hydrothermal alteration. Further detailed petrologic study to determine the origin and evolution of magma awaits results of electron probe analyses. Potassium-argon dating and strontium-isotopic study are completed. Oxygen-isotopic study has been started.

Program/Project Title: Seismic Studies of Hawaiian Magma Reservoirs

Sponsoring Organization: USGS

Research Area(s):

Geophysics-Other (Seismic)
Volcanology

Contract/Grant Number: NA

Type of Research Activities:

Performing Organization:

Field Research

USGS

Principal Investigators:

Fred W. Klein

Objective:

To gather and analyze seismic data to determine the detailed structure, location, size, and physical properties of magma chambers and conduits within Kilauea Volcano, Hawaii.

Information/Status:

The project helps support the computer-assisted reduction and analysis of earthquake data recorded on the Hawaiian Volcano Observatory's seismic network. The timing, accuracy, and ease of handling of data which is possible with computer-based processing has markedly improved the number and quality of earthquake locations since such processing began in early 1979. The high quality of earthquake locations helps to locate magma conduits within Kilauea's east rift zone (revealed by earthquakes at the leading edges of intrusive dikes) to an accuracy of a few hundred meters. Magma storage pockets are inferred from the initiation points of intrusive dikes. Digital seismograms will be used for studies of seismic attenuation within Hawaii's volcanoes.

Program/Project Title: Roots of Calderas and Fossil Geothermal Systems

Sponsoring Organization: USGS

Research Area(s):

Contract/Grant Number: NA

Volcanology
Mineralogy/Alterations
Structural Geology

Performing Organization:

USGS

Type of Research Activities:

Field Research
Modeling/Simulation

Principal Investigators:

Peter W. Lipman

Objective:

To undertake a regional reconnaissance of the transition between volcanic and plutonic environments of silicic igneous systems in the western U.S. To examine caldera-related structures in the southern Rocky Mountains that are sites of fossil geothermal systems and hydrothermal ore deposits. To determine the geometric structural relations between volcanic and plutonic features as precisely as possible and to use the constraints in investigating pressure-temperature-composition conditions of alteration and mineralization by geochemical and experimental petrologic techniques.

Information/Status:

About 200 km² of structurally complex Tertiary volcanic and intrusive rocks within and adjacent to the 23 m.y.-old Red River caldera near Questa, New Mexico, have been mapped at a scale of 1:24,000. Petrologic, major- and minor-element geochemical, potassium-argon and fission-track geochronologic, and paleomagnetic studies are also underway, in an attempt to decipher space-time relations in the evolution of a large silicic magmatic system, now exposed both as surficial volcanic deposits and as a highly evolved granitic intrusive complex, truncated by the frontal fault of the Sangre de Cristo Mountains. Petrologic comparisons between the intrusive and extrusive rocks will aid understanding of magmatic processes that are cogenetic with silicic volcanism, caldera collapse, development of large-scale hydrothermal systems, and associated molybdenum ore deposits. The project will include a mineral-potential evaluation of the Hondo-Columbine roadless area.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Laboratory Investigations of the Seismic and Thermal Properties of Basalt to Melting Temperatures

Sponsoring Organization: USGS

Research Area(s):

Physical Properties Rocks/Liquids
Heat Flow Studies

Contract/Grant Number: No. 14-08-0001-G-576

Type of Research Activities:

Performing Organization:
University of Hawaii at Manoa

Laboratory Research-Experimental

Principal Investigators:

Murli H. Manghnani

Objective:

To investigate in the laboratory the physical, seismic, and thermal properties (thermal diffusivity and conductivity and specific heat) of basalts and basaltic magmas as a function of composition and structure of the rock, fluid content, pressure and temperature (to melting temperature).

Information/Status:

The water-saturation technique, helium pycnometer and mercury porosimeter have been used to determine the porosity, and the scanning electron microscope has been used to study the pore and microcrack size-distribution structure. Extensional and tortional attenuation and longitudinal- and shear-wave velocities have been measured as a function of confining pressure on both dry and saturated samples. Both extension and tortional attenuation have been successfully measured in an alkalic basalt melt in the temperature range of about 1200-1400°C over a frequency range of 0.5 to 3 MHz by continuous wave interferometric technique. Both types of attenuation are relatively independent of frequency. The feasibility of a continuous-wave technique for measuring velocity and attenuation in melts has been demonstrated. Satisfactory results were obtained with ordinary radio-frequency oscillators generating 10-20 volt sine waves. High signal-to-noise ratios can be easily achieved with a lock-in amplifier without the sophisticated electronics.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Tephra Hazards from Cascade Range Volcanoes

Sponsoring Organization: USGS

Research Area(s):

Contract/Grant Number: NA

Volcanology
Geochronology/Stratigraphy
Mineralogy/Alterations

Performing Organization:

USGS

Type of Research Activities:

Field Research
Laboratory Research-Analytical

Principal Investigators:

O. R. Mullineaux

Objective:

To document the sequence of Holocene tephra erupted from Mount Mazama, Oregon, in order to assess potential hazard from future eruptions of that type and magnitude. To evaluate through cooperative efforts, processes recorded by changes in chemical and mineralogic compositions of tephra from Mount St. Helens, Washington, for possible use in evaluating cyclic activity and future eruptions. To provide data on magmatic systems that may be used to assess associated geothermal potential.

Information/Status:

Detailed study of tephra deposits and eruptive history of Mount St. Helens continues. The investigation of thicknesses of single, thick beds of tephra from Mount St. Helens and Mount Mazama continues in order to outline their stratigraphy and to determine what thicknesses of tephra might fall at various distances from explosive Cascade volcanoes during future eruptions.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Yellowstone Seismic Analysis

Sponsoring Organization: USGS

Research Area(s):

Geophysics-Other (Seismic)
Structural Geology

Contract/Grant Number: NA

Type of Research Activities:

Performing Organization:

Field Research

USGS

Principal Investigators:

Andrew M. Pitt

Objective:

To locate the earthquakes occurring in the Yellowstone National Park region on a timely basis to define the pattern of hypocenters, source mechanisms, energy release, frequency of occurrence, and signal character of P and S waves as a basis to better understand the fluid circulation, thermal regime, crustal structure, and contemporary tectonics of the region.

Information/Status:

Signals from a 16-station seismograph network in the Yellowstone region of Wyoming are now telemetered directly to Menlo Park, greatly facilitating the promptness and reliability with which the data can be processed. An open-file map of seismic activity in the Yellowstone-Hebgen Lake region from 1973 through 1978 was released in May 1979, and a catalog of the earthquake parameters for the years 1973-1975 was released in October 1980. A catalog for the years 1976-1978 was released in 1981. A paper on the magnitude-6 earthquake in Yellowstone National Park in 1975 was published in February 1979, and papers on focal mechanisms studies, crustal structure, and earthquake-induced changes in thermal area activity are in preparation.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Radiocarbon

Sponsoring Organization: USGS

Research Area(s):

Geochronology/Stratigraphy

Contract/Grant Number: NA

Type of Research Activities:

Performing Organization:

Laboratory Research-Analytical

USGS

Principal Investigators:

Stephen W. Robinson

Objective:

To determine radiocarbon ages of volcanic events, and to use radiocarbon as a tracer for geothermal processes.

Information/Status:

The project continues to provide radiocarbon dating in support of other geothermal projects. Radiocarbon in Clear Lake, California, has been monitored since March 1979. Extensive collections of vegetation from geothermal areas in Lassen Volcanic National Park, California, are being analyzed to determine the impact of geothermal carbon. A new technique of uranium-thorium isochron dating is being applied to young volcanic rocks from the Lassen region in northeastern California.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Partial Melting, Three-Dimensional Melt Topology, and Electrical Conductivity in Granitic and Basaltic Rocks of Geochemical Environments

Sponsoring Organization: USGS

Research Area(s):

Physical Properties Rocks/Liquids
Electrical Studies

Contract/Grant Number: 14-04-0001-G-631

Type of Research Activities:

Performing Organization:

Laboratory Research - Experimental
Modeling/Simulation

University of Hawaii at Manoa

Principal Investigators:

Michael P. Ryan

Objective:

To measure electrical conductivity in granite and basaltic partial melts. To develop criteria for aggregate changes in direct-current electrical conductivity in granitic and basaltic rocks with regard to rock microstructure, mineralogy, the nature of melt-crystal contacts, and water diffusivity and diffusion pathways. To apply laboratory results to granitic and basaltic magma chambers using numerical heat-transfer modeling.

Information/Status:

Research objectives completed thus far are: (1) scanning electron microscopy of melt microstructures, including the effects of voids (discrete gas phase); (2) electron probe microanalysis of melt chemistry and the compositional range; (3) compilation of available English, American, Soviet, Japanese and European data on transport properties of silicate melts, including electrical conductivity, viscosity, and cation-diffusion coefficients; (4) development of a three-dimensional model for mechanically constraining the three-dimensional geometry of magmatic chambers at depth. The model uses a mathematical approach for predicting displacement components associated with the draining of magmatic fluid from a rectilinear cavity whose width, thickness, depth of burial, and geometric aspect ratio in the horizontal plane may be independently varied.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Kinetics of Igneous Processes

Sponsoring Organization: USGS

Research Area(s):

Mass Heat Transport

Contract/Grant Number: NA

Type of Research Activities:

Performing Organization:

Theoretical Research

USGS

Principal Investigators:

Herbert R. Shaw

Objective:

To assess the kinetic processes of magma generation and ascent in the earth (including the heat and mass transfer processes affecting the evolution of magma chambers) as they bear on the energy budget of igneous-related geothermal resources.

Information/Status:

Papers have been published describing igneous-related thermal energy classifications (with R.L. Smith), a theory of chemical evolution of silicic chambers (with R.L. Smith and E.W. Hildreth), and theories of magma ascent. Rates of eruption for the Hawaiian-Emperor volcanic chain were calculated over the past 70 m.y. (with E.D. Jackson and K.E. Bargar). Current work involves evaluation of models of chemical evolution of magma chambers.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Regional Volcanology

Sponsoring Organization: USGS

Research Area(s):Volcanology

Contract/Grant Number: NA

Type of Research Activities:**Performing Organization:**

USGS

Data Analysis/Documentation
Modeling/Simulation

Principal Investigators:Robert L. Smith

Objective:

To classify, characterize, and evaluate volcanic systems for geothermal and related purposes. To develop models for the evolution of volcanic systems, their magma chambers and associated geothermal systems, based on field reconnaissance, mapping, sample collection and analysis. To compile and publish special-purpose volcanic maps at a scale of 1:1,000,000 (and other scales as appropriate), covering the eleven contiguous western states, Alaska, and Hawaii.

Information/Status:

Since its inception in 1972 this project has produced criteria useful for geothermal exploration, developed a rationale for estimating thermal energy in igneous systems, and provided the national estimate of the geothermal resource base related to igneous systems for the first two times that such estimates have been made, in USGS Circulars 726 and 790 respectively. The project is also producing a series of maps at 1:1,000,000 scale showing the composition, distribution, and age of late-Cenozoic volcanic rocks of the United States. Two of these maps, I-1091 A and B, have been published, C is near color proof stage, D is in review by the authors, and E and F are compiled at 1:1,000,000 but require several months additional work by the authors. A synthesis of data from the map series will follow. The project chief participated in the Alaskan Geothermal Project (Thomas P. Miller, Project Chief), from which several maps and papers have been published.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Geophysics of Young Volcanic Systems

Sponsoring Organization: USGS

Research Area(s):

Gravity/Magnetic Studies
Volcanology
Heat Flow Studies

Contract/Grant Number: NA

Type of Research Activities:

Performing Organization:

Field Research
Modeling/Simulation

USGS

Principal Investigators:

David L. Williams

Objective:

To improve understanding of young volcanic systems and their associated geothermal resources through a variety of geophysical tools, primarily gravity and magnetics. To integrate the geophysical results with the results of other studies to develop a general model of a volcanic system.

Information/Status:

The project began in 1977. The results of magnetic, gravity, thermal, and structural geology studies at Mt. Hood, Oregon, are in press. Reports on structure and heat flow at the summit of the volcano are in preparation. Work at Crater Lake, Oregon, includes heat flow measurements and coring in the lake floor and a gravity study of the area. A report on the heat flow, metal genesis and physical limnology of Crater Lake is in preparation. Gravity data from Crater Lake and the Medicine Lake volcano in California are currently being reduced.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: San Francisco Volcanic Field

Sponsoring Organization: USGS

Research Area(s):

Volcanology

Contract/Grant Number: NA

Type of Research Activities:

Performing Organization:

Field Research

USGS

Laboratory Research-Analytical

Principal Investigators:

Edward W. Wolfe

Objective:

To interpret the processes and evolution of magmatic activity in the San Francisco volcanic field of northern Arizona based on petrographic studies, chemical analyses, complementary geophysical investigations (gravity, seismic refraction, teleseismic delay, heat flow, microearthquake, magnetotelluric), strontium-isotopic measurements, potassium-argon (K-Ar) dating, and magnetostratigraphy. To determine whether hot, possibly molten, rock exists in the crust under the San Francisco volcanic field.

Information/Status:

The project began in 1974. Geologic mapping of the younger part of the volcanic field (about 6000 km²) has been completed at a scale of 1:50,000. An additional 2000 km² has been mapped for compilation of the Flagstaff 1° x 2° quadrangle (in press), which provides a regional framework for the geothermal study. A major report, aimed at accomplishing the principal objectives of the project, is in preparation.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Springerville Volcanic Field

Sponsoring Organization: USGS

Research Area(s):

Petrology
Volcanology

Contract/Grant Number: NA

Type of Research Activities:

Performing Organization:**Field Research**
Laboratory Research-Analytical**USGS**

Principal Investigators:**Edward W. Wolfe**

Objective:

To map the late Cenozoic Springerville-White Mountains volcanic field. To study the petrography and chemistry of its lavas. To interpret the magmatic history in terms of the geothermal potential of the area. To understand the geologic significance of the lavas, particularly with regard to their relationship to the boundary between the Colorado Plateau and Basin and Range provinces.

Information/Status:

One summer of geologic mapping in the area of Quaternary basalt flows and vents has been completed by C.D. Condit, L.S. Crumpler, and J.C. Aubele. Mapping will continue and will serve as a basis for thesis studies.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Potential-Field Methods for Mapping Magma at Kilauea Volcano, Hawaii

Sponsoring Organization: USGS

Research Area(s):

Electrical Studies
Volcanology

Contract/Grant Number: NA

Type of Research Activities:

Performing Organization:

Field Research
Data Analysis/Documentation

USGS

Principal Investigators:

Charles J. Zablocki

Objective:

To characterize geophysically the magma bodies in Kilauea Volcano, with the purpose of extracting meaningful in situ bulk physical property and configuration information on magma and the attendant hydrothermal regime. To develop a system for monitoring temporal changes in the measured properties related to movement of magma. To provide supplemental information needed for interpreting self-potential (SF) and very-low-frequency (VLF) data that already exist and are clearly related to geothermal phenomena.

Information/Status:

This project began in 1975. Through 1978 most efforts were concentrated on the application of magnetic, electrical, and electromagnetic techniques to the study of shallow magma bodies and their attendant hydrothermal fluids at Kilauea Volcano, Hawaii. These efforts generated over 15 technical reports, papers, and abstracts describing the results. Of note were: 1) the development of an hypothesis that explains the large SP anomalies that are associated with thermal areas in Kilauea; 2) the demonstrated utility of the VLF induction method to delineate shallow magma bodies; 3) the location of the water table of Kilauea using DC resistivity soundings; and 4) the successful application of the SP method in siting the HGP-A geothermal well in Puna. Since 1979 the major effort has been focused on delineating deeper-seated thermal zones at Kilauea by using a large-separation and extra-low-frequency (ELF) induction system. Precise measurements to 14 km source-receiver separations using specially designed large-moment transmitter source and a high-sensitivity cryogenic magnetometer receiver have been made. The results to date have defined parts of Kilauea's geoelectric section to depths of 5 km. The proven application of this deep-sounding ELF system prompted the establishment of two permanent monitoring sites on Kilauea's summit in 1979 in an attempt to detect changes in the conductance in the region of Kilauea's magma chamber. To date, no perceptible changes have been observed, but good baseline data have been obtained for comparison with future magmatic activity. In March and April, 1978, low-level aeromagnetic and airborne VLF surveys were made over Kilauea's and Mauna Loa's rift zones as was an island-wide, high-level aeromagnetic survey.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Geochemical Studies of Geothermal Systems

Sponsoring Organization: USGS

Research Area(s):

Brine/Gas Chemistry

Contract/Grant Number: NA

Type of Research Activities:

Performing Organization:

Laboratory Research-Analytical

USGS

Principal Investigators:

Ivan Barnes

Objective:

To collect and analyze liquid and gas samples from thermal springs and wells for chemical and isotopic data that can be used to estimate reservoir temperatures, outline favorable areas for geothermal exploration, identify possible pollution problems, and estimate recharge-discharge relations.

Information/Status:

Earlier emphasis on geochemical studies of thermal waters has evolved toward studies of CO₂ in geothermal and volcanic areas, with special attention on the origin of the CO₂ and its role in volcanic eruptions. Publications during the past year include a paper in Geology on the role of CO₂ in volcanic explosions and a map showing locations of spring-deposited travertine in eleven western states. A paper on CO₂ and seismicity is in press.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Yellowstone Thermal Areas

Sponsoring Organization: USGS

Research Area(s):

Mineralogy/Alteration
Petrology

Contract/Grant Number: NA

Type of Research Activities:

Performing Organization:

Laboratory Research-Analytical
Field Research

USGS

Principal Investigators:

Melvin H. Beeson

Objective:

To understand the hot-spring systems of Yellowstone National Park through: (1) Petrologic study of 1980 m of drill core obtained in 1967-1968, with emphasis on the hydrothermal minerals produced by interaction of water with rhyolite at temperatures up to 250°C; (2) Determination of paragenesis and compositional ranges of hydrothermal minerals and an evaluation of factors that may have controlled paragenesis and composition; (3) Geologic mapping of hot-spring basins emphasizing the nature of the hot-spring deposits and alteration products, structural controls of the hot springs, relationships with young volcanism and glaciation, and relationships of the geology and petrology to the chemistry of hot-spring waters.

Information/Status:

This project began in 1967. Fieldwork has been completed for geologic maps of Upper Geyser Basin (at the scale of 1:2,400 and 1:4,800), Lower Geyser Basin (at 1:2,400), and Pocket Basin (at 1:2,400). The Upper and Lower Geyser Basin maps are in press. Analytical work has been essentially completed on all drill core. A report on well Y2 and a report on scanning-electron-microscope mineralogy are in press. A report on wells Y11, Y3, and Y3 plus a topical report on feldspars were completed in 1981.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Earthquake Studies in The Geysers-Clear Lake Region

Sponsoring Organization: USGS

Research Area(s):

Geophysics-Other (Seismic)

Contract/Grant Number: NA

Type of Research Activities:

Performing Organization:

Field Research

USGS

Principal Investigators:

Charles G. Bufe

Objective:

To determine the relation of earthquakes in The Geysers-Clear Lake region of California to regional tectonics and to local deformation resulting from geothermal processes and/or steam extraction. To evaluate the usefulness of microearthquakes for geothermal exploration. To determine crustal structure and attenuation using P and S waves from local and regional earthquakes.

Information/Status:

The project, which began in 1977, utilizes data from 14 telemetered stations and 13 portable digital seismographs to determine locations, fault plane solutions, and source parameters for earthquakes in The Geysers-Clear Lake region. The telemetered network is scheduled for completion this year. The portable digital seismograph and playback facility are also in the final debugging process. It is anticipated that these systems will also find use in other geothermal areas. A report describing temporal-spatial patterns of seismicity at The Geysers since 1975 is in press, and a statistical study of seismicity is completed and in review. Current work includes an investigation of seismic attenuation in the steam field, determination of the three-dimensional velocity structure, and a regional refraction study.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Gas Geochemistry in Hawaii

Sponsoring Organization: USGS

Research Area(s):

Brine/Gas Chemistry
Volcanology

Contract/Grant Number: NA

Type of Research Activities:

Performing Organization:
USGS

Field Research
Laboratory Research-Analytical

Principal Investigators:

Thomas J. Casadevall

Objective:

To determine the nature and location of thermal activity and gaseous emissions from Hawaiian volcanoes. To measure the contribution to the atmosphere made by outgassing of Hawaiian volcanoes and to document the variations in these contributions due to changes in climatic conditions and volcanic activity. To investigate the mechanisms by which Hawaiian volcanoes outgas and the effects which these gases have on the enclosing rocks.

Information/Status:

An inventory of thermal areas on Kilauea and Mauna Loa volcanoes is in press. Since June, 1979, nearly daily measurements of sulfur dioxide emission have been made using a correlation spectrometer. For this same time period weekly collections of condensates and sublimates have been made from three sites on Kilauea. Reports of the results of these studies are in preparation.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Physical Chemistry of Stable Isotope Fractionation in Hydrologic Processes

Sponsoring Organization: USGS

Research Area(s):

Isotope Geochemistry

Contract/Grant Number: NA

Type of Research Activities:

Performing Organization:

Laboratory Research-Analytical

USGS

Principal Investigators:

Tyler B. Coplen

Objective:

To investigate equilibrium and non-equilibrium fractionation processes involving fluids and rocks in geothermal systems. To study the geohydrology of hot-water geothermal systems, especially the origin, history, and nature of geothermal fluids through the study of light stable isotopes.

Information/Status:

Water and rock samples have been collected from the Imperial Valley of southern California, Yellowstone National Park, and Cerro Prieto geothermal field in Baja California, Mexico. Analyses of these samples for stable isotopes of hydrogen, carbon, and oxygen have been used to determine the origin of the geothermal fluids and to investigate the geohydrology of these geothermal areas.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Isotopic and Chemical Studies of Geothermal Gases

Sponsoring Organization: USGS

Research Area(s):

Brine/Gas Chemistry
Isotope Geochemistry

Contract/Grant Number: 14-08-0001-G-361

Type of Research Activities:

Performing Organization:

Laboratory Research-Analytical

Scripps Institution of Oceanography at
University of California

Principal Investigators:

Harmon Craig

Objective:

To study geothermal gases in order to delineate important sources for the various components of dissolved and free gases in geothermal regions. To apply isotopic exchange equilibria to the measurements of reservoir temperatures in geothermal fields. To use compositional and isotopic variations in gases and waters in locating areas of maximum potential for geothermal development.

Information/Status:

Extensive sampling has been done at Yellowstone National Park, as well as collection of geothermal waters and gases in the Imperial Valley, California, Cerro Prieto, Mexico, and other localities. Analysis performed on these samples determined the content of stable isotopes of nitrogen, hydrogen, and methane; deuterium and ^{18}O ; total carbon and ^{13}C ; and helium for $^3\text{He}/^4\text{He}$ measurement. The accuracy required for isotopic studies resulted in a number of improved analytical techniques.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Rock-Water Interactions

Sponsoring Organization: USGS

Research Area(s):Brine/Gas Chemistry

Contract/Grant Number: NA

Type of Research Activities:**Performing Organization:**

USGS

Laboratory Research-Experimental
Data Analysis/Documentation

Principal Investigators:Robert O. Fournier

Objective:

To understand the processes that control the physical and chemical nature of hydrothermal solutions, particularly those associated with magmatic systems. To develop criteria for using compositions of thermal waters and gases from springs and wells to estimate subsurface temperatures deep in geothermal systems through (1) laboratory investigations of water-rock reactions at temperatures and pressures appropriate for hydrothermal systems, and (2) library and field investigations to determine the distribution and compositions of natural thermal fluids.

Information/Status:

Chemical geothermometers and mixing models that are widely used in exploration and evaluation of geothermal resources were formulated and/or revised under this project. Evaluation of other chemical and isotopic parameters is continuing. Studies of the aqueous geochemistry of the hydrothermal systems at Long Valley and Coso, California, have been completed. Studies are continuing on the hydrothermal systems at Yellowstone National Park; Lassen Volcanic National Park, California; Clear Lake, California; and Zunil, Guatemala. An equation for the solubility of quartz in water has been developed for conditions ranging from 20° to 900°C and specific volume of solution 1 to 100. Laboratory experiments are underway to determine the effect of NaCl on the solubility of quartz in hydrothermal solutions.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Reconnaissance Study of Thermal Springs and Wells and the Deposits of Recently Extinct Thermal Springs in the Peninsular Ranges Province of Southern and Baja, California

Sponsoring Organization: USGS

Research Area(s):

Geochronology/Stratigraphy
Brine/Gas Chemistry

Contract/Grant Number: 14-08-0001-G-547

Type of Research Activities:

Performing Organization:

Field Research
Laboratory Research-Analytical

San Diego State University

Principal Investigators:

R. Gordon Gastil

Objective:

To locate surface hydrothermal features less than 5 m.y. old in southern and Baja, California, and relate them to local and regional structure, host rocks, and recent volcanism. To determine the history and evolution of the thermal springs. To characterize the source of the thermal waters by chemical analysis. To measure the rate of travertine accumulation using ^{210}Pb dating.

Information/Status:

Data collection has been completed, as well as most of the laboratory analyses. Warm and mineralized spring waters have been analyzed and compared with available records. The following preliminary results are of particular significance: 1) contouring of chemical constituents has lead to recognition of several distinct thermal-water provinces; 2) cold carbonate springs appear to be fed from high-temperature reservoirs based on both Na-K-Ca-Mg and silica geothermometers; spatially these cold springs are associated with warm springs more than are other types of mineralized springs; 3) spatial correlation between earthquake-epicenters (magnitude 4 and greater) and thermal springs and wells indicates an association of warm waters with seismicity.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: National Center for the Thermodynamic Data of Minerals

Sponsoring Organization: USGS

Research Area(s):

Physical Properties
Rocks/Liquids

Contract/Grant Number: NA

Type of Research Activities:

Performing Organization:
USGS

Laboratory Research-Experimental

Principal Investigators:

John L. Hass, Jr.

Objective:

To provide critically-evaluated descriptions of the thermodynamic properties of minerals and other geological materials over the ranges in temperature, pressure, and composition that are observed in the geological environment.

Information/Status:

The project began at the Geological Survey in 1977 at the urging of the National Bureau of Standards' Office of Standard Reference Data. It is operating on a continuing basis to collect and evaluate experimental data on geological materials. Prior to the beginning of the project, a computer-based evaluation procedure was developed that permitted an evaluator to scan large sets of experimental data for a group of minerals in a chemical system after the data had been corrected to a standard state of one atmosphere. The program was used to determine the thermodynamic properties of 25 phases in the lime-alumina-silica-water system between 200 K and the upper stability limit or 1800 K, whichever was lower. These procedures have been enlarged to include the fitting of volumetric data, including expansivities and compressibilities. An improved equation for water was also adopted. These changes eliminated the need to reduce the data to a standard state of one atmosphere and eliminated most operator errors in extracting the experimental data and entering them into the evaluation routines. Other results include critical evaluation of the thermodynamic properties of vapor-saturated NaCl solutions and calcium-aluminum silicates, and an estimate of the solubility of methane in NaCl solutions.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Mapping of Volcanic and Conductive Heat Flow Sources for Thermal Springs in the Western United States Using Helium Isotopes and Other Rare Gases

Sponsoring Organization: USGS

Research Area(s):

Isotope Geochemistry
Brine/Gas Chemistry

Contract/Grant Number: 14-08-0001-G-541

Type of Research Activities:

Performing Organization:

Field Research

Woods Hole Oceanographic Institution

Laboratory Research-Analytical

Principal Investigators:

William J. Jenkins

Objective:

To map volcanic and conductive heat sources for thermal springs of the western United States in relation to helium-isotopic and other noble-gas isotopic abundances determined in geothermal gas and water samples and selected holocrystalline and glassy rock samples. To make other rare-gas measurements as required to interpret more complicated cases.

Information/Status:

Measurements of helium-isotopes suggest that The Geysers steam field in California has a volcanic heat source, a conclusion that is consistent with the results of geologic and geophysical studies. Evidence from helium isotopes at Steamboat Springs, Nevada, is less compelling but helium-isotope ratios similarly suggest that this geothermal system has a volcanic heat source. On the other hand, Raft River, Idaho, has a helium-isotopic ratio indicative of a crustal conductive heat source. Field collections have been completed in southern Montana and the Rio Grande Rift in New Mexico, and data analysis is proceeding with these as well as other samples from continental and oceanic areas.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Trace Element Reactions and Attenuation Processes in Waters of Geothermal Origin

Sponsoring Organization: USGS

Research Area(s):

Brine/Gas Chemistry

Contract/Grant Number: NA

Type of Research Activities:

Performing Organization:

Laboratory Research-Analytical

USGS

Principal Investigators:

Everett A. Jenne

Objective:

To obtain reliable chemical analyses (involving modification and development of methods) for trace and major constituents and carry out chemical modeling and geochemical interpretations on Cerro Prieto, Mexico, geothermal waters. To study and interpret the partitioning of trace elements among water, various solid inorganic phases (sinter, Mn and Fe oxides, carbonates and sulfides, organic detritus and biota in order to develop equilibrium and kinetic models for investigations of solubility controls and for identifying those processes which might be used in pollution abatement technology. To utilize trace-element data to understand and interpret geochemistry and hydrology of hot-water systems.

Information/Status:

Present efforts focus on analytical problems encountered with samples of very high silica concentration (as much as 1000 mg/L). The formation of polymerized silica after sample collection is thought to cause the loss of dissolved silica and other constituents upon standing even in 1/10 field dilutions. To test this idea various dilutions were prepared in the field (both acidified and non-acidified) of each sample taken at Cerro Prieto in March, 1980, in order to determine the stability of dissolved silica and other major constituents in the various dilutions with time. These dilutions are to be analyzed by plasma spectrometry immediately (within one week) after collection and 3 to 12 months after collection.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Thermophysical Properties of Water and of Aqueous Solutions

Sponsoring Organization: USGS

Research Area(s):

Physical Properties Rocks/Liquids

Contract/Grant Number: 14-08-0001-G-342

Type of Research Activities:

Performing Organization:

Laboratory Research-Experimental

Brown University

Principal Investigators:

Joseph Kestin

Objective:

To measure the viscosity of water and selected brines over the temperature range 38-300°C. To participate in the international standardization of the properties of the solvent.

Information/Status:

Tabulated values of the dynamic and kinematic viscosity of potassium chloride and sodium chloride have been completed and have been accepted for publication.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Chemical and Isotope Studies of Thermal Waters of the Western United States

Sponsoring Organization: USGS

Research Area(s):

Brine/Gas Chemistry

Contract/Grant Number: NA

Type of Research Activities:

Performing Organization:

Laboratory Research-Analytical
Field Research

USGS

Principal Investigators:

Robert H. Mariner

Objective:

To collect and analyze gases and water discharging from thermal springs and wells in the Western United States. To determine the origin of the dissolved constituents, the recharge areas for individual systems, and provide better estimates of reservoir temperatures. To investigate the relationship of the thermal systems to the general hydrologic setting in order to clarify mixing relationships.

Information/Status:

All available chemical and isotopic data for the thermal springs and wells of Oregon have been collected, interpreted, and submitted for publication as an open-file report. Isotopic data are being analyzed to determine recharge areas for Breitenbush and Belknap Hot Spring in the Oregon Cascades. Possible mineral sources for isotopically-depleted sulfate observed in some thermal waters in New Mexico, Nevada and the Cascades are being analyzed. Thermal, warm, and cold CO₂-charged waters from the Cascades are being examined to see if any systematic relationships exist in the chemical and isotopic data.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Geology of Pre-Tertiary Rocks in The Geysers-Clear Lake Area, Sonoma, Lake, and Mendocino Counties, California

Sponsoring Organization: USGS

Research Area(s):

Structural Geology

Contract/Grant Number: NA

Type of Research Activities:

Performing Organization:

Field Research

USGS

Principal Investigators:

Robert J. McLaughlin

Objective:

To determine structure of Pre-Tertiary rocks and its relation to geothermal resources in The Geysers-Clear Lake, California, geothermal area. To prepare geologic maps and structure sections of pre-Tertiary rocks using surface and subsurface geology. To determine distribution of landslides and active faults that may affect geothermal development. To investigate structure and sedimentology of Late Cenozoic deposits along major fault zones, critical to understanding fault tectonics. To correlate Pre-Tertiary geology with data from geochemical and geophysical studies in the area.

Information/Status:

Geologic field investigations for this project began in 1973 partly in conjunction with a study of the Clear Lake volcanic field by B. Carter Hearn. A 1:24,000 scale geologic map with structure sections, encompassing the region considered to be underlain by a vapor-dominated geothermal reservoir, was open-filed in 1978. A major report on the structure and tectonics of this area in relation to geothermal resources, is included in USGS Professional Paper 1141. Numerous other topical reports, maps, and abstracts, some of which are co-authored with Hearn and others, have been published. Other reports, including a fault-seismicity map and a regional crosssection from the Pacific Ocean through the Clear Lake volcanics, have been published. In late 1978 the project began a new phase, and mapping emphasis was shifted northeastward to areas of the Clear Lake geothermal regional considered to be underlain by one or more hot-water geothermal systems. This work is now well underway, with mapping northeast of Clear Lake largely completed, along with other mapping around the northwest and southwest side of the Lake. The project goal of mapping all pre-Tertiary rocks surrounding the Clear Lake Volcanics and of correlating these rocks with deep geothermal well data from wells drilled through the volcanics was completed in late 1981. Study of the lithology and hydrothermal mineralogy of cuttings from a 3050 m-deep geothermal well drilled at the Sulphur Mound mine south of Mt. Konociti was completed. Three abstracts were published in March 1980. Two concern Neogene pull-apart basin tectonics along the Maacama fault zone southwest of The Geysers steam field; the third concerns the age and structural relations of Late Mesozoic rocks in the Wilbur Hot Springs geothermal area in the Highland Springs area on the southwest side of Clear Lake.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Lassen Region of Cascades

Sponsoring Organization: USGS

Research Area(s):Structural Geology
Petrology

Contract/Grant Number: NA

Type of Research Activities:**Performing Organization:**Field Research

USGS

Principal Investigators:Patrick Muffler

Objective:

To evaluate the regional tectonic and petrologic setting of approximately 5,500 km² of the southeasternmost Cascade Range in northeastern California as a basis for geothermal evaluation.

Information/Status:

This project is an outgrowth of an earlier project to study the thermal areas of Lassen Volcanic National Park (LVNP). Geologic maps of the thermal areas at scales of 1:2,000 and 1:12,000 have been completed, and a geologic map at 1:24,000 has been prepared for approximately 150 km² in the southern part of LVNP and adjacent areas. Beginning in 1979, project work focused on 1:62,500 mapping in the Lassen Peak, Burney, and Jellico quadrangles. This work, together with additional mapping in the Little Valley and Mt. Harkness quadrangles, will be combined with the late Gordon Macdonald's published maps of the Manton, Manzanita Lake, Prospect Peak, and Harvey Mountain quadrangles in a regional tectonic, volcanic, and geothermal synthesis of the southeasternmost Cascade Range.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Chemical Mass Transfer Between Circulating Fluids and Rocks in Modern Geothermal Systems

Sponsoring Organization: USGS

Research Area(s):

Brine/Gas Chemistry

Contract/Grant Number: 14-08-0001-G-534

Type of Research Activities:

Performing Organization:

Theoretical Research

University of Arizona

Principal Investigators:

Denis L. Norton

Objective:

To develop a numerical solution of coupled partial differential equations constrained by characteristics of thermal springs and bore-hole fluids in order to quantitatively predict subsurface conditions in active geothermal systems. To compute chemical-composition changes for fluids along idealized flow and reaction paths and to compare the results with natural systems. To simulate heat and mass transport by thermodynamic analysis of the phase relations between alteration minerals and fluids commonly encountered in geothermal systems.

Information/Status:

The compatibility of aqueous solutions and minerals has been investigated in view of theoretical phase relations and empirical petrologic and hydrologic observations. Emphasis is on the consequences of substitutional order/disorder and compositional variation in minerals on the chemical characteristics of geothermal reservoir fluids. Compositional phase relations have been calculated for pressures and temperatures corresponding to the liquid-vapor equilibrium for water and indicate the extent to which minerals of variable composition react with aqueous solutions during geothermal processes.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Oxygen Isotopes

Sponsoring Organization: USGS

Research Area(s):

Isotope Geochemistry

Contract/Grant Number: NA

Type of Research Activities:

Performing Organization:

Laboratory Research-Analytical and
Experimental

USGS

Principal Investigators:

James R. O'Neill

Objective:

To conduct research on the stable-isotope relations in natural and laboratory systems of geothermal interest. To provide state-of-the-art operational facilities and technical staff to determine light stable-isotope ratios in geothermal materials. To provide aid in planning and data interpretation to those scientists using stable-isotope variations in their investigations of geothermal areas.

Information/Status:

The origins and temperatures of fossil hydrothermal fluids were determined in skarn deposits in the Osgood Mtns., California, and Elkhorn Mtns., Montana, in the jasperoid bodies at Drum Mtns., Utah, in recent ore deposits with current geothermal activity at Bodie, California, the Baguio District, Philippines, and the Tolfa and Monte-delle-Fate Districts, Italy. Determinations were made of the relative exchange rates of ^{18}O and D between clay minerals and water. A compilation was made of all measured and calculated stable-isotope fractionation factors of geochemical interest. In submarine hydrothermal systems, the first identification of a high-temperature smectite was made, and the low-temperature (35°C) origin of "hydrothermal" minerals in the altered trachyte on the Hess Rise was characterized. A new geothermometer based on ^{13}C (calcite-graphite) was developed for high-grade carbonate rocks. Three mass spectrometers were automated and a new method of rapid deuterium analysis of brines is being developed.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Modeling of Transport Phenomena

Sponsoring Organization: USGS

Research Area(s):

Mass Heat Transport
Fluid Migration

Contract/Grant Number: NA

Type of Research Activities:

Performing Organization:

Modeling/Simulation

USGS

Principal Investigators:

John Czarnecki

Objective:

To better understand the physics of flow and transport in hydrologic systems. To analyze existing quantitative methods that describe energy and mass transport in porous media involving both single and multiphase flow. To modify and expand these methods, if necessary, and to apply these methods to a variety of related field problems.

Information/Status:

A computer code is being modified to describe behavior of the geothermal reservoir at Raft River, Idaho. Modifications needed to handle heat and fluid-flow boundary conditions and to solve long time-scale problems of geologic interest have been made and several problems pertinent to the Raft River system have been tested with a 1-dimensional, 5-layer vertical column. After a more thorough review of publications dealing with the Raft River system, a 3-dimensional model will be developed to match the natural conditions of heat and mass flow and to analyze the effects of fluid production and reinjection.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: A Study of Gravity Variations as a Monitor of Water Levels at Geothermal Sites

Sponsoring Organization: USGS

Research Area(s):

Gravity/Magnetic Studies

Contract/Grant Number: 14-08-0001-G-297

Type of Research Activities:

Performing Organization:

University of California at San Diego

Field Research

Hardware/Instrumentation -
Development/Testing

Principal Investigators:

John M. Goodkind

Objective:

To study the effect of groundwater level on gravity measurements in order to monitor groundwater levels in geothermal wells. To investigate the influence of magma chambers on the response of local gravity to tidal forces and changes in barometric pressure. To attempt to minimize the noise-to-signal ratio in a superconducting gravimeter.

Information/Status:

Temporal gravity observations using a regular superconducting gravimeter are continuing at The Geysers geothermal field. It has been demonstrated that such continuous gravity observations at The Geysers may correlate with behavior of the geothermal reservoir. An automatic system was developed which continuously adjusts the suspension points of the gravimeter platform to maintain precise vertical alignment and thus virtually eliminate tilt-induced gravity effects. Data obtained to date reveal an anomalous relation between barometric pressure and gravity. A simple model of mass transport between air and ground demonstrates that this effect could be of meteorological, hydrological, or geothermal origin. An adjustment for changes in barometric pressure is needed to improve the usefulness of the instrument in monitoring changes in the geothermal system itself.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Transport Processes in Fluid Flow

Sponsoring Organization: USGS

Research Area(s):

Fluid Migration
Mass Heat Transport

Contract/Grant Number: NA

Type of Research Activities:

Performing Organization:

USGS

Theoretical Research
Laboratory Research-Experimental
Modeling/Simulation

Principal Investigators:

William Herkelrath

Objective:

To develop a quantitative description of the physics of combined flow of fluid and heat in porous granular and fractured materials at high temperature and pressure. To use analytical and numerical techniques to establish theories which are tested in laboratory experiments. To measure flow parameters of field samples in the laboratory to provide data for numerical models of the high-temperature flow regime in the field.

Information/Status:

Laboratory investigations of the transient flow of pure steam in sedimentary materials are nearly complete. Journal articles and open-file reports are being prepared which describe the experimental results and a steam-flow theory which has been developed.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Active Seismology in Geothermal Areas

Sponsoring Organization: USGS

Research Area(s):**Geophysics-Other (Seismic)**

Contract/Grant Number: NA

Type of Research Activities:**Performing Organization:****Field Research****Data Analysis/Documentation****USGS**

Principal Investigators:**David P. Hill**

Objective:

To resolve the P- and S-wave velocity structure of the crust and upper mantle in geothermal areas using state-of-the-art field and data-processing methods of active seismology. To provide velocity models of the crust and upper mantle for the accurate location of earthquake hypocenters within and adjacent to the geothermal areas. To establish constraints on the composition, temperature, pore pressure, and state of stress for rocks within and surrounding geothermal areas using velocity and attenuation models obtained from seismic field measurements together with laboratory and drill-hole measurements of these properties.

Information/Status:

Active seismic experiments were completed in 1979 in the following areas of geothermal interest: Mauna Loa, Hawaii; the Yellowstone-Snake River Plain region of Wyoming and Idaho; Mt. Hood in the Oregon Cascades; and the Imperial Valley region, California. The latter three involved using a newly developed 100-unit cassette recording system. Most of the subsequent effort in this project has involved processing and interpreting the data obtained from these experiments. At this stage, data processing is essentially complete and papers describing the results are in review or in press.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Teleseismic and Microearthquake Studies in Geothermal Areas

Sponsoring Organization: USGS

Research Area(s):

Geophysics-Other (Seismic)

Contract/Grant Number: NA

Type of Research Activities:

Performing Organization:

Field Research

Data Analysis/Documentation

USGS

Principal Investigators:

H.M. Iyer

Objective:

To study seismicity, P- and S-wave delays, and seismic attenuation to understand the tectonic framework, structure, and nature of the heat source in geothermal areas. To detect and delineate magma bodies under geothermal areas by measuring P-wave delays from teleseisms and regional earthquakes. To study S-delay measurements to infer the physical properties of material in the geothermal reservoir and heat source.

Information/Status:

P-wave delay studies using fixed and portable seismic networks have been completed in the following areas: Yellowstone National Park, Wyoming; Long Valley, Coso; The Geysers-Clear Lake region, California; Mt. Hood, Oregon; Roosevelt Hot Springs, Utah; San Francisco Mountains, Arizona. Each of these geothermal areas, except Mt. Hood, seem to have a low-velocity body (interpreted as a magma chamber) in the crust and upper mantle. Preliminary results are available from P-delay studies in Eastern Snake River Plain, Idaho, Newberry Volcano, Oregon, and the Battle Mountain Region, Nevada. Seismicity studies have also been done under this project and in collaboration with other projects in Yellowstone National park, Coso geothermal area and Mt. Hood. Currently a 32-station, state-wide seismic network is being installed in Oregon to study in detail the seismicity and deep structure of the Cascades. A detailed seismic experiment using an array of short-period and intermediate-period seismic systems has been completed at the Lassen Peak region in California.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Heat and Mass Transfer in Fault-Zone Controlled, Liquid-Dominated Geothermal Systems

Sponsoring Organization: USGS

Research Area(s):

Mass Heat Transport

Contract/Grant Number: 14-08-0001-G-628

Type of Research Activities:

Performing Organization:

University of Colorado

Theoretical Research
Modeling/Simulation

Principal Investigators:

David Kassoy

Objective:

To study processes of heat and mass transfer in hot-water geothermal systems along fault zones as a mathematical problem posed in terms of single-phase flow in a rigid, saturated, thermally active, porous medium. To develop conceptual models based on geological, geophysical and bore-hole data from a variety of systems, most notably the East Mesa, California, system.

Information/Status:

Studies of heat and mass transfer in generic models of hot-water geothermal systems have been completed and a quasi-analytical solution developed for an axisymmetric model of fracture-zone controlled charging of a geothermal reservoir. Significantly more rapid cooling of the deep sections of the reservoir was found than was the case in the planar model. The dilution of a hot, narrow plume of heated water emanating from a fracture zone at a basement-sediment interface, into an aquifer containing cooler water, was examined. The entrainment of cold water by the upward convecting plume was observed to cause a significant reduction of the temperature. A purely numerical approach to the planar fault-zone-controlled charging model, considered previously for high Rayleigh number flows only, was completed. Simplifications of the most general liquid porous media flow equations were obtained by assuming only horizontal flow in the aquifer in an effort to produce solutions for arbitrary Rayleigh number.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Multiphase Fluid Flow in Geothermal Systems

Sponsoring Organization: USGS

Research Area(s):

Mass Heat Transport

Contract/Grant Number: NA

Type of Research Activities:

Performing Organization:

Modeling/Simulation

USGS

Principal Investigators:

Susan Werner Kieffer

Objective:

To formulate a model for fluid flow in geothermal reservoirs and during eruptions of geysers (and, by application and analogy, in drilled wells and volcanoes) which allows one to use observed surface phenomena (photographic, seismic, geochemical) to infer source conditions at depth. To describe the relation between thermodynamic and geochemical properties of water-gas, water-steam and solid-liquid-gas magma mixtures and their fluid flow properties during eruption. To test the model against field observations at active geysers and, if available, volcanoes and drilled wells. To formulate a model for interactions of magma with ground water beneath geothermal areas and during volcanic and phreatic eruptions. To study theoretically and in the field the brecciation of host rocks during magmatic intrusions and the relation of fracture patterns.

Information/Status:

This project is new to the Geothermal Research Program as of 1980. Prior work has resulted in detailed equations of state and phase diagrams for H₂O, CO₂ and SO₂ particularly useful for fluid flow problems, and in equations of state for pseudo gas-liquid-vapor and solid-vapor mixtures. Prior field work has resulted in several hundred films of geyser eruptions in Yellowstone, Iceland, Nevada and New Zealand, and in reconnaissance seismic and geochemical work related to geyser eruptions in Yellowstone.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Heat Flow**Sponsoring Organization:** USGS**Research Area(s):**

Heat Flow Studies

Contract/Grant Number: NA**Type of Research Activities:****Performing Organization:**

Data Analysis/Documentation

USGS

Principal Investigators:

Arthur H. Lachenbruch

Objective:

To combine observations of heat flow, primarily in the western United States, with theoretical studies and geologic information to increase understanding of processes governing the generation, storage, and transport of heat in the crust and upper mantle, and the nature and geographic distribution of exploitable sources of geothermal energy in the United States. To develop new instrumentation for measuring rock temperatures, thermal properties, and heat flow, and to assist in the design of optimum strategies for the discovery and delineation of geothermal resources.

Information/Status:

Several reviews of the status of heat flow in the United States (including a series of both national and regional maps) have been published together with interpretive models of the tectonic, magmatic, and hydrologic regimes relative to regional heat flux. A system for in situ determination of heat flow during drilling has been developed and deployed, primarily in support of site-specific heat-flow studies near known or prospective geothermal areas. Manuscripts that describe heat flow in the western United States, regional heat-flow studies of the Claibornian Cascades, Coast Ranges, Mojave Block, and Sonoran Desert are in preparation.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Mathematical Modeling of Energy Transport in Multiphase Ground-water Systems

Sponsoring Organization: USGS

Research Area(s):

Fluid Migration

Contract/Grant Number: NA

Type of Research Activities:

Performing Organization:

Theoretical Research
Modeling/Simulation

USGS

Principal Investigators:

Allen F. Moench

Objective:

To understand the physical processes occurring in vapor-dominated geothermal systems. To improve numerical and analytical methods for analysis of steam pressure tests in wells. To account for the results of the laboratory tests of steam pressure-transient behavior in porous materials. To account for observed vapor-dominated reservoir behavior and to predict reservoir response.

Information/Status:

Early work on the project led to the finding that vaporization of liquid water within reservoir pores and fractures causes a large increase in the apparent compressibility of steam. This is manifested by large pressure support and plays an important role in the longevity of vapor-dominated reservoirs. Analytical and numerical models have been developed to simulate pressure behavior in wells and laboratory experiments. Recently a two-dimensional numerical model for steam flow to a well in a vapor-dominated reservoir was developed. In this model the reservoir was assumed to be composed of low-permeability blocks saturated with liquid water and high-permeability fissures saturated with vapor. The model has been successfully tested using analytical methods and is presently being used to analyze well test data from The Geysers, California, steam reservoir. A recently published abstract describes how the model is being used to relate steam production at The Geysers to induced seismicity.

The effect of increased apparent steam compressibility has been observed in laboratory experiments on unconsolidated porous materials. These experiments, conducted at various temperatures from 100°C to 146°C, have been successfully simulated by mathematical modeling techniques.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Geochronology

Sponsoring Organization: USGS

Research Area(s):

Geochronology/Stratigraphy

Contract/Grant Number: NA

Type of Research Activities:

Performing Organization:

Laboratory Research-Analytical

USGS

Principal Investigators:

Charles W. Naeser

Objective:

To study the effect of natural heating on fission-tracks in minerals through the use of samples from deep drill holes in geothermal areas.

Information/Status:

The laboratory work on fission-tracks in minerals from the Coso, California, drill holes is complete.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Geothermal Reservoirs

Sponsoring Organization: USGS

Research Area(s):**Fluid Migration**
Mass Heat Transport

Contract/Grant Number: NA

Type of Research Activities:**Performing Organization:****Data Analysis/Documentation****USGS**

Principal Investigators:**Manuel Nathenson**

Objective:

To understand the thermal and fluid mechanical characteristics of geothermal systems in their natural state and under exploitation. To develop methods for regional assessment of geothermal resources.

Information/Status:

Field studies have been performed at Raft River, Idaho, and East Mesa, California. Temperature measurements in, and water samples from, wells at Raft River have been used to show that: 1) thermal waters move vertically at several locations and charge aquifers for subsequent horizontal flow and 2) the usual assumption that there is a geothermal water with a unique chloride content and enthalpy is not true. Additional work is planned to analyze data obtained in other bore holes at Raft River. Preliminary analysis of data from East Mesa shows that some part of the geothermal system is dominated by a horizontal flow of hot water losing temperature along its flow path and that shallow (less than 200m) temperature measurements are dominated by the effects of irrigation canal leakage. Further analysis of temperature data is planned. A statistical methodology for assessing the geothermal resources in hydrothermal convection systems was developed by this project for the 1978 resource assessment. For the assessment of low-temperature geothermal resources, this project is preparing a temperature-gradient map of the conterminous U.S. The map displays temperature gradients that exist over broad areas in a conductive thermal regime to 2 km. Preliminary results indicate that low heat flow in the east is commonly expressed by gradients less than 25°C/km, and high heat flow in the west is generally reflected by gradients greater than 25°C/km.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Geothermal Petrophysics

Sponsoring Organization: USGS

Research Area(s):**Physical Properties Rocks/Liquids**

Contract/Grant Number: NA

Type of Research Activities:**Performing Organization:****Laboratory Research-Experimental**USGS

Principal Investigators:Gary Olhoeft

Objective:

To provide fundamental experimental data on the behavior of rock physical properties in geothermal environments, particularly those physical properties of use in the interpretation of field geophysical data. To use the experimental data to identify the physical and chemical mechanisms behind the observed properties so as to develop a petrophysical model to predict properties beyond the reach of current core and drill holes but where surface geophysics is still acquiring data. To perform experiments and model studies to help improve existing field geophysical techniques.

Information/Status:

Since the inception of this project in 1976, many experimental data have been acquired on the electrical, magnetic, and textural (permeability, porosity, etc.) properties of rocks in geothermal environments. The electrical properties of brine and brine-saturated rocks have been measured to 400°C, and the electrical properties of dry rocks have been measured in 1300°C. Seismic velocity and attenuation have been measured on molten basalt from 1250 to 1400°C. Magnetic properties and textural properties have been studied near room temperature and capabilities have been developed to study these properties up to 800°C. Measurements have been performed under both temperature and pressure to a depth equivalent of about 2 km, with pressure/depth capabilities to 40 km now existing. Preliminary petrophysical models of electrical properties have been developed.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Studies of Hydrogeothermal Circulation

Sponsoring Organization: USGS

Research Area(s):

Mass Heat Transport

Contract/Grant Number: 14-08-0001-G-626

Type of Research Activities:

Performing Organization:

Theoretical Research

Brown University

Principal Investigators:

E.M. Parmentier

Objective:

To theoretically study thermal convection in a fluid-saturated layer of permeable material containing discrete, regularly spaced fractures which are heated from below. To study the control which fractures place on the form of the circulation for a range of parameters such as the permeability of rock between fractures, the hydraulic conductivity of the fractures, and the fracture spacing. To consider the cooling of dikes in permeable country rock by groundwater circulation using the results of several recent theoretical studies of natural convection. To determine the influence of natural convection on cooling of the dikes using field data on their thermal aureoles.

Information/Status:

Results to date indicate that the fractured, permeable layer being considered has impermeable and isothermal top and bottom boundaries. A linear stability analysis has been used to establish conditions for the marginal stability of two-dimensional convective modes in the layer. The results demonstrate that the convective mode with the smallest critical Rayleigh number depends on the ratio of the fracture spacing to the layer depth. Numerical studies of finite-amplitude convection show that the fractures control the vertical flow in the layer. As flow patterns evolve from their initial state, vertical flow becomes concentrated in the fractures. The study is being extended to investigate the effects of a permeable upper-boundary on flow in the layer.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Rocks Under Geothermal Conditions

Sponsoring Organization: USGS

Research Area(s):

Physical Properties Rocks/Liquids

Contract/Grant Number: NA

Type of Research Activities:

Performing Organization:

Hardware/Instrumentation -
Development/Testing

USGS

Principal Investigators:

Louis Peselnick

Objective:

To develop instrumentation for measuring elastic and anelastic properties of rocks at high pressure and temperature. To determine anelastic properties of rocks at frequencies and strain amplitudes appropriate to seismic waves (0.1 to 10 Hz, and 10^{-7} strain amplitude). To interpret the experimental results in terms of the physical mechanisms of rock internal friction, with special application to geothermal systems.

Information/Status:

The laboratory determination of the compressional velocity in rocks of the Franciscan Formation at high pressure and temperature has provided data for seismic modeling of the crust in northern California. The results show that rock density determines the P-velocity. A shift of research emphasis from ultrasonic frequencies to the seismic frequency range (0.1 to 10 Hz) is underway. The redesigned high-pressure and high-temperature equipment should be in operation early in 1981. This laboratory facility should then provide a continuing output of data on internal friction as a function of pressure, temperature, frequency, and strain amplitude for rocks relevant to geothermal areas. Because a large increase in internal friction is to be expected when water in rocks transforms to steam, experiments are planned to measure, at various pressure and temperature, the internal friction in rocks of the Franciscan Formation that contain water and steam in pores. Such studies may provide methods for estimating physical properties for distinguishing between potential hot-water and vapor-dominated geothermal systems.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Pressurized Fractures in Hot Rock

Sponsoring Organization: USGS

Research Area(s):

Physical Properties Rock/Liquids
Mass Heat Transport

Contract/Grant Number: NA

Type of Research Activities:

Performing Organization:

Theoretical Research
Field Research

USGS

Principal Investigators:

David D. Pollard

Objective:

To study the processes of fracture, fluid flow, and heat transport associated with large, fluid-filled fractures such as natural igneous dikes and man-made hydraulic fractures in the rocks of geothermal regions. To increase our understanding of the form, stability, and growth of these fractures and of the transport of fluids and heat within the fractures and adjacent rock through research in theoretical continuum mechanics, field studies of dikes and hydraulic fractures, and laboratory model studies. To apply the results of our studies to the design and monitoring of hydraulic fractures for energy extraction and to the interpretation of geological and geophysical data from modern and ancient geothermal regions.

Information/Status:

An elastic solution for deformation around an arbitrary number of pressurized fractures has been derived and used to analyze fracture geometries found in nature. Solutions for fluid flow in fractures of varying crosssectional form have been derived and used to study magma flow in dikes and volcanic necks. Heat transport in fluids and through the walls of fractures has been analyzed using new solutions for the transport equations. Each of these theoretical efforts has been tested by detailed field studies of natural fractures. Since the project began in 1974, results have been published in many reports whose topics include the form and stability of fractures subjected to gradients in stress, the interaction of fractures with the Earth's surface, the growth of en echelon fractures, the transition from dikes (fissures) to necks (volcanic vents), solidification of magma, and brecciation of the fracture wall.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Geothermal Resource Assessment

Sponsoring Organization: USGS

Research Area(s):

Heat Flow Studies

Contract/Grant Number: NA

Type of Research Activities:

Performing Organization:

Data Analysis/Documentation

USGS

Principal Investigators:

Marshall Reed

Objective:

To quantitatively assess geothermal resources (less than 100°C) of the United States.

Information/Status:

This study began in 1980. Since the assessment relies heavily on data gathered by state agencies conducting geothermal studies funded by the Department of Energy, meetings have been held with all of these agencies to discuss the quality and type of data necessary for the assessment and the timing for submission of the data. Information on hot-water wells and springs goes directly to the USGS GEOTHERM computer file, and additional information comes directly to the assessment project. Methods are being developed to use the USGS hydrologic data base (WATSTORE) to estimate transmissivity and storage coefficient for low-temperature geothermal systems. Well known low-temperature geothermal systems are being identified to serve as case studies and then as models for estimating the recoverability of thermal energy in poorly-known areas.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Geothermal Tectonic Seismic Studies

Sponsoring Organization: USGS

Research Area(s):

Geophysics-Other (Seismic)
Structural Geology
Volcanology

Contract/Grant Number: NA

Type of Research Activities:

Performing Organization:
USGS

Field Research

Principal Investigators:

Craig Weaver

Objective:

To investigate the relationships among contemporary seismo-tectonics, earth structure, and volcanic/geothermal areas within different tectonic frameworks.

Information/Status:

Three studies are virtually complete: crustal structure at Coso, California; focal mechanism at Yellowstone National Park; seismicity at Mt. Hood, Oregon. Papers on all three areas are in press. The eruption of Mount St. Helens, Washington, has caused a sudden re-ordering of project priorities, with a major commitment now directed to the volcano. Between March 21-31, 1980, six 5-day recorders and 8 telemetry stations were installed near Mount St. Helens. Collection of high quality data for this unique seismo-volcanic sequency has been given special emphasis. The seismic studies at Mount St. Helens are being conducted jointly with the University of Washington. Crustal refraction experiments have been run, using earthquakes beneath Mount St. Helens as the source of energy.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Heat Flow Study of the Snake River Plain and Margins, Idaho

Sponsoring Organization: USGS

Research Area(s):

Heat Flow Studies

Contract/Grant Number: 14-08-0001-G-425

Type of Research Activities:

Performing Organization:

Field Research

Southern Methodist University

Modeling/Simulation

Principal Investigators:

David D. Blackwell

Objective:

To evaluate the geothermal character of the Snake River Plains and margins, Idaho, by determination and analysis of heat flow values, and to use these data for mathematical modeling of the region. To obtain thermal data from the Snake River Plain aquifer by measurement of temperatures in deep wells and shallow drillholes, associated geochemical studies of aquifer water, and theoretical modeling of the thermal effects of aquifers. To analyze the resulting data for their regional tectonic and geothermal significance, in combination with ongoing studies in surrounding areas for a complete regional synthesis.

Information/Status:

A heat-flow survey has shown that heat-flow values of 125 milliwatts/m² (3 HFU) or greater are characteristic of the margins of the eastern Snake River Plain. Theoretical considerations suggest that heat flow should be similarly high throughout the entire eastern Snake River Plain, but negative values were observed in the center of area (near Idaho Falls) with a gradual increase to about 63 milliwatts/m² (1.5 HFU) to the west (near Hagerman-Twin Falls). The low and negative heat-flow values result from lateral flow of groundwater in the Snake River Plain Aquifer. Flow rates in the aquifer are as high as several meters per day. A theoretical model of the aquifer can explain the observed pattern of surface heat flow and suggests that high heat flow is present beneath the aquifer.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Geomagnetic Sounding in the Cascade Range of Washington State as a Geothermal Exploration Technique

Sponsoring Organization: USGS

Research Area(s):

Gravity/Magnetic Studies

Contract/Grant Number: 14-08-0001-G-625

Type of Research Activities:

Performing Organization:

Field Research

University of Washington

Principal Investigators:

John R. Booker

Objective:

To make a detailed study of the Packwood, Washington, geomagnetic anomaly using an array of three-component flux-gate magnetometers in order to determine the depth and conductivity of the anomaly and its relation to Cascade volcanoes. To refine the original east-west geomagnetic sounding profile and to study the north-south variation of the anomaly.

Information/Status:

An east-west geomagnetic-sounding profile from the coast of Washington into the Cascade Range roughly midway between Mt. Rainer and Mts. Adams and St. Helens discovered a major anomaly near Packwood, Washington, where this profile crosses the volcanic front. The anomalous structure is believed to be in the crust, but may be deeper. Several subsequently run east-west profiles suggest that the geomagnetic anomaly extends northward from the Packwood area and projects toward Puget Sound just south of Seattle.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Evaluation of Detailed Seismic Refraction Profiling for Regional Geothermal Exploration and Application to Yellowstone and Snake River Plain

Sponsoring Organization: USGS

Research Area(s):

Geophysics-Other (Seismic)

Contract/Grant Number: 14-08-0001-G-674

Type of Research Activities:

Performing Organization:

Field Research

Purdue University

Data Analysis/Documentation

Principal Investigators:

Lawrence W. Braile

Objective:

To make a detailed seismic refraction profile in the Yellowstone-Snake River Plain region (Y-SRP) in order to evaluate the use of seismic refraction methods for regional geothermal exploration. To interpret the resulting seismic records in terms of the compressional- and shear-wave velocity structure and attenuation and the variations of these properties as a function of thermal environment along the Y-SRP.

Information/Status:

Field work in the Y-SRP was conducted during June and July, 1980 with three-component seismometers. Twenty-three shotpoints were utilized to record seismic refraction and reflection data along six profiles. In general, the seismic profiles yielded good to excellent data, particularly for stations within 20 km of shotpoints. Data reduction and digitizing of all seismograms is currently underway.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Delineation of Heat Flow Provinces in Utah

Sponsoring Organization: USGS

Research Area(s):

Heat Flow Studies

Contract/Grant Number: 14-08-0001-G-544

Type of Research Activities:

Performing Organization:

Field Research

University of Utah

Principal Investigators:

David S. Chapman

Objective:

To obtain heat-flow and heat-production measurements which will help delineate the following heat-flow provinces in Utah: a) Northern Basin and Range, b) Battle Mountain, c) South Bonneville, d) Northwest Colorado Plateau.

Information/Status:

A major effort has been directed toward measuring thermal conductivity, making topographic corrections at all relevant sites, and reducing heat flow values. Several new computer programs have been developed in order to store, retrieve and display data being accumulated. Thermal-conductivity behavior of all the major older (about 350 to 60 m.y.-old) lithologies of the central Utah-Colorado Plateau section has been characterized. This will greatly assist future estimates of heat flow where only temperature-depth results are known. Delineation of heat-flow provinces and evaluation of their geothermal resource potential are being made.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Aeromagnetic Measurements in the Cascades Range and Modoc Plateau of Northern California

Sponsoring Organization: USGS

Research Area(s):

Gravity/Magnetic Studies

Contract/Grant Number: 14-08-0001-G-623

Type of Research Activities:

Performing Organization:

Field Research

Oregon State University

Data Analysis/Documentation

Principal Investigators:

Richard Couch

Objective:

To obtain high quality aeromagnetic data (1.6 km-spaced east-west flight lines and 8km-spaced north-south tie lines flown at a constant barometric altitude of about 600 m average terrain clearance) over a 30,000 square-km area in the Cascades and Modoc Plateau of northern California. To analyze the data in terms of structure, volcanic centers, regional trends, Curie-temperature isotherm depths, and the geothermal energy potential of the area.

Information/Status:

The data-collection phase of this project was completed, with over 250,000 data points recorded on approximately 20,000 miles of flight lines in 215 hours of flight time. Interpretation of the data is underway.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: The Interpretation of Aeromagnetic Measurements from Southcentral Oregon for Geothermal Assessment

Sponsoring Organization: USGS

Research Area(s):

Gravity/Magnetic Studies

Contract/Grant Number: 14-08-0001-G-698

Type of Research Activities:

Performing Organization:

Data Analysis/Documentation

Oregon State University

Principal Investigators:

Richard Couch

Objective:

To analyze aeromagnetic measurements from southcentral Oregon in terms of regional and local structures as delineated by the near-surface anomalies and source depths. To determine the depths of the Curie-point isotherm using two-dimensional spectral techniques.

Information/Status:

High-quality aeromagnetic data of the area between 42° and 43° N latitude and 121° and 122°30' W. longitude have been collected. This area includes the Klamath Graben and Klamath KGRA and the axis and east and west flanks of the Cascade Range, a sector of the zone of transition between Basin and Range and Cascade structures, and extends from just north of Crater Lake south to the Oregon-California border. Data were collected along 1.6-km-spaced east-west lines and 8-km spaced north-south lines. Analysis of data is underway.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Regional Assessment of Intermediate-Temperature Geothermal Resources of Southwestern New Mexico

Sponsoring Organization: USGS

Research Area(s):

Structural Geology

Contract/Grant Number: 14-08-0001-G-630

Type of Research Activities:

Performing Organization:

Field Research

University of New Mexico

Principal Investigators:

Wolfgang E. Elston

Objective:

To assess the geothermal resources in southwestern New Mexico, by geologic mapping. To compile regional geologic and tectonic maps.

Information/Status:

The assessment of the geothermal potential of southwestern New Mexico has concentrated on three areas: 1) Lightning Dock KGRA, Animas Valley, Hidalgo County. A 1:48,000 geologic map of the KGRA and nearby parts of the Pyramid Mountains is being prepared for publication. Hydrologic and geochemical studies on waters of the Animas Valley are in progress. Preliminary indications suggest possible extension of the thermal anomaly southwestward from the KGRA; 2) Gila Hot Springs KGRA, and Mimbres Hot Springs, Grant County. Geologic mapping of poorly-known areas has been completed and preliminary geologic and tectonic maps have been compiled. At Gila Hot Springs, an unwelded zone of an ash-flow tuff appears to serve as an aquifer for thermal water. Mimbres Hot Springs seems to be localized at the intersection of a Basin and Range fault (Mimbres Hot Springs fault) and an older, caldera-related fault. Fractures in caldera-filling ash-flow tuff appear to act as conduits for hot water; 3) Geologic mapping of part of the Mangas Trench, southeastward from Lower Frisco Hot Springs KGRA (Grant and Catron Counties) is in progress.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Basement Trends in Metamorphism, Plutonism, Structure and Heat Flow Under the Atlantic Coastal Plain for Potential Geothermal Resources

Sponsoring Organization: USGS

Research Area(s):

Structural Geology

Contract/Grant Number: 14-08-0001-G-685

Type of Research Activities:

Performing Organization:

Data Analysis/Documentation
Field Research

Virginia Polytechnic Institute and
State Univ.

Type of Research Activities:

Principal Investigators:

Lynn Glover III

Objective:

To understand the regional geologic framework of the Atlantic Coastal Plain in order to locate radiogenic heat sources in the basement. To investigate the apparently systematic eastward decrease in ages of plutons and in ages of amphibolite-facies metamorphic thermal maxima across the crystalline terrain.

Information/Status:

This study is based on a model which proposes that radiogenic heat sources will normally be syn- to post-metamorphic granites having concentrations of U and Th that are several times background. Such plutons may heat overlying sedimentary rocks of low thermal conductivity, including aquifers suitable for development for space heating and other non-electrical applications. Rock recovered from drill holes near Lumberton and Camp LaJeune, North Carolina, are being studied to test the model. Petrographic, geochemical and geochronologic studies are underway.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Volcanology and Structural Geology of the Southeastern Part of the Cascade Range, Northeastern California

Sponsoring Organization: USGS

Research Area(s):

Structural Geology
Geochronology/Stratigraphy
Volcanology

Contract/Grant Number: 14-08-0001-G-624

Type of Research Activities:

Performing Organization:

Field Research
Laboratory Research-Analytical

Colorado School of Mines

Type of Research Activities:

Principal Investigators:

L. Trowbridge Grose

Objective:

To investigate the volcanic, tectonic, and hydrologic framework and evolution of the southeastern part of the Cascade Range in northeastern California. To estimate the geothermal potential of the area and to determine additional studies needed to improve this estimate.

Information/Status:

The study area is bounded on the west by the east flank of the Lassen Peak - Mt. Shasta axis, on the north by the Pit River Valley and the Medicine Lake Highlands, on the east by the Modoc Lava Field and the Basin and Range Province, and on the south by the Sierra Nevada. The methods of investigation include reconnaissance and detailed geologic mapping, petrography and K-Ar geochronology. All field data have been collected and the synthesis of these data, including geologic maps and cross sections, is underway.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Imperial Valley Geothermal Studies

Sponsoring Organization: USGS

Research Area(s):

Geophysics-Other (Seismic)

Contract/Grant Number: NA

Type of Research Activities:

Performing Organization:

Field Research

USGS

Data Analysis/Documentation

Type of Research Activities:

Principal Investigators:

Carl E. Johnson

Objective:

To develop an understanding of the seismotectonic processes that affect the geothermal resources of the Imperial Valley, California, one of the few places in the world where an oceanic ridge system encroaches onto a continental regime. To study the dynamic balance between fault breakage and hydrothermal healing of this seismically active geothermal area.

Information/Status:

The field work associated with a refraction experiment is complete. Preliminary analysis of data has resulted in knowledge of crustal structure in the Imperial Valley of unprecedented detail. These results are being combined with earthquake data from a permanent 25-station Imperial Valley network to provide better control of seismicity distribution and focal mechanisms. Interpretations based on these data show that the geothermal areas are associated with zones of complex fracturing. Crack extension apparently occurs during earthquake swarms.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Magmatic Gas Geochemistry

Sponsoring Organization: USGS

Research Area(s):

Brine/Gas Chemistry
Volcanology

Contract/Grant Number: NA

Type of Research Activities:

Performing Organization:

Laboratory Research-Analytical
Field Research

USGS

Principal Investigators:

David Johnston

Objective:

To sample and analyze volcanic gas emissions from active and dormant volcanoes, particularly calc-alkaline volcanoes of Alaska and the Cascades. To examine major volatile-element contents of magmas primarily by analysis of glass inclusions within phenocrysts. To understand the processes by which magmatic gases evolve and escape from magma chambers.

Information/Status:

Volcanic gases have been sampled from 6 volcanoes in Alaska, 3 in the Cascades, from Kilauea in Hawaii, and 2 thermal areas in the Azores. Gases from Augustine Volcano, Alaska have been sampled repeatedly since its 1976 eruption, and glass inclusion studies have disclosed its 1976 magma to be volatile-element-rich.

Note: David Johnston was lost at Mount St. Helens during the violent eruption of May 18, 1980.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Regional Geothermal Hydrology of Southwestern Montana

Sponsoring Organization: USGS

Research Area(s):

Brine/Gas Chemistry

Contract/Grant Number: NA

Type of Research Activities:

Performing Organization:

Laboratory Research-Analytical
Field Research

USGS

Principal Investigators:

Robert B. Leonard

Objective:

To describe the thermal waters of southwestern Montana in terms of temperature, discharge, chemical character, areal distribution, and depth of occurrence. To determine the nature of local and regional hydrogeologic controls on the occurrence of thermal water. To develop conceptual models of selected hydrothermal systems as a guide to appraisal and potential development of the geothermal resource.

Information/Status:

The project began in August 1975. Reconnaissance geological, geochemical, and hydrologic studies of 24 hot-spring areas have been completed, and the data collected through 1978 have been released. Detailed surface geological studies and additional hydrologic studies have provided a description of the basic structural controls of hot-spring systems and have been released. Test holes were drilled at two sites, one representative of systems in fractured crystalline rock and the other in a sediment-filled valley. Results of surface and borehole geophysical surveys, pumping tests, seepage studies, and chemical analyses of water samples describe the hydrothermal systems at six sites where access to thermal wells was obtained. Field work was essentially completed in March 1980. Basic data reports and several interpretive reports have been published or released. Final reports are in preparation.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Oregon Geothermal Reconnaissance

Sponsoring Organization: USGS

Research Area(s):

Volcanology

Contract/Grant Number: NA

Type of Research Activities:

Performing Organization:

Field Research

USGS

Laboratory Research-Analytical

Principal Investigators:

Norman S. MacLeod

Objective:

To evaluate the geothermal potential of southeastern and central Oregon, an area of about 125,000 km² that is underlain almost exclusively by middle and upper Cenozoic volcanic rocks, and to provide concepts and data useful for geothermal exploration. To identify possible geothermal systems that may be associated with cooling igneous bodies in the west half of the Crescent two-degree sheet, including Newberry Volcano.

Information/Status:

This project is now winding down. All field work is complete and maps are nearly ready for publication. A final report will be prepared upon completion of analytical work and potassium-argon dating that is now in progress.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Alaska Geothermal

Sponsoring Organization: USGS

Research Area(s):

Volcanology
Petrology

Contract/Grant Number: NA

Type of Research Activities:

Performing Organization:

Field Research
Laboratory Research-Analytical

USGS

Principal Investigators:

Thomas P. Miller

Objective:

To make a reconnaissance evaluation of the geothermal resources of Alaska. To study the geology, geochronology, and petrology of the Quaternary volcanic centers in the Aleutian volcanic arc and the Wrangell Mountains. To define the nature and character of the volcanic centers that may have near-surface magma chambers.

Information/Status:

The reconnaissance aspects of the project are now largely completed for all major Quaternary volcanic centers on the Alaska Peninsula, the eastern Aleutian Islands, and some of the Wrangell Mountains. Pilot studies are completed on Mt. Drum in the Wrangells and have begun on Peulik Volcano on the Alaska Peninsula. Topical papers and maps have been published, and more are in preparation.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Magnetotelluric and Telluric Methods

Sponsoring Organization: USGS

Research Area(s):

Electrical Studies

Contract/Grant Number: NA

Type of Research Activities:

Performing Organization:

Field Research

USGS

Data Analysis/Documentation

Principal Investigators:

Jim O'Donnel

Objective:

To assess geothermal resource potential by determining the geoelectrical structure in geothermal areas in terms of geologic models at depths of approximately 1 to 30 km. To evaluate and define parameters which cause scatter in magnetotelluric soundings and evaluate methods which substantially reduce the cost of magnetotelluric surveys.

Information/Status:

Telluric current (TC) and magnetotelluric (MT) surveys have outlined resistivity lows in Island Park, Raft River and Soda Springs, Idaho; Vale, Breitenbush and Newberry Caldera, Oregon; Pinto Hot Springs, Steamboat Springs and Darrough Hot Springs, Nevada; Kilbourne Hole, New Mexico; Coso Hot Springs, Randsburg, Wendel-Amadee and Lassen, California; San Francisco Volcanic Field, Arizona. The data, analysis and interpretation of the TC surveys and part of the MT surveys have been published in open-file reports and outside journals. Results of MT surveys of Lassen and Randsburg, California, Newberry Crater, Oregon, and Soda Springs, Idaho, are in preparation.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Simultaneous Inversion of Data for Disparate Geophysical Experiments

Sponsoring Organization: USGS

Research Area(s):

Gravity/Magnetic Studies

Contract/Grant Number: 14-08-0001-G-536

Type of Research Activities:

Performing Organization:

Data Analysis/Documentation
Modeling/Simulation

Southern Methodist University

Principal Investigators:

Wayne Peeples

Objective:

To determine whether the simultaneous inversion of geophysical data from disparate experiments, such as gravity and magnetotelluric (MT) studies, can produce additional information about structural features common to both the gravity and the magnetotelluric model.

Information/Status:

The basic model proposed is one in which a two-dimensional Earth model is divided into regions separated by non-planar boundaries. The Backus-Gilbert inverse procedure is applied to both theoretical and experimental data, and a complete statistical analysis of the tradeoff between precision and resolution of common structural parameters can be made. The two-dimensional boundary value problem for the gravity and magnetotelluric case (multiple layers separated by non-planar interfaces) has been solved for both TE and TM modes of propagation, and computer programs are operational. The inversion program has been rewritten for computational speed and is fully operational for the gravity inverse problems. The three-dimensional MT problem has now been fully derived. In addition, an analysis of the magnetotelluric effect of a perched geothermal system will be made.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Geoelectric Sounding Studies

Sponsoring Organization: USGS

Research Area(s):

Electrical Studies

Contract/Grant Number: NA

Type of Research Activities:

Performing Organization:

Field Research
Data Analysis/Documentation

USGS

Principal Investigators:

W.D. Stanley

Objective:

To investigate the electrical structure of the crust to depths of 20 km using primarily the magnetotelluric technique as an aid to regional assessment of geothermal potential. To integrate the electrical data with other geophysical data and advance the technique of magnetotellurics.

Information/Status:

A major study of the Snake River Plain-Yellowstone region has been completed and a regional study of the Cascades and eastern Oregon is 50% complete. A real-time magnetotelluric system and companion software based upon microprocessors and a superconducting magnetometer have been completed. A major journal article on the Snake River Plain-Yellowstone work has been published and an open-file report on the Cascades work is in preparation. An open-file report on the real-time magnetotelluric system is in press.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Geomagnetic-telluric Array Investigations of the Crust and Upper Mantle

Sponsoring Organization: USGS

Research Area(s):

Electrical Studies

Contract/Grant Number: NA

Type of Research Activities:

Performing Organization:

USGS

Hardware/Instrumentation Development/Testing
Field Research

Principal Investigators:

James N. Towle

Objective:

To develop and implement methods for the determination of geoelectrical structure of the Earth's crust at mid- and lower-crustal depths.

Information/Status:

The development of instrumentation for a 14-station geomagnetic-telluric array is essentially complete, allowing future studies to be conducted with the full complement of instrumentation. Studies in the Rio Grande Rift, New Mexico, Coso Range, California, and San Francisco Peaks, Arizona, have been conducted. Current field investigations are in the Cascade Range of Washington, Oregon, and California. Methods of data interpretation have been developed to permit rapid and direct determination of geoelectrical structure, allowing redeployment of the array during periods of moderate geomagnetic activity to obtain greater regional coverage. Descriptions of geoelectrical structure related to geothermal activity in the Rio Grande Rift and Coso Range are published. A preliminary report on the geoelectrical structure of the central part of the Cascades Range is in preparation.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Evaluation of Geothermal Systems Using Teleseisms

Sponsoring Organization: USGS

Research Area(s):**Geophysics-Other (Seismic)**

Contract/Grant Number: 14-08-0001-G-426

Type of Research Activities:

Performing Organization:**University of Texas at Dallas****Data Analysis/Documentation
Field Research**

Principal Investigators:**Ronald W. Ward**

Objective:

To develop and assess techniques which use the lateral variation of the spectra of teleseismic P waves produced by seismic attenuation to infer the location and extent of a geothermal system. To improve the generalized two-dimensional inversion procedure for interpreting areal changes in attenuation. To develop improved techniques of seismogram analysis to fit the entire P-wave seismogram in an attempt to determine the source spectrum and crustal reverberation as well as the seismic attenuation; to apply the technique to seismograms from geothermal areas.

Information/Status:

These studies complement P-wave travelttime-delay studies of lateral-velocity anomalies associated with geothermal systems. Seismic attenuation caused by high rock temperature, partial melting, and fluid or gas saturation within the pores or rocks may be associated with a geothermal system, or a magma chamber at depth. A two-dimensional model of seismic attenuation at The Geysers-Clear Lake geothermal area has been developed. A zone of high attenuation is located in the middle crust centered southeast of Mount Hannah, roughly coincident with zones of gravity low and delayed arrival times for P-waves.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Remote Sensing-Geothermal

Sponsoring Organization: USGS**Research Area(s):**

Heat Flow Studies

Contract/Grant Number: NA**Type of Research Activities:****Performing Organization:**Data Analysis/Documentation
Field Research

USGS

Principal Investigators:

Kenneth Watson

Objective:

To develop thermal-infrared remote-sensing techniques for reconnaissance geothermal exploration. To evaluate data collected by thermal-infrared scanner for assessing minimum detectable heat-flux anomalies. To map differences in geologic materials as expressed in their thermal properties.

Information/Status:

Study at a regional scale uses thermal satellite data (equivalent noon and midnight data; 500-m resolution) and study at a more local scale uses aircraft scanner data (data at various times, 10-m resolution). Algorithms to map the near-surface thermal properties and geothermal heat flux have been developed for aircraft and satellite data. Image sets for aircraft data acquired of Mt. Hood, Oregon, Newberry Caldera, Oregon, and the island of Hawaii have been prepared and open-filed along with the ground station data acquired during the overflight.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Resistivity Interpretation

Sponsoring Organization: USGS**Research Area(s):**Electrical Studies

Contract/Grant Number: NA**Type of Research Activities:****Performing Organization:**Field Research
Modeling/SimulationUSGS

Principal Investigators:Adel Zohdy

Objective:

To make direct-current resistivity surveys in geothermal areas in order to define subsurface geologic structure and to help site deep test wells. To develop mathematical formulas, computer programs, and pocket-calculator programs for improved acquisition and refined quantitative interpretation of resistivity data. To develop new theories, techniques, and field procedures for gathering high-resolution resistivity data over two- and three-dimensional structures.

Information/Status:

Deep resistivity soundings were carried out at the Idaho National Engineering Laboratory in Idaho Falls in the summers of 1978 and 1979. The results of this resistivity work, interpreted in the light of data from a subsequently drilled, 3 km-deep test well in the area of the survey, were presented at the 49th annual meeting of the International Society of Economic Geologists. Six new computer programs have been written in Enhanced BASIC for the HP-9845T to compute sounding curves obtained by 4 different types of electrode arrays over three vertical layers. An album of theoretical curves and the computer program for the full Schlumberger electrode array have been released in two open-file reports. An additional program for the Hankel Transform was written in Enhanced BASIC and converted from the original version of FORTRAN language. Three new albums of theoretical sounding curves have been computed for pole-pole, pole-dipole, and half-Schlumberger arrays expanded at right angles to three vertical layers. A manuscript on the theory of resistivity sounding over vertical layers is in preparation.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Geothermal Drilling at Mt. Hood, Oregon

Sponsoring Organization: USGS

Research Area(s):**Heat Flow Studies**
Well Logging

Contract/Grant Number: NA

Type of Research Activities:

Performing Organization:**Field Research****USGS**

Principal Investigators:**James H. Robison**

Objective:

To help assess the geothermal potential of the Mt. Hood area by drilling observation wells to determine temperature gradients and to characterize the subsurface geology and hydrology.

Information/Status:

This project is part of an interagency study (U.S. Department of Energy, U.S. Forest Service, U.S. Geological Survey, and Oregon Department of Geology and Mineral Industries) of the geothermal potential of a young Cascade stratovolcano. In 1979 four wells were drilled on the cone of the volcano including one to 610 m near Timberline Lodge. In 1980 the well near the Lodge was deepened to 1,200 m, one of the other wells was deepened, and three new wells were drilled. Temperature gradients vary from about 30°C/km to 84°C/km. The cone of Mt. Hood is comprised mostly of pyroxene andesite, both as lava flows and fragmental deposits. Near Timberline Lodge, pre-Mt. Hood rocks (altered andesitic lavas and epiclastic debris, with secondary mineralization) lie below an altitude of about 900 meters. Perched, water-saturated zones occur locally within the cone. In the 1,220-m-deep well near the Lodge the water table is 573 meters below the surface, substantially deeper than expected. A production test of this well is planned; temperature in the production zone is expected to be more than 70°C. Deepening and possible testing is proposed for two other wells.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Geothermal Hydrology of Lower Coachella Valley,
Southeastern California

Sponsoring Organization: USGS

Research Area(s):

Heat Flow Studies

Contract/Grant Number: NA

Type of Research Activities:

Performing Organization:

Field Research

USGS

Principal Investigators:

James H. Robison

Objective:

To describe the general geohydrologic framework of Lower Coachella Valley, California, especially as related to geothermal systems. To evaluate geologic, geochemical, and geophysical data that may indicate geothermal potential. To determine additional work needed for geothermal evaluation of high-potential areas.

Information/Status:

A drilling program of temperature-gradient holes and piezometers at 11 sites near Oasis was completed in 1979. Drillers' geophysical, and temperature logs have been made of the wells, which average 150-m deep, with maximum temperatures to 47°C and gradients as high as 107°C/km. Water samples from 8 piezometers have been analyzed.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Hydrogeologic Reconnaissance of Geothermal Areas in Oregon

Sponsoring Organization: USGS

Research Area(s):

Heat Flow Studies

Contract/Grant Number: NA

Type of Research Activities:

Performing Organization:

Field Research
Modeling/Simulation

USGS

Principal Investigators:

Edward A. Sammel

Objective:

To describe the hydrologic environment of several identified but unevaluated geothermal systems in Oregon and northern California. To interpret geologic, geochemical, geophysical, and hydrodynamic data in terms of the size, shape, and hydraulic characteristics of the geothermal reservoirs. To provide a basis for quantitative assessment of energy contained in the reservoirs. To apply existing numerical models to data obtained from several types of low- to moderate-temperature Basin and Range geothermal systems utilizing existing hydrologic, geologic, and geophysical knowledge in order to define the extent and functioning of these systems.

Information/Status:

USGS Professional Paper 1044-G that describes and evaluates the Klamath Falls, Oregon, geothermal area has been published. Core-hole drilling to a depth of 610 m in the crater of Newberry Volcano, Oregon, has increased our knowledge of this Cascade volcano; deepening of this hole to about 915 m was done in 1981. A report that describes the hydrology and evaluates the high-temperature geothermal resource in Warner Valley, Oregon, was completed. More sophisticated numerical models are currently being tested on the Klamath Falls geothermal system. A more precise understanding of boundary conditions and flow relations in this system is necessary for a reliable estimate of the geothermal resource.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Studies of the Geothermal Systems in the Western Black Rock Desert, Nevada

Sponsoring Organization: USGS

Research Area(s):

Gravity/Magnetic Studies

Heat Flow Studies

Brine/Gas Chemistry

Contract/Grant Number: NA

Type of Research Activities:

Performing Organization:

Field Research

Modeling/Simulation

USGS

Principal Investigators:

Alan Welch

Objective:

To develop an understanding of the geothermal systems of the western part of the Black Rock Desert through a variety of geologic, geophysical, geochemical and hydrologic studies.

Information/Status:

The first phase of the study, which includes results from gravity, thermal scanner, and 1-m-deep temperature surveys, is being prepared as an open-file report. Work is continuing on shallow test drilling, geochemical sampling, and the collection of hydrologic data. Numerical modeling of heat and mass flow will be used to assess conceptual models of the thermal system.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Geothermal Studies of the Snake River Plain, Idaho

Sponsoring Organization: USGS

Research Area(s):

Structural Geology

Contract/Grant Number: NA

Type of Research Activities:

Performing Organization:

Field Research

USGS

Principal Investigators:

Paul L. Williams

Objective:

To locate, map, and geologically define areas in and near the eastern Snake River Plain, Idaho, that may have geothermal potential. To provide a 3-dimensional geologic framework for further geological and geophysical interpretations by combining surface mapping with subsurface data. To provide geological expertise for the interpretation of the deep geothermal test well at Idaho Falls. To develop exploration concepts and case histories.

Information/Status:

This project began in 1974 and has supported geologic mapping and related studies in areas of rhyolite volcanism throughout the eastern Snake River Plain region. In areas of active geothermal exploration and development (Raft River Basin and Rexburg-Sugar City) subsurface studies are being carried out in cooperation with hydrologists and geophysicists. Present focus is on completing final reports for Raft River and Idaho Falls areas, completing mapping and petrographic studies of silicic volcanic rocks, and contributing to an assessment of geothermal resources of the Snake River Plain region.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Geothermal Investigations in Idaho

Sponsoring Organization: USGS

Research Area(s):

Brine/Gas Chemistry

Contract/Grant Number: NA

Type of Research Activities:

Performing Organization:

Laboratory Research-Analytical

USGS

Principal Investigators:

H.W. Young

R.E. Lewis

Objective:

To determine the occurrence, nature, and flow regime of geothermal fluids at selected sites, including Bruneau - Grand View, southwest Idaho, and parts of the Idaho batholith.

Information/Status:

Collection and interpretation of data from southwest Idaho and parts of north-central Nevada have been completed and a final report has been published discussing the hydrology and geochemistry of the area; residence time, recharge, and thermal energy of the reservoir are estimated. Investigation of the geochemistry of hot springs in the Idaho batholith has been divided into the drainage areas of the Payette, Salmon, and Boise rivers. Collection of data has been completed from the Payette and Salmon river drainages, and a report summarizing the results for the Payette River drainage has been completed. Data collection from the Boise drainage is underway.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Engineering Geophysics

Sponsoring Organization: USGS

Research Area(s):

Geophysics-Other (Seismic)
Well Logging

Contract/Grant Number: NA

Type of Research Activities:

Performing Organization:

Field Research
Data Analysis/Documentation

USGS

Principal Investigators:

Hans D. Ackermann

Objective:

To determine relationships between rock properties within geothermal systems and their seismic-wave transmission properties by seismic measurements in the field. To apply these relationships to geothermal exploration.

Information/Status:

A vibroseis seismic reflection survey consisting of 35 km of line was done under contract by the Colorado School of Mines in the Raft River, Idaho geothermal area. The results show a highly complex geologic section. Sonic logs from the wells in the area have been digitized to aid in the final interpretation.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Electromagnetic Modeling and Inversion of Controlled Source Measurements

Sponsoring Organization: USGS

Research Area(s):

Electrical Studies

Contract/Grant Number: NA

Type of Research Activities:

Performing Organization:**USGS****Modeling/Simulation****Field Research**

Principal Investigators:**Walter L. Anderson**

Objective:

To develop new numerical techniques and associated computer programs for electromagnetic (EM) modeling and inversion of controlled-source data. To investigate enhancements of existing forward and inverse programs and to study advanced techniques for further development of one- to three-dimensional EM problems.

Information/Status:

A comprehensive collection of one-dimensional forward and inverse programs for dipolar and grounded-wire sources over layered-Earth models were developed for both frequency and time domains. Two field studies in geothermal areas (Raft River, Idaho and Randsburg, California) were performed, and the results of data inversion published. Two-dimensional (2D) forward and inverse programs have been purchased and in some cases, modified to suit specific needs of the geophysical studies. One particular 2D modification describes EM scattering due to a plane-wave source using an integral equation solution. An important new concept was discovered for integrating related Hankel transforms of orders 0 and 1 by adaptive digital filtering. This new technique saves computer time (e.g., 50-80 percent faster than direct convolution methods) for forward and inverse programs using loop sources. Present research is aimed at three-dimensional (3D) EM modeling for conductors in a horizontally stratified Earth using natural or controlled sources at the surface.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Magnetotelluric Interpretation Procedures for Three Dimensional Earth Structures in Geothermal Areas

Sponsoring Organization: USGS

Research Area(s):

Electrical Studies

Contract/Grant Number: 14-08-0001-G-629

Type of Research Activities:

Performing Organization:

Theoretical Research

University of Texas

Principal Investigators:

Francis X. Bostick

Objective:

To develop procedures for interpretation of magnetotelluric (MT) data acquired over three-dimensional Earth structures and to test them against existing models. To develop techniques that provide for more efficient processing of MT data, particularly at low frequencies.

Information/Status:

Time-domain methods for estimating MT impedance functions utilize auto- and cross-correlation functions of the time-varying electric (E) and magnetic (H) fields. These methods were tested using synthetic data generated by three different techniques. One technique derives theoretical expected values of the auto- and cross-correlation functions from an assumed power density spectrum of the H field. Another technique uses synthetic data generated by a time-domain model in the form of a recursive digital filter. The third technique uses synthetic data generated using Fourier Transform techniques.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Mercury and Other Trace Elements in Soils as
Geochemical Tracers for Geothermal Activity

Sponsoring Organization: USGS

Research Area(s):

Fluid Tracer Studies

Contract/Grant Number: 14-08-0001-G-593

Type of Research Activities:

Performing Organization:

Field Research

Arizona State University

Data Analysis/Documentation

Principal Investigators:

Peter R. Buseck

Objective:

To study the distribution of mercury (Hg) and other selected elements in soil and rock samples in the vicinity of hot-water and vapor-dominated geothermal systems in order to develop a technique of exploration for new geothermal areas. To measure radon contents in soil gas from several geothermal areas to determine if radon anomalies occur and if they correlate with Hg anomalies. To investigate the occurrence of Hg in lake sediments from Clear Lake, California and Yellowstone National Park to determine variations of geothermal activity with time.

Information/Status:

Data gathered to date indicate a relationship between observed Hg-anomaly patterns and geologic structure of geothermal areas. Trace-element data from Lassen region, California, enable the modeling of transportation and distribution processes of trace elements in geothermal systems and serve as a general model for the evaluation of other geothermal areas.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Physical Properties of the Crust/Upper Mantle by Geomagnetic Variation and Laboratory Studies

Sponsoring Organization: USGS

Research Area(s):

Gravity/Magnetic Studies

Contract/Grant Number: NA

Type of Research Activities:

Performing Organization:

Hardware/Instrumentation
Development/Testing

USGS

Principal Investigators:

David V. Fitterman

Objective:

To develop a geomagnetic sounding technique for evaluating the physical state of the crust and upper mantle. To develop self-potential modeling techniques. To measure streaming-potential coefficients at elevated temperatures.

Information/Status:

Development of software and documentation for transcribing geomagnetic array data has been completed. Most of the work on software for automatically computing induction vectors has been completed. The remaining software and documentation is in preparation. Self-potential modeling techniques for several geometries useful in geothermal exploration have been developed, including an inversion technique for certain types of data.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Stable Isotopes

Sponsoring Organization: USGS

Research Area(s):

Geochronology/Stratigraphy
Heat Flow Studies

Contract/Grant Number: NA

Type of Research Activities:

Performing Organization:
USGS

Data Analysis/Documentation

Principal Investigators:

Irving Friedman

Objective:

To evaluate the use of the Pallman and Ambrose methods of temperature integration in assessing the geothermal potential of a region. To improve the obsidian-hydration dating method and to apply the technique to the dating of young volcanic rocks. To develop methods for the long-term continuous monitoring of hot-spring features.

Information/Status:

The Pallman method of temperature integration was applied to over 60 sites in and near Yellowstone National Park, in areas remote from known hot springs. Data on ground temperatures to be used in deriving hydration rates for obsidian used in geologic dating was collected. An area of anomalous heat flow was located near Slough Creek in the north central part of Yellowstone. A new type of temperature-integrating device, the Ambrose cell, has been modified for field use and is presently being compared to the Pallman solution at a number of sites in Yellowstone. Pallman ground temperature measurements were carried out at two geothermal sites in Nevada. Integration periods of 1 year and 3 months were compared with traditional ground temperatures measured monthly at depths of 1 meter and 15 meters and good correlation was found at one geothermal area. The other area in Nevada has a much smaller thermal anomaly, and neither the Pallman measurements at 1 and 2 meter depths nor the traditional thermistor measurements were able to pick up this anomaly. A new laboratory has been set up to study the hydration of obsidian at temperatures from 0° to 40°C. A newly developed micrologger has been purchased to monitor water flow, water temperature, and specific conductivity of hot springs. The data are collected hourly and are stored on a tape cassette. The equipment is about the size of a cigar box and will run for over 6 months on internal flashlight batteries.

Program/Project Title: Geophysical Instrumentation and Field Support

Sponsoring Organization: USGS

Research Area(s):

Electrical Studies

Contract/Grant Number: NA

Type of Research Activities:

Performing Organization:

Hardware/Instrumentation Development

USGS

Principal Investigators:

Frank Frischknecht

Objective:

To develop new geophysical instrumentation. To repair and maintain existing equipment. To provide technical support as required by field operations. To assist in procurement of commercially available equipment as required to meet the needs of other geophysical projects in the geothermal program.

Information/Status:

Instrumentation needed in the development and application of electromagnetic methods for geothermal studies is not generally available from commercial sources. Since the beginning of the project in 1976, several new instruments have been developed and constructed including: 14 digitally recording instruments for magnetometer-array-induction studies; two magnetotelluric (MT) systems using SQUID magnetometers; one microcomputer-based in-field MT processing system; two telluric-profiling instruments; self-potential monitoring equipment; controlled-source extra-low-frequency (ELF) systems and audio-magnetotelluric (AMT) systems. Modifications and improvements have been made in other equipment, including the airborne very-low-frequency (VLF) system. The staff has assisted several other projects with a variety of MT, controlled-source electromagnetic (EM), AMT, and airborne VLF and magnetometer surveys and has repaired and maintained existing, commercially obtained, and newly constructed instruments. Open-file reports on some of the new equipment have been prepared.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Statistical Separation of Random and Non-Random Components of the Spatio-Temporal Seismicity Distribution for Correlation with Geothermal Systems

Sponsoring Organization: USGS

Research Area(s):

Geophysics-Other (Seismic)

Contract/Grant Number: 14-08-0001-16379

Type of Research Activities:

Performing Organization:

Data Analysis/Documentation
Field Research

Sierra Geophysics, Inc.

Principal Investigators:

David M. Hadley

Objective:

To group earthquakes at geothermal areas into random and non-random components and correlate each component with geological and geophysical characteristics of the geothermal reservoirs such as gravity, heat flow, magnetics, resistivity, and structural geology in order to determine what earthquake characteristics are related to geothermal systems.

Information/Status:

Analysis has been completed for average magnitude 1.75 - 2.5 earthquakes for the Imperial Valley, Lassen, Coso and The Geysers. Comparison of these four geothermal areas with one non-geothermal area (San Jacinto fault zone) reveal several similarities and certain notable differences which lead to a possible definition of a geothermal earthquake. It was determined that 75% of the earthquakes are clustered temporally within 18 hours and spatially within 10 km in the geothermal areas. The average clustering time in the non-geothermal area is 5 or more days, and the average spatial separation is greater than 10 km. The significant exception is The Geysers area in which no temporal clustering of earthquakes is observed. This contrasts to the Lassen area which is tightly clustered in time and is also a vapor-dominated reservoir. The spatial and temporal pattern of earthquakes at The Geysers suggests that the geothermal wells may affect the normal seismicity associated with the reservoir. At the Salton Sea and Coso, earthquake clusters tend to lie outside of regions of high heat-flow.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Precision Magnetotelluric Measurements in the Geothermal Environment

Sponsoring Organization: USGS

Research Area(s):

Electrical Studies

Contract/Grant Number: 14-08-0001-G-627

Type of Research Activities:

Performing Organization:

Field Research

Brown University

Modeling/Simulation

Principal Investigators:

John F. Hermance

Objective:

To apply electromagnetic geophysical techniques to studies evaluating physical processes in the geothermal environment, including interpreting deep electrical studies from representative rift regions of the world. To incorporate new developments in data-processing software into the new PDP 11-34 computing facility and develop precision numerical modeling techniques for optimizing the recovery of information from actual field surveys.

Information/Status:

A comparison between a magnetotelluric study in an inter-plate rift, Iceland, with a similar study in an intra-plate rift, the Rio Grande valley of New Mexico, suggests several common features; 1) an anomalous, highly-conductive layer at crustal levels appears to be intimately associated with rifting in both regions, 2) measurements in adjacent areas (pre-glacial volcanic area in Iceland; Colorado Plateau near the Rio Grande rift) indicate that, although the anomalous conducting crustal layer is absent, conductivities in the upper mantle change little with depth to 100 km.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Shallow-Probing Electrical Techniques

Sponsoring Organization: USGS**Research Area(s):**Electrical Studies

Contract/Grant Number: NA**Type of Research Activities:****Performing Organization:**

USGS

Hardware/Instrumentation Development/Testing
Modeling/Simulation

Principal Investigators:Donald B. Hoover

Objective:

To develop shallow- to medium-depth electrical techniques as effective tools for geothermal exploration, especially audio-magnetotelluric (AMT), E-field-ratio-telluric and self-potential (SP) methods. To address problems of signal noise and a lack of understanding of source mechanisms associated with the self-potential method.

Information/Status:

The natural-source scalar AMT method has been demonstrated to be an effective reconnaissance tool for geothermal exploration. Numerous open-file and four summary and topical papers have been published on these results. Work is continuing on developing better instruments, both scalar and tensor; tensor capability will significantly improve the information contained in the AMT data. An international program in synoptic measurement of AMT fields is just getting started. The E-field-ratio-telluric method has been demonstrated to be an effective tool for defining faults along which thermal fluids migrate. Principal problems remaining under study are: 1) how to predict optimum times for field work, since natural signals are used; 2) how to extend the frequency range; and 3) how to obtain a better means of measuring the voltage ratios in the field.

The largest SP anomaly ever reported was measured on the slopes of Mt. Hood, Oregon. Work is underway to interpret this anomaly. A significant breakthrough appears to have been made recently in SP electrode design using a solid-state impermeable ceramic membrane rather than the conventional porous ceramic. The Department of Energy funds some research in this project to assess airborne electromagnetic surveys in geothermal areas.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Borehole Geophysics as Applied to Geothermal Research

Sponsoring Organization: USGS

Research Area(s):

Well Logging

Contract/Grant Number: NA

Type of Research Activities:**Performing Organization:**

USGS

Hardware/Instrumentation
Development/Testing

Principal Investigators:W. Scott Keys

Objective:

To develop reliable geophysical well-logging equipment for obtaining data from high-temperature wells. To develop specific interpretation techniques for analyzing logs from geothermal reservoirs.

Information/Status:

The equipment-development phase of this project is decreasing because a comprehensive suite of high-temperature apparatus has been developed and successfully tested. The most important contribution to date has been the development and application of a high-temperature acoustic televiewer for logging fractures in geothermal wells. The location, apparent width, strike and dip can be derived from these logs. A number of high-temperature logging probes and the necessary cable have been developed and operated in geothermal wells at temperatures up to 260°C. These include flow meter, temperature, natural gamma, gamma spectra, neutron, single-point resistance, spontaneous potential, multielectrode resistivity, mechanical caliper, acoustic caliper, and acoustic televiewer. A high-temperature acoustic velocity probe is undergoing preliminary tests. Most of these probes have been utilized in wells at six different geothermal reservoirs in the western United States. The major effort is now equipment modification for improved performance. Progress has been made on the development of log-interpretation techniques for unique geothermal environments, but considerable work needs to be done on quantitative interpretation and development of computer algorithms to provide relative magnitude and character of porosity and permeability, lithology and correlation, thermal conductivity and heat flow, fluid quality and monitoring changes in the reservoir. Papers have been published or are in review on the following topics related to the application of borehole geophysics to geothermal reservoirs: problems and progress in geothermal logging; the physical character of the Raft River reservoir from borehole geophysics; the delineation of hydraulic fractures induced for geothermal well stimulation; borehole geophysics in igneous and metamorphic rocks; and a quantitative analysis of flowmeter logs made during an injection test of a geothermal well. Studies underway on the quantitative analysis of gamma spectra and fracture characterization by acoustic wave form analysis will have geothermal applications, and papers on these subjects are in review.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Magnetotelluric Modeling for a Crustal Environment

Sponsoring Organization: USGS

Research Area(s):

Electrical Studies

Contract/Grant Number: 14-08-0001-G-643

Type of Research Activities:

Performing Organization:

Modeling/Simulation

Massachusetts Institute of Technology

Theoretical Research

Principal Investigators:

Theodore R. Madden

Objective:

To develop practical methods of dealing with magnetotelluric data in areas of complex resistivity structures.

Information/Status:

Complex resistivity structures distort the electric-current distributions so that simple interpretations of the data based on one- or two-dimensional models can give misleading results. The combination of generalized thinsheet analysis and multiple-scale analysis seem to be a powerful method of dealing with the low-frequency response of a crustal region, although more work needs to be done to fully understand and optimize the multiple-scale analysis. Because of the preponderance of lenticular shapes in geologic structures, a thin-layer approach seems optimum for realistic modeling. Improving the multiple-scale methods applied to thin-layer modeling appears to be the most difficult aspect of developing a practical three-dimensional magnetotelluric modeling scheme. The difficulty has been traced to a specific operation and several ways of circumventing this operator are being examined. As expanding the thin layer analysis to a three-dimensional analysis is considered, the subtleties between different solution methods are more clearly understood. In earlier work on network analogies to two-dimensional EM problems a simultaneous solution of the entire network was used. In order to keep the network simply connected, simple impedance boundary conditions were needed at the boundaries of the system. This was accomplished by pushing the boundaries far enough away from the measurement surface so that the error effects at the boundaries caused negligible errors on the measurement surface. This technique avoided the use of an air admittance operator, and can be used just as well with the three dimensional approach.

Program/Project Title: Interpretation of Self-Potential Data from Geothermal Areas

Sponsoring Organization: USGS

Research Area(s):

Electrical Studies

Contract/Grant Number: 14-08-0001-16546

Type of Research Activities:

Performing Organization:

Field Research

University of California at Berkeley

Principal Investigators:

Frank Morrison

Objective:

To investigate the self-potential method of geothermal prospecting with emphasis on improvement of the quality of data and reduction of noise. To collect reliable self-potential data from geothermal areas where high-quality self-potential surveys have not yet been conducted and to analyze these data using the analytical methods currently being developed.

Information/Status:

Electrode response to changes in soil properties at a non-geothermal area (Law Ranch, California) and at Beowawe, Nevada, KGRA indicate that variations in potential caused by changes in measured soil properties (moisture content, pH, and conductivity) probably do not exceed about 10 millivolts where the soil is fairly uniform. In areas where soil properties vary more drastically these variations may reach a few tens of millivolts. Variations in soil properties at Beowawe show little or no correlation with a large dipolar self-potential anomaly (about 450 millivolts peak-to-peak) measured in the area of surface thermal activity. Results of a self-potential profile run with five different electrode types across a zone of sinter soil at the Steamboat Springs, Nevada, KGRA indicated that all of the electrode types gave essentially the same results, even in an area where soil type changed drastically from point to point, and the effects of cumulative error on data taken "leap-frog" fashion in such an area are severe. Analysis of self-potential data taken at the East Mesa, California, KGRA indicates that geothermal activity along fault zones inferred by previous investigations could account for the form of the anomaly, but that measurements of coupling coefficients at in situ temperature and pressure conditions are needed before any conclusion can be reached about the relative contributions of fluid and heat flow to the total anomaly. Consequently, a test cell for measuring thermoelectric coupling coefficients of rocks from geothermal reservoirs under in situ conditions has been designed and constructed. Core samples have been obtained for East Mesa and Cerro Prieto, Mexico, and are being tested.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Navy Environment: Shallow Temperature Geothermal Exploration

Sponsoring Organization: DOD/Navy

Research Area(s):

Heat Flow Studies

Contract/Grant Number: DN875691; N00014-78-C-0535

Type of Research Activities:

Performing Organization:

Modeling/Simulation

Leschack Associates, Ltd.

Principal Investigators:

L.A. Leschack

Objective:

Examine the shallow temperature (2 M) geophysical survey technique for use in evaluating the geothermal energy potential at U.S. Navy installations and other potential geothermal anomalies.

Information/Status:

The principal investigator will examine the effects of thermal diffusivity, albedo and surface roughness on the shallow temperature exploration technique for geothermal field studies. Using an energy budget simulation model, seasonal variation corrections for shallow temperature surveys will be determined and verified from data collected at the Naval Weapons Center, China Lake, California, and the Long Valley Geothermal Area, California. The Department of Energy, Division of Geothermal Energy, will also provide partial support for this work.

Contract began May 1978 and is continuing. FY 1980 funding was \$12,300.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Porosity With Fluids: Origin and Effects on Physical Properties of Crustal Rocks

Sponsoring Organization: DOE/Office of Energy Research

Research Area(s):

Physical Properties - Rocks/
Liquids

Contract/Grant Number: DE-AT03-76ER 71045

Geophysics-Other (Seismic)

Performing Organization:

Type of Research Activities:

Stanford University

Laboratory Research-Experimental

Principal Investigators:

A.M. Nur

Objective:

(1) to find the relations between the physical properties of porous rocks with fluids, which are measured routinely by geophysicists and the state of these rocks; (2) to discover new effects or processes in these rocks, which influence the permeability of fluids flowing through the pore space, the changes of porosity with time, and the effects of compaction, chemical reaction, and temperature on the pore space; and (3) to develop applications of the results to new in situ geophysical techniques in boreholes and on the surface.

Information/Status:

Measurements of wave velocities and attenuation as a function of confining pressure, pore pressure, temperature, and pore fluid type are made on a variety of rocks to determine the effects of porosity, clay minerals, fluid chemistry, pore shape, and grain size. The results will provide the data necessary to determine what information about the state of rock in situ can be inferred from measurements of seismic waves.

Measurements of flow in porous rocks are done at elevated confining and ore pressures, with reaction fluids and gas. The reactive fluids--in which FE^{+3} and pH are controlled--are used to understand the mechanism by which permeability in porous rock changes with time--an often observed effect in the lab, and potentially a desirable effect in situ. The gas flow is studied in very tight gas sandstones, in order to understand the dependence of flow rate on pore pressure and particularly the immobile partial water saturation.

The velocity and attenuation results from rocks with steam/hot water in the pores suggest that seismic methods can be developed to detect the presence of steam in the subsurface or to detect changes with time, such as during steam flooding of reservoirs. The relation between Q^{-1} and partial water saturation may be utilized to determine water saturation in situ. The results of the chemical permeability control experiments are being applied among others to modeling the effects of silica transport in the crust, crustal permeability, and pore pressure distribution. The last two parameters are the key to understanding a number of crustal phenomena ranging from reservoir-induced seismicity to the formation of overpressurized zones.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Seismic Velocity Variations and Attenuation to
Delineate Geothermal Reservoirs

Sponsoring Organization: DOE/Office of
Energy Research

Research Area(s):

Well Logging
Geophysics-Other (Seismic)

Contract/Grant Number: DE-AT03-76ER71045

Type of Research Activities:

Performing Organization:

Field Research
Laboratory Research-Analytical

Stanford University

Principal Investigators:

R.L. Koach
A.M. Nur

Objective:

Estimate macrocrack density for sonic well logs

Information/Status:

A study of the effects of macroscopic fractures on P- and S-wave velocity has been completed in four wells drilled in fractured rock to depths between 0.6 and 1.2 km. The macroscopic fractures decrease both V_p and V_s and increase V_p/V_s . In wells with a low density of macroscopic fractures, the in situ velocity was similar to that of saturated core samples under confining pressure in the laboratory, and a clear correlation could be made between macroscopic fracture zones and zones of anomalously low velocity. In wells with numerous macroscopic fractures, the in situ velocity is distinctly lower than that of intact samples under pressure, and a correlation was seen between the rate at which in situ velocity increases with depth and the rate at which velocity of laboratory samples increases with pressure. Differences in in situ P-wave velocity between wells could not be explained solely by differences in the degree of macroscopic fracturing, thus emphasizing the importance of composition and microfractures on velocity. The change of in situ velocity with depth in the wells indicates that only at very shallow depths (less than a few hundred meters) is the stress sensitivity of P-wave velocity appreciably greater in situ than in laboratory specimens under pressure.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Rock Deformation in Hydrothermal Systems: The Nature of Fractures in Plutons and Their Host Rocks

Sponsoring Organization: DOE/Office of Energy Research

Research Area(s):
Structural Geology

Contract/Grant Number: DE-AC02-81ER10842

Type of Research Activities:

Performing Organization:
University of Arizona
Department of Geosciences

Field Research
Modeling/Simulation

Principal Investigators:

D. Norton

Objective:

Reconstruct the state of stress in magma-hydrothermal systems using field data and transport theory

Information/Status:

Work has centered on developing mapping techniques for the collection of data on fractures in fossil magma-hydrothermal systems. Fracture characteristics such as frequency, spacing, continuity, and effective aperture are being mapped in one fossil system in detail and in several systems at a reconnaissance scale. New computer techniques are then being used to summarize the data in a form that will benefit engineers concerned with waste repositories and geothermal systems and that will improve the theoretical basis for analyzing processes in magma-hydrothermal systems.

A method for mapping fractures has been designed and partially tested: the geometry and relative ages of fractures are recorded on photographs, then converted into digital form for analysis by computer. These field methods are being used in the study of the Cochise, Diamond Joe, Papoose Flat, Ponder, and Dells plutons. The intent is to reconstruct the thermal history of these plutons by comparing their structural state with that of mathematical models.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Thermal Regimes of Major Volcanic Centers

Sponsoring Organization: DOE/Office of
Energy Research

Research Area(s):

Electrical Studies
Volcanology

Contract/Grant Number: DE-AC02-79ER10401

Type of Research Activities:

Performing Organization:

Brown University
Department of Geological Sciences

Field Research
Modeling/Simulation

Principal Investigators:

J.F. Hermance

Objective:

Apply geophysical and electromagnetic techniques to detect and characterize geological features and physical processes within the earth that are related to energy sources

Information/Status:

- 1) Conducting geophysical investigations of thermal processes associated with major volcanic centers particularly in Long Valley/Mono Basin area, and Valles Caldera.
 - 2) Interpretation of the physiochemical processes associated with the genesis of primitive crust in the Mid Atlantic Ridge.
 - 3) Development of a geophysical field system (using tellurics, magnetotellurics, and geomagnetic variations) which is being used for preliminary field work in the Mono Basin/Long Valley volcanic complex.
 - 4) Development of models to simulate the electromagnetic response of representative geologic structures.
 - 5) Research is in progress to generalize concepts regarding the interaction between the spatial wavelength of source fields and the scale size of lateral heterogeneities.
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Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Relationship of Rock Physics to Geothermal Energy Technology

Sponsoring Organization: DOE/Office of
Research Energy

Research Area(s):
Physical Properties Rocks/Liquids

Contract/Grant Number: DE-AS03-76F00034
DE-AT-03-76ER70224

Type of Research Activities:

Performing Organization:

Theoretical Research

University of California Los Angeles
Institute of Geophysics and Planetary
Physics

Principal Investigators:

O.L. Anderson
N. Warren

Objective:

Develop analytical tools and carry out integrated analyses of rock mechanical properties controlled by microstructure; define the statistical interrelationships of rock microstructure to petrographic and mechanical rock properties.

Information/Status:

By considering both dynamic and static strain data, and strain spectra derived from the data, work is centering on resolving hysteresis, changes in crack and populations with stress, and ratios of dynamic to static moduli which may yield a measure of crack porosity.

Techniques for the statistical analysis of petrographic structures have been developed. The output of this analysis is a set of evaluated parameters which cross-correlate petrographic, mineralogical, and microstructural variables, to aid in the prediction of rock mechanical properties.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Characterization of the Physical, Seismic, Electrical and Thermal Properties of Kilauea Iki Lava Lake Samples to Melting Temperatures Under Elevated Pressures and Controlled Volatile Content: Potential Uses of the Results in Seismic Exploration and Delineation of Magmatic Bodies, and in Thermal Modeling

Sponsoring Organization: DOE/Office of
Energy Research

Research Area(s):

Physical Properties Rocks/Liquids

Contract/Grant Number: DE-AT03-80ER12099

Type of Research Activities:

Performing Organization:

Laboratory Research - Experimental

University of Hawaii
Hawaii Institute of Geophysics

Principal Investigators:

M.H. Manghnani

Objective:

(1) to understand how the physical properties of basalts relevant to geothermal exploration and thermal modeling in a volcanically active area are affected by a total environmental system; (2) to investigate interrelationships between the various properties; and (3) to correlate the laboratory data with the models based on theory and field measurements.

Information/Status:

The research effort is concerned with two areas of laboratory investigation: (1) characterization of physical (density, porosity, and pore size distribution), seismic (V_p , V_s , Q^{-1}), and thermal (conductivity) properties of core samples from Kilauea Iki Lava Lake under in situ conditions, and (2) viscosity, electrical conductivity, and V_p , V_s , and Q^{-1} of magmatic fluids at elevated pressures and temperatures and as a function of controlled volatile (e.g., H_2O , CO_2) content.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Seismology of Crack Formation and Natural Geothermal Systems

Sponsoring Organization: DOE/Office of
Energy Research

Research Area(s):

Geophysics-Other (Seismic)

Contract/Grant Number: DE-AC02-76ER02534-
A006

Type of Research Activities:

Performing Organization:

Massachusetts Institute of Technology

Modeling/Simulation
Theoretical Research

Principal Investigators:

H. Aki

Objective:

Define the geometrical and physical properties of geothermal systems and estimate the mass and energy transport through measurements of seismic signals generated by the geothermal system, such as volcanic tremors.

Information/Status:

Models are being developed for the hot dry rock fracture system at Fenton Hill, magma lens in Kilauea Iki, deep and shallow tremor sources under Kilauea, inside Mt. St. Helens and other volcanoes. The data needed for study are collected by a network of mobile digital seismographs from the Massachusetts Institute of Technology as well as from the U.S. Geological Survey, Los Alamos National Laboratory, Oregon State University, the University of Washington, the Centro de Investigacion Cientifica y de Educacion Superior de Ensenada in Mexico, the University of Paris, through cooperative arrangements.

Work is also being undertaken on developing a new borehole seismograph which can be operated at high temperature.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Investigation of Magma Chambers in the Western Great Basin

Sponsoring Organization: DOE/Office of
Energy Research

Research Area(s):

Geophysics-Other (Seismic)
Volcanology

Contract/Grant Number: DE-AS08-82ER12082

Type of Research Activities:

Performing Organization:

Field Research

University of Nevada

Principal Investigators:

A. Ryall

Objective:

Resolve questions related to the depth and configuration of the Long Valley, CA, magma chamber, depth and configuration of a possible magma chamber in the Adobe Hills volcanic complex, and temporal and spatial behavior of earthquakes where seismicity is known to be related to the movement of magma.

Information/Status:

Seven additional seismic stations are being installed to improve coverage in the Long Valley-Mono Craters area. Data obtained from the Mina station (wide-band, wide dynamic range, digital seismographs) will be used to determine special characteristics of seismic signals affected by attenuation in the Long Valley magma chamber.

Analysis efforts are focussed on developing an improved picture of hypocentral distribution and focal mechanisms of microearthquakes and small earthquakes in the area covered by the Long Valley-Mono Craters network.

Analysis of field and network data will continue to search for effects that would provide more concrete evidence of new magma in the Long Valley.

Work is also underway on characterizing the attenuation of seismic waves by a possible magma chamber in the Adobe Hills area, and comparing such effects with those observed for earthquake waves propagating through the Long Valley magma chamber.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Reservoir Dynamics

Sponsoring Organization: DOE/Office of
Energy Research**Research Area(s):**Heat Flow Studies

Contract/Grant Number: W-7405-ENG-48

Type of Research Activities:**Performing Organization:**Modeling/Simulation
Theoretical ResearchLawrence Berkeley Laboratory

Principal Investigators:J.A. Apps
C.F. Tsang

Objective:

Obtain a better understanding of various underlying physical and chemical processes and their effects through analytic studies and numerical modeling, as related to geothermal energy, thermal energy storage in aquifers, and geological isolation of nuclear waste.

Information/Status:

The possibility of storing hot or chilled water in aquifers has attracted considerable attention during the last few years. The goal is to store large amounts of heat or chill in a confined aquifer and at a later time pump up for space heating or cooling. Most reservoir engineering and well testing experiences have been based on hydrology and petroleum engineering fields which usually assume isothermal conditions. The presence of nonisothermal fluid flow in a geothermal reservoir introduces a number of interesting problems. Heat released by the radioactive decay of nuclear wastes in an underground repository causes a long term thermal disturbance in the fluid flow in the fractured rock mass in which the repository is situated. Studies in regional thermally induced convection around and above the repository in the rock mass will be made to understand the crucial question of fluid flow characteristics from the repository to the biosphere. As more experiences are gained in the field work and modeling studies, new possible directions of energy research and development may emerge. Initial investigations will be made to determine the practicability of these ideas.

Started in 1980, with FY 1980 funding of \$210,000.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Fundamental Studies of Fluid Mechanics and Heat Transport in Porous Media

Sponsoring Organization: DOE/Office of Energy Research

Research Area(s):

Fluid Migration

Contract/Grant Number: EY-76-S-03-0326062

Type of Research Activities:

Performing Organization:

Stanford University

Theoretical Research
Laboratory Research-Experimental

Principal Investigators:

G.M. Homsy

Objective:

Study mechanical flow of non-Newtonian fluids through porous media and examine convection in porous media which is driven by temperature differences.

Information/Status:

We propose to study two important fundamental problems in flow and transport in porous media. The first problem is a mechanical description of the flow of non-Newtonian fluids through porous media. We will develop a theory based upon retarded motion expansions for rheologically slow flow. The theory will provide a rational extension of Darcy's law to account for non-Newtonian effects. We plan to test these predictions by a series of experiments in which we first characterize the rheology of the fluid in question and then measure the response for flow through fixed beds. Using these results, we will then examine the stability of the displacement of a Newtonian fluid by a non-Newtonian fluid. Application will be made to processes for improved recovery of oil.

The second problem will examine convection in porous media which is driven by temperature differences. We will use modern computational techniques to describe the flow which is known to bifurcate from steady two-dimensional flows, but whose detailed description is unavailable. Applications in the field of geothermal energy production are indicated, and these furnish the prime motivation for the study.

Work on the effort was undertaken during the period March 1978 to February 1980.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Microcracks and Energy

Sponsoring Organization: DOE/Office of
Energy Research**Research Area(s):**

Physical Properties Rocks/Liquids

Contract/Grant Number: AS02-78ER04972**Type of Research Activities:**

Performing Organization:

Data Analysis/Documentation

Massachusetts Institute of Technology

Principal Investigators:

G. Simmons

Objective:

Information/Status:

This project applies the techniques that have been developed for the study of microcracks to various energy programs within the Department of Energy. Microcracks in geothermal rocks, potential source rocks for uranium deposits, Devonian shales of eastern North America that may provide significant production of natural gas, and oil shales are being examined. The objective of the project is to indicate directions for the solution of practical problems on the basis of the microcracks in appropriate rocks. The final product is a comprehensive report on the application of microcrack techniques to various energy programs. The relation of microcracks in granitic source rocks to the transport of uranium and other radioactive elements is being examined. On the basis of a suite of samples of core from a 3000-foot hole at the Redstone Quarry, New Hampshire, it is shown that the microcracks are probably the channels through which radioactive elements have migrated.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Physical Chemistry With Emphasis on Thermodynamic Properties

Sponsoring Organization: DOE/Office of Energy Research

Research Area(s):

Heat Flow Studies

Contract/Grant Number: 005953

Type of Research Activities:

Performing Organization:

University of California
Lawrence Berkeley Lab.

Theoretical Research
Laboratory Research-Experimental

Principal Investigators:

H.S. Pitzer

Objective:

The objectives are the discovery and development of methods of calculation of thermodynamic and related properties of important chemical systems by use of quantum and statistical mechanics together with experimental measurements for key systems.

Information/Status:

Current efforts include relativistic quantum mechanical methods for the calculation of energies, bond distances, and other properties of the ground and excited states of molecules containing very heavy atoms where the conventional nonrelativistic methods are inadequate. Such results are important in evaluation of possible laser systems and for models of catalytic entities including heavy atoms such as platinum. Another general area is that of ionized systems, electrolyte solutions and plasmas. Theoretical work includes the exact statistical treatment of dissociation equilibria in a plasma at very high temperature. Systems comprising fused salts mixed in any proportion with water are being studied experimentally and with semiempirical theory. Earlier theoretical advances for electrolytes are now being applied to a wide variety of systems of industrial or geological interest including geothermal brines. Work was begun in FY 80 with funding of \$130,000.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Geosciences Program

Sponsoring Organization: DOE/Office of
Energy Research

Research Area(s):

Physical Properties Rocks/Liquids
Mass Heat Transport
Brine/Gas Chemistry

Contract/Grant Number: DE-AC-03-76SF00098

Type of Research Activities:

Performing Organization:
Lawrence Berkeley Laboratory

Laboratory Research-Experimental
Modeling/Simulation
Hardware/Instrumentation Development

Principal Investigators:

P.A. Witherspoon
C.D. Tsang
W.H. Somerton
H.S. Pitzer

Objective:

The Geosciences Program at Lawrence Berkeley Laboratory consists of nine projects. These projects are broadly based fundamental studies that support development of hot water energy storage, stimulated recovery of oil, isolation of radioactive wastes, and uranium resource evaluation and recovery. Studies include formulating theoretical concepts, developing new instrumentation, executing experimental measurements in the laboratory and field, and simulating processes using computer models.

Information/Status:

a) Non-isothermal Reservoir Dynamics - project encompasses a wide range of fundamental studies of fluid, heat, and solute transport in underground formations. The goal of the effort is to better understand various physical and chemical processes in porous or fractured media and their effects through analytical and numerical modeling; (b) Properties and Behavior of Rock-Fluid Systems - measure the properties and behavior of the fluid container (porous rock) at reservoir conditions. Models are being developed that allow property changes to be predicted for changes in environmental conditions. The models will have important applications to numerical simulation of reservoir behavior; (c) Thermodynamics of High Temperature Brines - theoretical and experimental studies concerning the thermodynamic properties of aqueous electrolytes. The components important in natural waters and brines are emphasized. The experimental program involves measuring the heat capacity and the density of solutions in the 0 - 300°C and 0 to 1 kbar range to give a comprehensive equation of state. The theoretical work has yielded equations predicting the properties of mixtures based on the knowledge of the pure component solutions in water. Calculations for solutions of Na⁺ with CO₃²⁻, HCO₃⁻, OH⁻, and Cl⁻ were recently completed. Current experimental work relates to MgSO₄; (d) Rock-Water Interactions - the objective is to understand factors controlling ground-water chemistry by measuring the dissolution of common rock-forming minerals in aqueous solutions of 25-400°C and 0.1 to 50 MPa. Results are used to test rock-water interactive models and refine existing rock-water interaction computer codes and data bases; (e) Thermodynamic Properties of Silicate Liquids - measure physical properties of

Information/Status: (continued)

silicate liquids (1300 - 1800 Temp K) in order that the generation of magmas deep in the earth, their ascent toward the surface, and their subsequent cooling can be quantified. A solution model has been formulated and is being used to address the complexities of the equilibration of calcium-rich pyroxene with liquid; (f) Chemical Transport in Natural Systems - derive descriptions of phenomena associated with chemical transport in natural systems which account directly for a system's irreversibility and produce quantitative results consistent with experience and thermodynamic principles; (g) Aqueous Solutions Data Base for Nuclear Waste Disposal - provide basic data on relevant properties of aqueous solutions to high temperatures and pressures. Emphasis is on providing mathematical equations and tabulated values to be used for calculations and in computer codes for the disposal of nuclear wastes; (h) Deep Electromagnetic Sounding of the Crust - studying the feasibility of deep sounding by a controlled-source electromagnetic method in which a large alternating current is applied to a loop transmitter. Work has been conducted in an area of Central Nevada; (i) Effect of Fracture Characteristics Upon Acoustic Wave Propagation in Boreholes - conduct of a field experiment which will provide digitized sonic waveform measurements across single horizontal, isolated fractures intersecting a borehole in a crystalline rock mass. The work covers areas such as geothermal energy extraction, oil and gas recovery, deep crusted studies, and the storage of hazardous wastes; (j) Continental Scientific Drilling Program - focus is to geochemically characterize and evaluate the hydrothermal-magma system beneath the Valles Caldera, New Mexico. In progress is a wellhead sampling program of a number of relatively deep (7,000 ft) wells. Work is continuing on the conceptual design and engineering feasibility of a downhole sampler to be used at temperatures to 500°C.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Well Engineering and Sampling Variables in the Evaluation of Geobrine

Sponsoring Organization: U.S. DOI/Bureau of Mines

Research Area(s):

Brine/Gas Chemistry

Contract/Grant Number: N/A

Type of Research Activities:

Performing Organization:

Laboratory Research-Analytical

U.S. DOI/Bureau of Mines

Principal Investigators:

W.D. Riley

G.R. Conner

R.P. Walters

P.B. Needham, Jr.

F.X. McCawley

Objective:

Perform and evaluate chemical analyses of selected high-salinity and low-salinity geothermal brines found in California's Imperial Valley in support of the Bureau's geothermal minerals recovery investigations.

Information/Status:

The Bureau of Mines has been conducting minerals recovery research in support of the nation's geothermal program since 1974. The Bureau's program of laboratory and field studies has focused on determining the materials of construction for geothermal resource recovery plants and on the recovery of mineral values from the geobrine. As part of this effort, an analytical program has been conducted at the Avondale Research Center to determine the chemical constituents of some high- and low-salinity geobrine found in the Imperial Valley of California.

Data have been reported for the early stages of brine production of four geothermal wells--the low-salinity, medium-enthalpy brines from the East Mesa Known Geothermal Resource Area (KGRA), Mesa 6-1 and 6-2, and the high-salinity, high-enthalpy brine from the Salton Sea KGRA, Magmamax 1 and Woolsey 1. The reported results indicate the importance of the operating and engineering history, the operating parameters during sampling, and the method of sampling in order to evaluate the chemical analyses.

Findings of the study are highlighted below.

Analysis of geobrine poses unique and special problems to the analytical chemist. However, problems associated with the physical aspects of sampling and well operations present equally unique and special problems. Analytical technique is but one factor in establishing baseline chemistry data. In order to completely characterize a geobrine, all facets of the brine must be

Information/Status: (Continued)

examined, from the history of the producing reservoir through the operational steps in the process plant to the treatment of the brine in the laboratory.

In order to fully understand the analysis of a geothermal fluid, several reportable conditions must be specified: (1) sampling and handling procedures, (2) flow characteristics of the well, (3) recent engineering changes, and (4) changes in the baseline chemistry.

Normal AAS techniques may not be satisfactory for analysis of high-salinity geobrine. The complex composition of the high-temperature, saline brines may require specialized techniques for a true analysis.

Furthermore, each particular brine may require special modifications to both the normal and specialized analytical techniques. In the use of atomic absorption spectroscopy, simple standards are not sufficient to provide accurate results.

A single analysis of a geobrine does not provide a complete evaluation of the composition. Many factors can influence the true chemical composition of the solution. Chemical analyses of brines reported in the literature may be extremely accurate. However, for most of the data, conditions of sampling, reservoir history, or other influencing factors are not reported and the data are of little or no value.

The Bureau is continuing the investigation of methods of improving: (1) procedures of sampling, both gas and liquid, (2) gas analyses, and (3) characterization of the two-phase environment.

- Well Engineering and Sampling Variables in the Evaluation of Geobrine.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Thermodynamics of High Temperature Brines

Sponsoring Organization: DOE/Office of
Energy Research

Research Area(s):

Mass Heat Transport

Contract/Grant Number: 005981

Type of Research Activities:

Performing Organization:

University of California
Lawrence Berkeley Laboratory

Theoretical Research
Laboratory Research-Experi-
mental

Principal Investigators:

J.A. Apps
H.S. Pitzer

Objective:

Information/Status:

A study will be made of the solution thermodynamics of brines covering systems both simple and complex, weak and strong, over a wide temperature and pressure range, combining a theoretical and experimental program to provide essential information for the technical utilization of many geothermal resources. The experimental program includes construction and use of a flow calorimeter and of a densimeter measuring heat capacities and densities up to about 300 degrees C and a kilobar on systems previously unreported plus extending existing data to higher temperatures and pressures. Work on the project was initiated in FY 80 with funding of \$125,000.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Aqueous Solutions Database

Sponsoring Organization: DOE/Office of
Energy Research

Research Area(s):

Brine/Gas Chemistry

Contract/Grant Number: 005989

Type of Research Activities:

Performing Organization:

Data Analysis/Documentation

University of California
Lawrence Berkeley Lab.

Principal Investigators:

J.A. Apps
S.I. Phillips

Objective:

Provide a single, comprehensive computerized data base of properties of aqueous solutions involved in basic geothermal energy.

Information/Status:

The compilation, which includes critical evaluation and correlation, constitutes a single source of recommended values to be used in research and development of both power production and direct utilization. In addition, the result of this work includes identification of areas where data are lacking or are inadequate, and recommendations for research designed to provide the needed data. The properties covered range up to 350 degrees C, 50 MPa and saturation concentration; they include the following: enthalpy, heat capacity, viscosity, thermal conductivity, solubility and density. The substances covered include mainly sodium chloride, but other important solids and gases, for example calcium and potassium chlorides and hydrogen sulfide are considered. The project is expected to shift emphasis to that of providing critically evaluated data on the migration, leaching and treatment of nuclear wastes. This will continue to involve us in basic data such as complex ion formation constants for aqueous solution species. However, the dissolved substances will be those elements important to nuclear waste isolation, e.g., the actinides. Work on the effort was initiated in FY 80 with funding of \$85,000.

Treatment Methods for Geothermal Brines, Phillips, S.L., Mathur, A.K., and Garrison, W., April 1979.

Thermal Conductivity of Aqueous NaCl Solutions From 20 to 330°C, Azbek, H., and Phillips, S.L., Feb 1980.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Geothermal Prospecting With SQUIDS

Sponsoring Organization: DOE/Office of
Energy Research

Research Area(s):

Electrical Studies

Contract/Grant Number: 005327

Type of Research Activities:

Performing Organization:
Argonne National Lab

Hardware/Instrumentation -
Development/Testing

Principal Investigators:

C.M. Falco
I.K. Schuller

Objective:

Develop and evaluate instrumentation based on Superconducting Quantum interference Devices (SQUIDS) to be used for geophysical prospecting.

Information/Status:

By measuring the electromagnetic response of the earth to a driving current as a function of frequency, it is planned to model the conductivity of the earth and correlate the results with the existence of hydrocarbon and mineral deposits. The use of advanced superconducting technology allows a greatly increased sensitivity over other available methods. Such instrumentation has been developed and is being constructed along with suitable data acquisition equipment. This will then be utilized directly in field tests. Work on the project began in 1980 and is ongoing. Funding during FY 80 was \$190,000.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Exploration for Geothermal Resources in the Capital District of New York

Sponsoring Organization: DOE/Office of Energy Research

Research Area(s):

Brine/Gas Chemistry
Gravity/Magnetic Studies

Contract/Grant Number: FGO5-79ER10082

Type of Research Activities:

Performing Organization:

Field Research

New York State Energy Research and Development Auth. and Dunn Geoscience

Principal Investigators:

M.R. Sneeringer
J.R. Dunn

Objective:

Evaluate the potential for a hydrothermal system for the Capital District Area of New York.

Information/Status:

Water chemistry, gas analyses, and geophysical methods including gravity and magnetic surveys, microseismic monitoring, and temperature gradient measurements were used in the Capital District area to evaluate the potential for a hydrothermal geothermal system. Water and gas chemistries provided indirect indicators, and temperature gradients provided direct indications of a geothermal system. Gravity results were supportive of gradient and chemistry data, but seismic and magnetic work have thus far provided little information on the potential system. Gradients throughout the area ranged from an average background value of about 10/sup O/C/km to a high of roughly 44/sup O/C/km. The highest gradient values, the most unusual water chemistries and largest carbon dioxide exhalations occur along the Saratoga and McGregor faults between Saratoga Springs and Schenectady, and indicate a good potential for a usable hydrothermal geothermal system at depth. Results of the project were documented in NYSEDA report #81-11 completed in November 1981.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Rock Deformation in Hydrothermal Systems

Sponsoring Organization: DOE/Office of
Energy Research

Research Area(s):

Structural Geology

Contract/Grant Number: AC02-81ER10842

Type of Research Activities:

Performing Organization:

Field Research

University of Arizona

Principal Investigators:D. Norton

Objective:

The purpose of this program is to accumulate the types of field data which are important for the analysis of magma-hydrothermal systems.

Information/Status:

The structural effects of thermal processes were identified in order to distinguish the thermally induced deformations from the deformations that occurred subsequent to complete cooling of the system. Mapping techniques were developed to record the structural data on the ground from local domains characteristic of larger areas in the magma chamber, and in the air from low-angle oblique aerial photography of the entire region. The ground system is complete and preliminary testing is currently being carried out to verify the method. The results indicate that granitic crystalline rocks have no structural resistance to thermal perturbations. If nuclear wastes are to be stored in granite, precautionary buffers would have to be incorporated into the system. A total of 30 fossil magma chambers have been studied over the past 2 years. An extensive set of fracture imagery has been collected, together with information related to the geological history of the plutons. Fossil magma chambers in Arizona, Utah, California, Washington, Montana, and British Columbia have been studied.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Geosciences Related to Resource Assessment

Sponsoring Organization: DOE/Office of
Energy Research

Research Area(s):

Geophysics-Other (Seismic)

Contract/Grant Number: 000256

Type of Research Activities:**Performing Organization:**University of California
Dept. of Earth and Space Sciences

Hardware/Instrumentation Develop-
mentData Analysis/Documentation

Principal Investigators:M.G. Kivelson

Objective:

Information/Status:

The research is divided into three parts: (1) development of microcomputer instrumentation for use in field geophysics; (2) analysis of seismic data in Imperial Valley, California, and implication of the results concerning geothermal activity, also similar analysis of seismic data from Mt. Etna, Italy and implications of the results concerning magma chambers; and (3) a study of the genesis of an uranium ore deposit in an alpine bog. For Part 1, a microcomputer controlled base station magnetometer and an induced polarization system was completed. For Part 2, a region of high seismic crustal velocity paralleling the Brawley-Imperial fault system was found. Also, a reservoir of magma beneath Mt. Etna was positively identified. In Part 3, a literature review and numerous discussions leading to the identification of a number of similar occurrences was completed. Initial field mapping and a preliminary geochemical analysis of samples were completed. The work was funded at \$65,000 during October 1979 through March 1981.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Fundamental Studies of Silica Polymerization and Deposition

Sponsoring Organization: National Science Foundation, Directorate for Engineering and Applied Science

Research Area(s):
Mineralogy/Alterations

Contract/Grant Number: ENG79-15160

Performing Organization:
Princeton University

Type of Research Activities:
Theoretical Research
Laboratory Research-Experimental

Principal Investigators:

R.C. Axtmann
D.A. Saville

Objective:

Develop a theoretical description of the kinetic and transport phenomena of aqueous silica solutions with emphasis on the latter stages of the silica-tion reaction, including coagulation, agglomeration and deposition.

Information/Status:

Specifically, the effects of the particle size, number densities of growing particles, and shear fields on the reaction are being explored.

In the theoretical aspects of this work, a new model was developed of the competing effects of diffusion and chemical reaction during silica polymerization. Experimentally, this is to be confirmed with the aid of a new specially-developed mass spectrometer to calibrate a hydrodynamic chromatograph which, in turn, is uniquely suited for the characterization of submicron silica particles encountered in this research. Data from New Zealand researchers will also supplement these data.

This research has potential implications in a wide range of scientific problems and technological applications: from the graph of chart on the ocean floor to the control of boiler scale; from petrogenesis in siliceous rocks to solution mining of ore bodies; and from production of synthetic opal and commercial silica to reinjection of geothermal wells.

Contract from Sept. 1976 to Feb. 1982. FY 1980 funding was \$57,462.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Seismic Fracture Mapping

Sponsoring Organization: National Science Foundation, Directorate for Engineering and Applied Science

Research Area(s):

Geophysics-Other (Seismic)

Contract/Grant Number: DAR79-17424

Type of Research Activities:

Performing Organization:

Data Analysis/Documentation
Modeling/Simulation

Utah Geophysical, Inc.

Principal Investigators:

L. Katz

Objective:

Investigate the feasibility of monitoring acoustical signals, generated during induced fracturing of subsurface rock, as a means of mapping the location of the newly-formed fractures.

Information/Status:

The field data have been collected as part of a previous study. The present study will be to determine if signal processing techniques can be applied to the acoustical data in order to provide a means of mapping the location of man-made fractures.

If the technique is successful, the results will be a means of accurately determining locations for secondary recovery cells for solution mining, as well as oil, gas, and geothermal production.

Contract from Oct. 1979 to March 1980.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Collaborative Research on Fluid Compositions and Densities in Metamorphic Rocks by Fluid Inclusion Studies

Sponsoring Organization: National Science Foundation, Directorate for Astronomical Atmospheric Earth and Ocean Sciences

Research Area(s):
Fluid Inclusions

Contract/Grant Number: EAR78-05887 A02

Performing Organization:
Princeton University

Type of Research Activities:
Laboratory Research-Analytical

Principal Investigators:

L.S. Hollister

Objective:

Study fluid inclusions in metamorphic rocks by heating and freezing methods combined with petrologic and chemical studies of the host minerals. Objectives of this investigation are: (1) to determine the fluid compositions; (2) to learn the temperatures and pressures and fluid densities which are obtained during metamorphism; (3) to evaluate the extent and consequences of fluid immiscibility at high temperature and pressure.

Information/Status:

Fluid inclusions in metamorphic rocks are the only direct samples of fluids known to have passed through the rocks during metamorphism. Such fluids are thought to be crucial participants in metamorphism as chemical reactants, as media for mass transfer, and as transporters of heat.

The research supported here is attacking fundamental questions in petrology. The answers to these questions are relevant to many instances of chemical transport in the crust, including pre-forming and geothermal phenomena.

The project is being done in collaboration with Maria L. Crawford of Bryn Mawr College, who is being supported by a companion award.

Contract from May 1976 to Oct. 1982. FY 1980 funding was \$47,300.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Kinetics of Catalyzed Dissolution of Silicate Minerals

Sponsoring Organization: National Science Foundation, Directorate for Engineering and Applied Sciences

Research Area(s):
Mineralogy/Alterations

Contract/Grant Number: CPE79-15173

Performing Organization:
University of Michigan

Type of Research Activities:
Theoretical Research
Laboratory Research-Experimental

Principal Investigators:

H.S. Fogler

Objective:

Relate the rates of dissolution of various aluminosilicates to mineral structure, nature of catalyst, and the type of dissolution medium.

Information/Status:

In addition to fundamental knowledge of how reaction-limited dissolutions occur, these studies are of direct importance in solution mining and in the stimulation of petroleum gas, and geothermal reservoirs. It has already been shown that dissolution catalysis is a function of the catalysts cation, and is independent of the anion in many systems, and that both catalysts and dissolution in pure hydrofluoric acid vary with isomorphous substitutions and with layering in the mineral lattice. These findings are being extended to determine the nature and mechanism of solid-liquid dissolution, the relationship between reaction kinetics and mineral structure, and the effects of electrolytes. This includes measurements of surface absorption and the effects of partial dissolution on silicate lattices.

Contract from Sept. 1977 to Aug. 1982. FY 1980 funding was \$119,000.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Geochemistry and Petrology of Mount St. Helens Volcano, Washington

Sponsoring Organization: National Science Foundation, Directorate for Astronomical Atmospheric Earth and Ocean Sciences

Research Area(s):
Volcanology
Petrology
Mineralogy/Alterations

Contract/Grant Number: EAR79-19998

Type of Research Activities:

Performing Organization:
Rice University

Laboratory Research-Analytical
Field Research

Principal Investigators:

W.P. Leeman

Objective:

Study in detail the lavas and pyroclastic deposits of the Mt. St. Helens volcano in the Cascade Range, southern Washington.

Information/Status:

The origin and evolution of calcalkaline magmas remain unsatisfactorily explained, in part because of the complexity and diversity of processes involved. A deficiency in many studies is that stratigraphic and geochronologic data are not generally sufficient for individual volcanoes to establish a firm geologic framework to interpret petrologic and geochemical evolution. Such a framework is necessary to phases of magmas emplacement and processes which modify these magmas. As a result it is difficult to address the fundamental problem of magma genesis.

During the last 40,000 years the volcano has produced frequent tephra and lava eruptions (basalt to dacite) that record nearly continuous activity. Major element, trace element, and oxygen isotopic studies of lavas, glassy tephra and their constituent phenocrysts will be performed to improve existing stratigraphic control and to document petrologic evolution of this volcano. These data will help establish physical conditions in the magma chamber(s) and constrain the petrologic processes that have operated. Models of magmatic evolution will be evaluated numerically and tested by means of experimental phase equilibria studies. Results of this study will have applications toward: 1) understanding origins of calcalkaline magmas; 2) improving tephra-stratigraphic methods; 3) understanding the volcano as a geothermal system; and 4) documenting evolutionary trends and predicting future eruptive behavior at Mt. St. Helens.

Contract from Jan. 1980 to June 1982. FY 1980 funding was \$59,000.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Application of Rock Physics to Borehole Studies

Sponsoring Organization: National Science Foundation, Directorate for Engineering and Applied Science

Research Area(s):

Physical Properties Rocks/Liquids
Well Logging

Contract/Grant Number: DAR79-17379

Type of Research Activities:

Performing Organization:
Stanford University

Laboratory Research-Experimental

Principal Investigators:

A. Nur

Objective:

Develop a laboratory technique for simulating borehole conditions to a depth of several kilometers and for measuring various rock properties under these simulated conditions.

Information/Status:

Simulate, in the laboratory, the in-place conditions within the borehole of several kilometers depth in the earth's crust and then measure various rock properties. The independently controlled parameters which will be utilized to simulate in-place conditions are: confining pressure, stress, fluid pore pressure, and temperature. The laboratory system will be used to study the following problems for three rock types: (1) seismic wave velocities and attenuation in a borehole configuration as a function of overburden and pore pressures as well as temperature; and (2) development of the basic characteristics for a means of determining the permeability of the rock from an instrument lowered down a borehole.

Rock types to be analyzed are fractured granite, porous sandstone, and shale.

This project will demonstrate the feasibility of this approach and obtain preliminary data for the aforementioned rock types. Once the system is validated, a basis will be provided for more extensive tests and utilization of the concept for a new borehole technique to be used in exploration. The technique is particularly applicable in exploration for energy and geothermal resources as well as for determining the potential for in-place gasification and liquification of oil shales and tar sands.

Contract from Oct. 1979 to Nov. 1981. FY 1980 funding was \$93,180.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Investigation of Electrothermal Integrated Circuits

Sponsoring Organization: National Science Foundation, Directorate for Engineering and Applied Science

Research Area(s):
Electrical Studies

Contract/Grant Number: ENG77-25017

Performing Organization:
University of Arizona

Type of Research Activities:
Laboratory Research-Experimental
Theoretical Research

Principal Investigators:

W.J. Kerwin
D.J. Hamilton

Objective:

Investigate certain aspects of the use of electrothermal integrated circuits for electronic filters and pulse generators.

Information/Status:

Electrothermal integrated circuits are those which use the interaction between electrical and thermal properties of silicon; this is done by converting electrical signals to heat signals, and then after suitable processing, converting the heat signals to electrical signals. Exploitation of this interaction enables the realization of electronic filters and pulse generators, none of which require capacitors or inductors. In this project the aspects to be investigated are: 1) Monolithic single-chip second-order filters (low-pass, band-pass, high-pass, notch) with no external components; 2) Low-frequency oscillators of two types: high stability, and high sensitivity to ambient temperature variations. The later type is intended for use as a temperature sensor to interface with microprocessors; 3) electrothermal circuits using all-MOS transistor technology.

These circuits can find applications in geological exploration including seismic and geothermal sources.

This research was previously supported under NSF Grant ENG74-21849.

Contract from Nov. 1975 to Nov. 1980.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Engineering Research Initiation - Fluid Flow in Heterogeneous Porous Media

Sponsoring Organization: National Science Foundation, Directorate for Engineering and Applied Science

Research Area(s):

Fluid Migration

Contract/Grant Number: ENG78-05528

Type of Research Activities:

Performing Organization:

Modeling/Simulation

University of Oklahoma

Principal Investigators:

D. Tiab

Objective:

Follow an approach based on pressure analysis to define types of reservoir heterogeneities and develop computer models to characterize their qualitative and quantitative effects on fluid flow through porous media.

Information/Status:

Techniques for identifying reservoir heterogeneities such as permeability, porosity and thickness variations, linear discontinuity, fractures, multiple layers, and their combined effects will be developed. The performance of heterogeneous reservoirs during primary recovery, waterflooding and enhanced oil recovery will be simulated. The achievement of these objectives through usage of information provided by reservoir cores and log data and geological and petrographic studies should lead to better predictions of reservoir performance, more successful injection operations and higher oil recovery. The results will be of considerable importance not only in oil reservoir engineering, but also in groundwater hydrology and geothermal systems.

Contract April 1978 to March 1980.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Hydroelastic Phenomena in Liquid Subsurface Systems

Sponsoring Organization: National Science Foundation, Directorate for Astronomical Atmospheric Earth and Ocean Sciences

Research Area(s):
Physical Properties Rocks/Liquids

Contract/Grant Number: EAR77-23938

Type of Research Activities:

Performing Organization:
Oregon State University

Theoretical Research

Principal Investigators:

G. Bodvarsson

Objective:

Study the hydroelastic dynamics of simple but practically relevant systems to provide the necessary theoretical basis for future field work on hydroelastic oscillations.

Information/Status:

There are various observations indicating that liquids enclosed in subsurface openings are capable of oscillations which are here referred to as hydroelastic oscillations. Such oscillations are possibly sources of the seismic ground noise which has been observed over convecting geothermal systems and of volcanic tremor associated with subsurface magma flow. Moreover, they may greatly modify the pressure responses of the subsurface liquid systems to excitations by tidal strain, earthquakes, and controlled pressure tests. Observational data on hydroelastic oscillations may yield information on the dimensions of the systems and may thus provide data of importance for geothermal resource exploration and volcanological investigations. The present project involves an analytical-theoretical study of the hydroelastic dynamics of simple but practically relevant systems. Normal modes and dynamical response functions are to be derived.

Contract from Feb. 1978 to Aug. 1980.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Studies of Convection in a Porous Medium at High Rayleigh Number and Its Geothermal Implications

Sponsoring Organization: National Science Foundation, Directorate for Astronomical Atmospheric Earth and Ocean Sciences

Research Area(s):
Mass Heat Transport
Fluid Migration

Contract/Grant Number: EAR77-23222

Performing Organization:
University of Washington

Type of Research Activities:
Theoretical Research
Laboratory Research-Experimental

Principal Investigators:

J.R. Booker
C.R. Lister

Objective:

Conduct experimental and theoretical studies to settle the problem of heat transfer rates in porous-medium convection.

Information/Status:

Prior experiments have not modelled a porous medium closely enough to obtain consistent results at Rayleigh numbers more than a few times critical. Determinations of the temperature- and flow-structure in the convecting medium have not had the resolution to detect the development of boundary layers, except for a few experiments done in a two-dimensional Hele-Shaw cell. The simultaneous requirement of reaching a high Rayleigh number in a porous bed, and at the same time ensuring that the grain size is smaller than the boundary layers that develop near the heat source and heat sink, means that satisfactory experiments can be carried out only in a very large apparatus. Such a large facility will be constructed and once-and-for-all the relationship between heat transport and Rayleigh number will be delineated up to a value of 10 to the fourth power for the latter.

Contract from Feb. 1978 to July 1980.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: High Pressure and Temperature PVT Properties of Geothermal Brines

Sponsoring Organization: National Science Foundation, Directorate for Astronomical Atmospheric Earth and Ocean Sciences

Research Area(s):

Physical Properties Rocks/Liquids

Contract/Grant Number: EAR79-04237

Type of Research Activities:

Performing Organization:
University of Miami

Laboratory Research-Experimental

Principal Investigators:

F.J. Millero

Objective:

Study the PVT properties of geothermal brines at conditions ranging from 1 atm. to 1 kbar pressure and 0 to 200°C.

Information/Status:

Many geologically and economically interesting natural phenomena involve interactions between brines and their surroundings at elevated temperatures and pressures. Examples are hydrothermal deposition of base metal ores, geothermal energy sources, and hydrocarbon-saturated brine reservoirs. In order to understand such phenomena, we need fundamental pressure-temperature-volume data about the behavior of various brines under various conditions.

The measurements will be made on brines containing typical components (NaCl, Na₂SO₄, MgCl₂, CaCl₂, MgSO₄, etc.) at concentrations ranging from 0.5 molal to saturation. The data provided by this investigation will greatly increase our ability to quantitatively model, and thereby understand, geothermal processes.

Contract from Jan. 1980 to June 1982. FY 1980 funding was \$110,200.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Natural and Forced Thermal Convection in Porous Media Effects of Variable Properties, Phase Changes and Dimensionality

Sponsoring Organization: National Science Foundation, Directorate for Engineering and Applied Science

Research Area(s):
Mass Heat Transport

Contract/Grant Number: ENG76-82119 A01

Performing Organization:
Aerospace Corp.

Type of Research Activities:
Theoretical Research

Principal Investigators:

J.M. Straus

Objective:

Conduct a numerical study to examine the characteristics of finite-amplitude three-dimensional convection in rectangular boxes of different shapes.

Information/Status:

Heat transport rates are calculated and a quantitative description of the flow is developed. Detailed analysis of time-dependent convection is also carried out. The power spectrum of the fluctuations is determined and implications for the transition to turbulent convection are drawn. An analytic study of convection in solutions of water and carbon dioxide is carried out and the change in effective thermal expansion coefficient of the solution due to the escape of carbon dioxide is determined. Finally, the stability of one-dimensional flow models of geothermal areas is investigated. This grant is a continuation of NSF Grant No. ENG 76-82119.

Contract from July 1977 to Feb. 1982. FY 1979 funding was \$59,946.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: High Temperature Triaxial-Torsional Testing Machine for Concrete and Rock

Sponsoring Organization: National Science Foundation, Division of Engineering

Research Area(s):

Physical Properties Rocks/Liquids

Contract/Grant Number: ENG78-24603

Type of Research Activities:

Performing Organization:

Hardware/Instrumentation-
Development/Testing

Northwestern University

Principal Investigators:

Z.P. Bazant

Objective:

Develop laboratory equipment to measure triaxial-torsional effects on rock and concrete.

Information/Status:

The specialized engineering research equipment being developed accommodates solid or hollow cylinders up to six inches in external diameter and twelve inches in height under the following maximum conditions: (a) axial stresses to 20,000 p.s.i., (b) confining and pore water pressures to 20,000 p.s.i., (c) torsional loads to 50,000 inch pounds, and (d) temperatures to 6,000 degrees C. Direct axial, shear and diametrical strain measuring devices are attached to or embedded in the specimen and indirect strain measurements are made outside the chamber by dial gages and transducers.

The types of measurements possible on cement and rock specimens include: (a) creep as a function of moisture content and as a function of rate of change of moisture content, (b) triaxial response under high temperatures for both cubical and hollow cylinders, and (c) pore pressures in heated specimens.

Examples of the types of engineering activities in which these measurements are critical include nuclear containment vessels, geothermal energy and oil shale reduction and in-situ hydrofracturing in oil drilling.

Contract from June 1979 to Nov. 1980. FY 1979 funding was \$188,770.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Specialized Research Equipment - Laser Doppler Anemometer System

Sponsoring Organization: National Science Foundation, Division of Engineering

Research Area(s):
Mass Heat Transport

Contract/Grant Number: ENG79-11431

Performing Organization:
Oregon State University

Type of Research Activities:
Hardware/Instrumentation
Development/Testing

Principal Investigators:

M.B. Larson

Objective:

Investigate heat transfer and fluid flow processes of importance in geothermal wells using a laser doppler anemometer system.

Information/Status:

This research equipment grant provides funds for a laser doppler anemometer system which is initially used on a natural convection study. The study deals with heat transfer and fluid flow processes of importance in geothermal wells and involves a detailed investigation of the velocity and temperature fields in a vertical glass tube mounted on top of a heated reservoir. The information to be obtained concerns the flow regime, velocity profile and Nusselt number as a function of position for various length to diameter ratios and Rayleigh number. Another use to which the equipment is applied is in fluidized bed studies.

Contract from July 1979 to Dec. 1980. FY 1979 funding was \$30,300.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Seismic Studies of Shallow Magma Bodies in the Crust of the Rio Grande Rift Near Socorro, New Mexico

Sponsoring Organization: National Science Foundation, DAAEOS

Research Area(s):

Geophysics-Other (Seismic)
Structural Geology

Contract/Grant Number: EAR77-23166

Type of Research Activities:

Performing Organization:

Field Research

New Mexico Institute of Mining and Technology

Principal Investigators:

A.R. Sanford

J.W. Schlue

Objective:

Locate and map magma bodies in the crust of the Rio Grande rift using P and S phases from local microearthquakes, mining explosion, and teleseisms.

Information/Status:

An analysis of SzP and SzS reflections on microearthquake seismograms indicates the existence of an extensive magma body beneath the Rio Grande rift in the vicinity of Socorro, New Mexico. As presently mapped, the magma occurs beneath 1200 square km of the central part of the rift at depths ranging from about 18 to 20 km. Screening of SV waves and unusually high values of Poisson's ratio in segments of the upper crust suggest the existence of several small, shallow (less than 10 km) magma bodies possibly connected to the deeper, more extensive magma body.

Specific research projects are (1) inversion of microearthquake travel time data, (2) inversion of SzS reflection time data, (3) inversion of mining explosion and teleseismic travel-time data, (4) attenuation studies using spectra of mining explosions and microearthquakes. Data generated by this research will be correlated closely with COCORP profiles in the Rio Grande rift which cross regions believed to contain magma bodies and which have a high level of microearthquake activity.

A knowledge of magmatic processes in an active rift zone is important to an understanding of the rifting process and to the practical problems of sources of geothermal energy and ore deposits in continental rifts.

Contract from March 1978 to Aug. 1980.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Lithospheric Structure of an Intraplate Hotspot--The Yellowstone-Snake River Plain Region

Sponsoring Organization: National Science Foundation, DAAEOS

Research Area(s):

Structural Geology
Geophysics-Other (Seismic)

Contract/Grant Number: EAR77-23707

Type of Research Activities:

Performing Organization:

Field Research

University of Utah

Principal Investigators:

R.B. Smith

Objective:

This project will involve a detailed seismic refraction reversed-profile across Yellowstone and the northern Snake River Plain to be conducted in 1978 in conjunction with continuation of the profile along the Snake River Plain by Purdue University.

Information/Status:

The SRF-Yellowstone feature is hypothesized to be rift or extension structure above an asthenospheric thermal instability that decoupled the northern Rocky Mountains from the Great Basin and Middle Rocky Mountains. However, no large-scale crust-mantle measurements have yet been made that directly assess the subsurface properties of this intraplate tectonic feature. The profiles will sample the general crust-upper mantle structure, Pn-velocity, low velocity zones, attenuation, and will provide detailed data to assess Vp/Vs ratios across the inner-caldera uplift necessary to investigate the possible role of dilatancy and to search for the presence of crustal or upper-mantle magma or partial melt bodies. Inversion of amplitude corrected travel-time curves will be used to estimate rock composition, pressure, and temperatures through new velocity-depth data. A group of five U.S. universities (University of Utah, Wisconsin, Texas-El Paso, Wyoming and Purdue University) in cooperation with the European geophysics groups at the Swiss Federal Institute of Technology and the Karlsruhe University will provide 55 FM-and digital-recording seismographs.

Contract from March 1978 to Aug. 1980.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Establishment of an Electron Microprobe Facility

Sponsoring Organization: National Science Foundation, Division of Earth Sciences

Research Area(s):
Petrology

Contract/Grant Number: EAR78-23689

Type of Research Activities:

Performing Organization:
Southern Methodist University

Hardware/Instrumentation Development

Principal Investigators:

M.A. Dungan
M.J. Holdaway

Objective:

Establish an electron microscope facility to obtain geochemical data for petrologic investigations.

Information/Status:

This contract provides partial funding for the establishment of an electron microprobe facility.

There are four main areas of investigation in which the microprobe will play a vital role in obtaining geochemical data that is necessary in unraveling the petrologic problems involving: 1) volcanic petrology associated with basalts, andesites, and rhyolites of the northern Rio Grande Rift plus the alkali basalts and hawaiites with included xenolith and megacryst suite of the Geronimo volcanic field, San Bernardino Valley, southeastern Arizona; 2) metamorphic petrology-the study of equilibrium assemblages in metamorphic rocks to establish geothermometers and geobarometers in an area west of Augusta, Maine; 3) sedimentology and petroleum geology - diagenetic studies and analysis of individual grains of clastic sediments to help identify the nature of source terranes; 4) geothermal resource areas - characterization of very young volcanic rocks in regions of geothermal anomalies such as found in the Jemez Caldera, New Mexico.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Geothermal Studies in Northern Mexico

Sponsoring Organization: National Science Foundation, Division of Earth Sciences

Research Area(s):
Heat Flow Studies
Geochronology/Stratigraphy

Contract/Grant Number: EAR75-13572 A01

Performing Organization:
University of Florida

Type of Research Activities:
Field Research
Laboratory Research-Analytical

Principal Investigators:

D.L. Smith

Objective:

This project seeks funds to continue the program of geothermal studies in northern Mexico, including the acquisition of heat flow values and the sampling of major igneous exposures for radioactive heat production analyses by gamma ray spectrometry. In addition, major and trace element abundances, $^{87}\text{Sr}/^{86}\text{Sr}$ ratios, and radiometric ages will be determined to delineate the general nature of the magmatic history of northern Mexico.

Information/Status:

Nineteen new heat flow values from northern Mexico, combined with previous data from the same area, demonstrate unique thermal conditions in northern Mexico related to the Gulf of California, the Sierra Madre Occidental, and the Rio Grande Rift Zone. A distinctive trend of decreasing heat flow is observed eastward from the Gulf of California through the Sierra Madre Occidental and is tentatively attributed to thermal influences from spreading ridges in the gulf. Basin and Range thermal province conditions prevail in northwestern Mexico except near the Gulf of California where a zone of high reduced (mantle) heat flow exists. Heat flow values in the central Mexican Plateau and the Sierra Madre Oriental resemble those from the Great Plains province, but limited evidence suggests the presence of the Rio Grande Rift Zone thermal anomaly trending southeast through this region.

Contract from May 1978 to Dec. 1979.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Study of the Limits of Applicability of Superposition in Electromagnetic Methods for Geophysical Prospecting

Sponsoring Organization: National Science Foundation, Division of Earth Sciences

Research Area(s):
Electrical Studies

Contract/Grant Number: EAR78-24611

Performing Organization:
Colorado School of Mines

Type of Research Activities:
Theoretical Research

Principal Investigators:
G.V. Keller

Objective:

Evaluate the conditions under which superposition of electromagnetic field effects in mineral and geothermal resource exploration can be applied.

Information/Status:

This will require an analytical study, using the integral equation approach, in which the effects of a finite conducting body are expressed in terms of a perturbation series. This analysis will permit separation of interactive and non-interactive contributions to the field. These will be used to estimate the errors involved in superposition and the limits over which superposition may be applied. The results will be evaluated by applying interpretations to realistic exploration programs.

Contract from March 1978 to Aug. 1980. FY 1979 funding was \$50,000.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Investigation of a Tectonic Model for the Snake River Plain Using Seismic Refraction Profiling

Sponsoring Organization: National Science Foundation, Division of Earth Sciences

Research Area(s):
Geophysics-Other (Seismic)
Structural Geology

Contract/Grant Number: EAR77-23357 A01

Performing Organization:
Purdue University

Type of Research Activities:
Field Research

Principal Investigators:
L.W. Braille

Objective:

Use seismic refraction profiling to determine detailed crystal structure of the eastern Snake River Plain.

Information/Status:

The data will be used to test the various models which have been suggested to explain the structural and tectonic development of the SRP. The data will also provide valuable information on the potential earthquake hazard and geothermal potential of the area.

A significant aspect of the proposed research is the cooperation of scientists from Switzerland and Germany, the European leaders in refraction seismology. This cooperation should be of great benefit to both sides.

Contract from March 1978 to Aug. 1980. FY 1979 funding was \$5,000.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Study of Active Hydrothermal Ore Formation in the Salton Sea Geothermal Field, California

Sponsoring Organization: National Science Foundation, Division of Earth Sciences

Research Area(s):

Mineralogy/Alterations
Isotope Geochemistry

Contract/Grant Number: EAR78-01969

Type of Research Activities:

Performing Organization:
University of California, Riverside

Laboratory Research-Analytical

Principal Investigators:

W.A. Elders

Objective:

Conduct a chemical and isotopic study of sulfide minerals present in the Salton Sea Geothermal system.

Information/Status:

This active hydrothermal system is depositing pyrite at shallow depths; with increasing depth (and temperature) pyrite is joined by chalcopyrite, sphalerite, and pyrrhotite. A series of five wells will provide sample coverage so that the three dimensional distribution of the ore minerals (and their modes of occurrence and textures) can be determined. These data, along with a study of fluid inclusions and of the stable isotopic variations, should allow an estimation of changes in temperature and pore fluid salinity with time as well as oxygen and sulfur fugacity, pH and oxidation potential.

The Salton Sea Geothermal Field appears to be an area undergoing active hydrothermal ore formation, giving the opportunity of understanding better the complicated ore fluid/rock interaction that takes place during ore deposition.

Contract from July 1978 to Dec. 1979. FY 1978 funding was \$27,900.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: A Comparison of Gas Techniques Useful in Geochemical Exploration and Analysis of Time Variation in Gas Emission

Sponsoring Organization: National Science Foundation

Research Area(s):
Fluid Tracer Studies

Contract/Grant Number: DAR80-08106

Performing Organization:
Colorado School of Mines

Type of Research Activities:
Field Research
Laboratory Research-Analytical

Principal Investigators:

R.W. Klusman

Objective:

A number of time dependent meteorological and secondary variables influence gaseous emission from the earth's crust. The objective is to determine the crustal emission of several gases useful in geochemical and geothermal exploration and potentially useful in earthquake prediction, simultaneously, in a "continuous" mode over a period of one year. The similarities and differences in the behavior of Hg, Rn and He in a closely monitored natural experiment are being determined.

Information/Status:

The emission of these gases is being related to the following meteorological and secondary variables: outside temperature, outside relative humidity, outside barometric pressure, instrument vault temperature, vault relative humidity, vault barometric pressure, water table, solid moisture, soil temperature, precipitation events, wind, soil freeze-thaw, and solid earth tide. The mercury emission is integrated over 2-1/2 hour intervals. Radon is measured by two techniques in duplicate: weekly, using Track Etch cups, and daily, using small electronic detectors. Helium is measured in duplicate on a daily basis using a small mass spectrometer system.

The different gas techniques are being compared to each other using correlation analysis and each with meteorological and secondary influences using stepwise regression analysis. During data analysis, methods will be proposed for the application of the results to a practical geochemical or geothermal exploration program.

Period of performance was 8/80 to 4/82 with FY 80 funding of \$23,575.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Studies in Geophysics

Sponsoring Organization: National Science Foundation

Research Area(s):

Geophysics-Other (General)

Contract/Grant Number: EAR79-02458

Type of Research Activities:

Performing Organization:

Data Analysis/Documentation

National Academy of Sciences

Principal Investigators:

P.J. Hart

Objective:

This award provides for the continuation of a project of the National Academy of Sciences (NAS) to produce a series of studies dealing with timely scientific and societal aspects of geophysics and the corresponding demand on geophysical knowledge.

Information/Status:

The series of studies is guided by the Geophysics Study Committee of the Geophysics Research Board (GRB) of the National Academy of Sciences. Each study is conducted by a panel selected for that particular study. The studies include: (1) problem-oriented studies, e.g., those related to demands on geophysical knowledge in connection with climatic variations, fresh water resources, mineral resources, continental structure and processes, geothermal and other energy sources, geophysical predictions, air quality, and food; (2) science-oriented studies such as international programs in geophysics, status of developments and opportunities in geophysics, impact of technology in geophysics and criteria for assessment of priorities.

Period of performance for the studies was 3/79 through 8/81 with FY 81 funding of \$29,000.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Characterization of Interfacial Processes in Structural and Geophysical Composites

Sponsoring Organization: National Science Foundation

Research Area(s):
Heat Flow Studies

Contract/Grant Number: CME 80-21054

Type of Research Activities:

Performing Organization:
University of Cincinnati School of Engineering

Modeling/Simulation

Principal Investigators:

A. H. Nayfeh

Objective:

This research program involves the modification of an existing model for wave propagation and heat transfer in a three component composite in order to investigate geophysical/geothermal phenomena.

Information/Status:

Specifically, two phenomena are considered: (a) Seismic waves propagating in a geophysical system composed of two component fluids in rock (for example, combinations of oil, water, vapor, gas). These studies are aimed at the seismic mapping of subsurface fluids; (b) Geothermal systems involving the circulation of water and vapor through hot rock. By solving a transient temperature boundary value problem, the amount of heat energy extracted by the fluids from the hot rock can be determined. Work on the research was begun in May of 1981 and will continue through October 1983. Funding during FY 81 was \$71,725.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Theoretical Investigation of Geochemical Processes

Sponsoring Organization: National Science Foundation

Research Area(s):

Mineralogy/Alterations

Contract/Grant Number: EAR77-14492

Type of Research Activities:

Performing Organization:

Data Analysis/Documentation
Theoretical Research

Univ. of California, Berkeley Dept. of
Geology and Geophysics

Principal Investigators:

H.C. Helgeson

Objective:

This project is the continuation of a long term effort to enable the prediction of mineral-aqueous solution reactions that occur during metamorphism, ore deposition, and geothermal rock alteration.

Information/Status:

The predictive technique used is based on a set of equations that combine a quantitative knowledge of the conditions of chemical equilibrium with mass balance restraints on the system in question. The work to be carried out during this grant period will concern the accumulation of a better thermodynamic data base for the prediction of chemical equilibrium, the development of equations to represent specific kinds of mineralogic reactions, and the application of the technique to a number of geologic problems. The research will focus on: (1) equilibrium and mass transfer among minerals and aqueous solutions under various petrologic conditions, (2) thermodynamic and kinetic constraints on reaction rates among minerals and aqueous solutions, (3) thermodynamic prediction of stable isotope fractionation at high temperatures and pressures, (4) the effects of composition variation and order/disorder in silicates on their thermodynamic behavior in geochemical processes, and (5) equations of state, elastic constants, and thermodynamic prediction of phase relations in the upper mantle of the earth. The effort was begun in April of 1977 and completed in March 1982.

Funding for FY 81 was \$119,000.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Role of Gases In Subduction Zone Volcanism

Sponsoring Organization: National Science Foundation

Research Area(s):

Volcanology
Brine/Gas Chemistry

Contract/Grant Number: EAR79-26485

Type of Research Activities:

Performing Organization:

Laboratory Research-Analytical

University of Chicago
Dept. of Geophysical Sciences

Principal Investigators:

A.T. Anderson

Objective:

Information/Status:

This study is about the migration of H₂O, CO₂, Cl and S from the interior of the earth to the surface by means of volcanism. The processes whereby such volatile substances enter into and escape from natural melts probably are complex. A new machine facilitates the study of the processes by permitting direct analysis of H₂O, CO₂, Cl and S dissolved in tiny inclusions of melt trapped in crystals. Consequently, the proposed work will trace out additions and losses of the above constituents to and from magmas beneath volcanoes in subduction zones. The results will bear on the origin and evolution of oceans and continents and probably on the eruptive behavior of volcanoes, as well as the potential value of certain volcanic rocks for ore and geothermal energy.

Work on the project was initiated in Feb. of 1980 and completed in July of 1982. FY 81 funding was \$48,000.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: The Effect of Temperature on the Absolute Permeability of Stressed Unconsolidated Geological Media

Sponsoring Organization: National Science Foundation

Research Area(s):

Fluid Migration
Physical Properties Rocks/
Liquids

Contract/Grant Number: CME 81-06430

Type of Research Activities:

Performing Organization:

Laboratory Research-Experimental

University of California, Berkeley
School of Engineering

Principal Investigators:

K.S. Udell

Objective:

Information/Status:

The success or failure of thermally enhanced oil recovery methods and certain geothermal projects depends on the permeability change of the porous formation with respect to temperature. Permeability has been observed to decrease over 60 percent for temperature increases of 150 degrees C at reservoir stress conditions. Permeability reduction data for unconsolidated media are scarce and a fundamental description of the permeability-temperature dependence is lacking. The research consists of experiments directed towards the acquisition of fundamental permeability-temperature data for three types of unconsolidated samples: glass beads, sand, and sand containing small percentages of clay. These experiments are conducted at confining pressures up to 50 mPa, pore pressures up to 40 mPa and temperatures up to 400 degrees C. From these tests, the relative contributions of anisotropic thermal expansion, temperature-dependent material properties, fines release and clay swelling are deduced. Work on the effort was initiated in April 1981 and will continue through Sept. 1983. Funding during FY 81 was \$48,000.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Complexing and Thermodynamic Properties of Manganese in Hydrothermal Fluids

Sponsoring Organization: National Sciences Foundation

Research Area(s):

Brine/Gas Chemistry

Contract/Grant Number: EAR80-08798

Type of Research Activities:

Performing Organization:

Laboratory Research-Experimental

Carnegie Institute of Washington

Principal Investigators:

J.D. Frantz

Objective:

Enhance the understanding of the processes of mobilization, transport, and redistribution of metals in the earth's crust.

Information/Status:

This is a continuation of research previously supported by NSF grant EAR 78-14274 involving the determination of metal solubilities and the identification of metal complexes in hydrothermal chloride solutions. The project will investigate thermodynamic properties and the nature and distribution of complexes of manganese in supercritical chloride-bearing fluids. The data for manganese are necessary for modelling transport of manganese in hydrothermal systems associated with mid-ocean ridges. Initial work on the project began in November of 1978 and will continue through June of 1983. Funding for FY 81 was \$37,800.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Acoustic Properties of Partially Saturated Geothermal and Petroleum Reservoirs

Sponsoring Organization: National Science Foundation, Directorate for Engineering and Applied Science

Research Area(s):

Geophysics-Other (Seismic)
Physical Properties Rocks/
Liquids

Contract/Grant Number: CEM80-19278

Type of Research Activities:

Performing Organization:
Oklahoma State University

Laboratory Research-Experimental
Theoretical Research

Principal Investigators:

J.N. Lange

Objective:

Provide a more fundamental understanding of the acoustic properties of porous rocks containing a gas/liquid mixture.

Information/Status:

This research attempts to delineate the dominant mechanisms (i.e., rock cracks, fluid/gas dynamics, surface coupling, etc.) which affect the acoustic velocity and attenuation in porous structures. Empirical determinations of rock properties are compared to the various theoretical mechanisms affecting the acoustic properties. Measurements are made in pressure and temperature environments duplicating in-situ conditions. A particular feature of this investigation is the broad range of measurement frequencies used to differentiate between the relative contribution of various acoustically active mechanisms. An important parameter affecting the acoustic properties is the distribution of fluid in the partially saturated rocks. Particular attention is given to the development of various diagnostic techniques (x-ray absorption, laser fluorescence) designed to define the gas/liquid distribution in the porous materials as well as to the method of introducing gas (flow, pressure saturation, etc.). A wide range of native sandstones are used as the porous matrix with an eventual extension of the measurements to unconsolidated matrices and manufactured porous materials (scintered matrix). Work on the project began in March 1981 and is a three year continuing grant. FY 81 funding was \$50,627.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Interstitial Fluid Pressure Signals in Reservoir Testing and Volcanology

Sponsoring Organization: National Science Foundation

Research Area(s):

Geophysics-Other (Seismic)
Well Stimulation/Reservoir
Engineering

Contract/Grant Number: EAR 80-23850

Type of Research Activities:

Performing Organization:
Oregon State University

Laboratory Research-Experimental
Modeling/Simulation

Principal Investigators:

G. Bodvarsson

Objective:

Information/Status:

This is a two year program to carry out an analytical/numerical study of interstitial fluid pressure signal propagation/diffusion in a number of structures: (1) fractures of uniform equilibrium aperture with elastic walls, (2) capacitor/conductor networks, (3) approximation of signal propagation in bounded arbitrary Darcy flow regions by networks as under (2), (4) Hookean Darcy flow half-spaces where the signals are generated by surface loads, (5) Hookean Darcy flow-half-spaces where the signals are generated by internal fluid sources and (6) non-permeable half spaces with Darcy flow or network layers where the signals are generated by the same loads as under (4) and (5). The results obtained will be applied to fluid resource reservoir testing, geothermal systems and to volcanic systems in the Oregon-Washington Cascades. Work was initiated on the project in April of 1981 with FY 81 funding of \$77,500. The effort is scheduled for completion in October, 1983.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Low- to Moderate-Temperature Reservoir Engineering Program

Sponsoring Organization: DOE/Geothermal and Hydropower Technologies Division

Research Area(s):
Well Stimulation/
Reservoir Engineering

Contract/Grant Number: DE-AC07-761D01570

Type of Research Activities:

Performing Organization:
EG&G, Idaho and Lawrence Berkeley Laboratory

Data Analysis/Documentation

Principal Investigators:

B.F. Russel

Objective:

Ensure that appropriate methods of reservoir testing and analysis are available to facilitate the development and use of low- to moderate-temperature hydrothermal resources. Emphasis now on long-term, high-risk research pertinent to resource definition and development.

Information/Status:

Case studies covering geology, hydrology, geothermal background, exploratory programs, production drilling, aquifer testing, and current project status were conducted for following localities:

- St. Mary's Hospital, South Dakota
- White Sulphur Springs, Montana
- Pagosa Springs, Colorado
- Utah Roses, Utah
- Monroe, Utah
- Susanville, California

Reservoir engineering handbook (see below) prepared as guideline to developers and consultants for evaluation of reservoir characteristics. Document undergoing peer reviews. Major topics addressed are:

- Reservoir classification
 - Reservoir engineering
 - Conceptual modeling
 - Testing during drilling
 - Theory of testing
-

Information/Status: (continued)

- Test planning and methodology
- Geochemistry
- Reservoir monitoring

Case Studies of Low- to Moderate-Temperature Hydrothermal Energy Development, IDO-10098

Low- to Moderate-Temperature Hydrothermal Reservoir Engineering Handbook
Semiannual Progress Report for the Idaho Geothermal Program, April 1 through
September 30, 1981, J.T. Parker (ed.), EG&G Idaho, Inc., NTIS No. EGG-2140,
Jan. 1982.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Recently Developed Well Test Instrumentation
For Low- to Moderate-Temperature Hydrothermal
Reservoirs

Sponsoring Organization: DOE/Geo-
thermal and Hydropower Technologies
Division

Research Area(s):
Geophysics-Other

Contract/Grant Number: W-7405-ENG-48

Type of Research Activities:

Performing Organization:
Lawrence Berkeley Laboratory,
Earth Sciences Division

Hardware/Instrumentation Develop-
ment/Testing

Principal Investigators:

R. Solbay
C.B. Goranson
S.M. Benson

Objective:

Develop a suite of instruments for downhole geothermal well testing to
overcome inadequacies of commercially available instruments.

Information/Status:

Report published providing engineering drawings, assembly instructions,
and recommended usage of the following devices for $<150^{\circ}\text{C}$ hydrothermal well
testing:

- o Downhole pressure and temperature instrument
- o Multi-conductor cablehead
- o Line driver to be used with the downhole pressure and temperature
instrument
- o Fluid-level detector.

Recently Developed Well Test Instrumentation For Low- to Moderate-
Temperature Hydrothermal Reservoirs, R. Solbau, et. al., Lawrence Berkeley
Laboratory, NTIS No. LBL-13260, Aug. 1981.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Benefit/Cost Analysis for Research in Geothermal Log Interpretation

Sponsoring Organization: DOE/Division
of Geothermal Energy, Los Alamos
National Laboratory

Research Area(s):

Well Logging

Contract/Grant Number: L68-1908E-1

Type of Research Activities:

Performing Organization:

Data Analysis/Documentation

Science Applications

Principal Investigators:

F.A. Rigby
P. Reardon

Objective:

Evaluate the net benefits of expected improvements in logging and log interpretation in geothermal applications.

Information/Status:

Well log interpretation, the process of inferring subsurface geology from geophysical measurements made in boreholes, is the most versatile and direct means available of assessing important physical and structural reservoir properties. Historically, well logging has been developed primarily for use in oil and gas wells, and its application in a different environment such as a geothermal reservoir creates complex problems. Present geothermal development is severely hindered by lack of data. Adaptation of well logging techniques holds the promise of reducing development costs, encouraging investment, and assisting regulatory permitting. Such benefits will translate directly into lower power costs and an increased domestic energy supply. A significant acceleration of geothermal power-on-line is possible plus cost reductions through reduction of drilling failure rate, reduction of average well cost, earlier recognition of bad wells, reduced flow testing, and savings due to provision of better data for regulatory decisions. Net undiscounted benefits in 1979 dollars from improving logging and interpretation in geothermal areas can exceed half a billion dollars in slightly more than a decade, about 300 million of this should be regarded as the potential benefit of the Los Alamos Scientific Laboratory Geothermal Log Interpretation Program or similar research.

Benefit/Cost Analysis for Research in Geothermal Log Interpretation,
Final Report, F.A. Rigby and P. Reardon, Los Alamos Scientific Laboratory,
Informal Report No. LA-7922-MS, May 1979.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Geothermal Gradient Map of the Conterminous United States

Sponsoring Organization: DOE/Division
of Geothermal Energy

Research Area(s):

Heat Flow Studies

Contract/Grant Number:

Type of Research Activities:

Performing Organization:

Data Analysis/Documentation

Los Alamos Scientific Laboratory

Principal Investigators:

Andrea Kron
Grant Heiken

Objective:

Produce, from published and unpublished data, a geothermal gradient map to assist in evaluation and exploration of U.S. hot-dry-rock resources.

Information/Status:

Map (#LA-8476-MAP) issued in August 1980.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Map of Known Potential Areas for Geothermal Resources in the United States

Sponsoring Organization: DOE/Division of Geothermal Energy

Research Area(s):

Heat Flow Studies

Contract/Grant Number:

Type of Research Activities:

Data Analysis/Documentation

Performing Organization:

Gruy Federal, Inc. and NOAA/National Geophysical and Solar-Terrestrial Data Center

Principal Investigators:

Objective:

Information/Status:

Map produced in 1979.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Raft River Reservoir Engineering

Sponsoring Organization: DOE/Geothermal
and Hydropower Technologies Division

Research Area(s):

Well Stimulation/Reservoir-
Engineering
Brine/Gas Chemistry

Contract/Grant Number: DE-AC07-76ID01570

Type of Research Activities:

Performing Organization:

Field Research

Idaho National Engineering Laboratory

Principal Investigators:

B.F. Russell

Objective:

Conduct research in the areas of reservoir engineering, monitor well support, and geochemistry in support of DOE's 5 MWe Raft River facility.

Information/Status:

The geothermal reservoir engineering work included the compilation of the geoscientific data collected at Raft River since 1974 into a single document. This Raft River Geoscience Case Study details information regarding geology, geophysics, hydrology, and geochemistry. The Raft River Geoscience Case Study concludes that fractures play a dramatic role in fluid production. The reservoir is anisotropic, with the major axis of hydraulic conductivity coincident to the Bridge Fault Zone; this is typical of many Basin and Range systems.

Production and injection testing at Raft River over the past 6 months was confined to short-duration tests, primarily associated with the installation of the new Peerless & Line shaft pumps. These pumps were installed during the month of August. The injection system was modified to allow the spent fluids to flow into the lined injection ponds immediately prior to injection downhole. The benefits of this procedure, primarily a function of available plant operation options, greatly outweigh the weaker aspects of the modification. A geochemical-hydrologic analysis to evaluate the effects of the modification was initiated and will continue during plant startup and operation.

The geochemical data collected from previous research was loaded into a computer data bank to provide greater accessibility and easier analysis. Research is continuing in the area in conjunction with the development of a better understanding of the hydrogeology of the Raft River area.

Raft River Geoscience Case Study, Semiannual Progress Report for the Idaho Geothermal Program, April 1 through September 30, 1981, J.T. Parker (ed.), EG&G Idaho, Inc., NTIS No. EGG-2140, Jan. 1982.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Raft River Environmental Program

Sponsoring Organization: DOE/Geothermal
and Hydropower Technologies Division

Research Area(s):

Hydrology - Other

Contract/Grant Number: DE-AC07-76ID01570

Type of Research Activities:

Performing Organization:

Field Research

Idaho National Engineering Laboratory

Principal Investigators:

T.L. Thurow

Objective:

Information/Status:

Monitor well and water chemistry data were collected as part of continuing program designed to provide information that enables evaluation of impact of geothermal development on shallow aquifers. Seven monitor wells are used to detect response of groundwater to geothermal production or injection. Each monitor well has a continuously-reading water level recorder. Baseline water level data were collected which tended to reflect natural seasonal fluctuations. No water chemistry changes were detected.

Seismic monitoring in Raft River Valley consists of 3 stations recording microseismic events. No such events were observed within 40 km of the sampling array.

A first order, second class land survey to detect well field subsidence. Although a dilation of up to 20 cm occurred near the injection wells, it is believed this was an anomalous sighting, perhaps due to distortion caused by heat waves.

Semiannual Progress Report for the Idaho Geothermal Program, April 1 through September 30, 1981, J.T. Parker (ed.), EG&G Idaho, Inc., NTIS No. EGG-2140, Jan. 1982.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Environmental Support Program: Injection Program Research

Sponsoring Organization: DOE/Geothermal and Hydropower Technologies Division

Research Area(s):

Hydrology-Other (Injection)

Contract/Grant Number: DE-AC07-76ID01570

Type of Research Activities:

Performing Organization:

Field Research

Idaho National Engineering Laboratory

Principal Investigators:

B.F. Russell

M.R. Dolenc

Objective:

Perform injection-related research aimed at better understanding and predicting geothermal injection phenomena.

Information/Status:

Two new areas of research were initiated in the Program: (a) pressure monitoring, and (b) dispersion studies.

The pressure monitoring research is designed to relate observable pressure changes in a geothermal reservoir and associated groundwater aquifers to observed and anticipated solute movement as a result of spent geothermal fluid injection. The initial phase of this task was to acquire a numerical model for use in predicting chemical contamination in potable resources. Two computer models were studied: the Survey Waste Injection Program (SWIP) available from the USGS and a Mass Balance/Energy Balance code to simulate pressure response and the velocity field within the hydrothermal system. The latter code appears to be the better one for this program because of code size, logic problems with SWIP, and the need for multispecies.

The objective of the dispersion research program is to increase the accuracy of models that predict the movement of geothermal fluids in fractured rock systems. Emphasis is being placed on improving the accuracy of dispersion coefficients in the fluid models. A literature search of available dispersion coefficient data from both laboratory and field tests has been completed. Experiments are being designed to obtain additional needed data in volcanic and fractured rocks.

In conjunction with the dispersion coefficient work, the Frickett and Lonnquist code was adapted to an Apple Minicomputer. The program is used to simulate non-leaky artesian conditions for a reservoir with given hydraulic characteristics. One extension of the original code that has been implemented is an option for variable grid spacing. This permits greater detail near pumping wells. The program automatically scales all aquifer coefficients on the basis of grid spacing entered by the user. The orientation of the program is toward the casual user with some hydrologic experience. The final product should be an easily used tool to make rather simplified simulations of groundwater flow.

Information/Status:

Woodward-Clyde Associates, under contract to EG&G, prepared a detailed report on a multiple-completion injection-monitoring well for a typical Basin and Range environment. The report will be released to the general public.

Work will continue in FY-82, with the main efforts directed toward pressure monitoring research and dispersion coefficient work for injection wells.

Semiannual Progress Report for the Idaho Geothermal Program, April 1 through September 30, 1981, J.T. Parker (ed.), EG&G Idaho, Inc., NTIS No. EG&G-2140, Jan. 1982.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: HYCSOS: Chemical Heat Pump and Energy Conversion System Based on Metal Hydrides

Sponsoring Organization: DOE/Conservation and Renewable Energy

Research Area(s):
Mass Heat Transport

Contract/Grant Number: 49405 & W-31-109-ENG-38

Type of Research Activities:

Performing Organization:
Argonne National Laboratory

Hardware/Instrumentation -
Development/Testing

Principal Investigators:

J.G. Asbury
J.M. Clinch
J.S. Horowitz

Objective:

Information/Status:

The HYCSOS chemical heat pump uses the heat of absorption and desorption of hydrogen from different metal hydride beds to provide space heating or cooling. The heat source for HYCSOS could be: solar, waste heat, geothermal, or natural gas. The development of HYCSOS has reached the point of initiating development of a commercial device. A multi-year effort has recently been begun to contract with an industrial firm to select an application, and then to develop, design, and construct a prototype metal hydride heat pump to meet this application. Brookhaven National Laboratory (BNL) has the lead assignment for development of chemical heat pumps, but has selected ANL, which developed the concept, to serve as the technical monitor of the industrial contract. As part of this monitoring activity, parallel analytical studies to further optimize the design will be conducted.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Theoretical and Experimental Research on Two-Phase Flow in Geothermal Well Bores

Sponsoring Organization: DOE/Division of Geothermal Energy

Research Area(s):

Mass Heat Transport
Physical Properties Rocks/
Liquids

Contract/Grant Number: AC03-78-ET27141

Type of Research Activities:

Performing Organization:

University of Denver, Denver Research
Institute

Data Analysis/Documentation
Modeling/Simulation

Principal Investigators:

J. Butz
M.C. Mickly

Objective:

1) acquire test data from flowing, commercial geothermal wells at five field test sites; (2) improve the two-phase flow pressure drop computer model; 3) transfer to the geothermal industry the technology and analytic techniques developed during the course of the research.

Information/Status:

The research resulted in a second-generation two-phase flow logging tool being designed, fabricated, and field tested. The probe incorporated pressure and improved temperature measurements, as well as a flowmeter and an experimental phase (gas/liquid) sensor. The two-phase flow computer model was extensively modified; the treatment of dissolved gases was expanded, and a uniform treatment based on Henry's Law was applied to all gases considered. A new set of two-phase pressure drop correlations developed at the University of Houston under a previous contract were added and tested in the model and results with this new correlations set showed the best agreement to date between model predictions and field test data. The improvements have resulted in a computer model that can be used to model two-phase wellbore flow in most U.S. geothermal resources. A Geothermal Well Design Handbook was developed that enables the user with a pocket calculator to compute well-head temperature, pressure and flowrates as a function of changing reservoir conditions and well casing schedule.

Theoretical and Experimental Research on Two-Phase Flow in Geothermal Well Bores, J. Butz, and M.C. Mickly, NTIS No. DOE/ET/27141-3.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Seismicity Related to Geothermal Development in Dixie Valley, Nevada

Sponsoring Organization: DOE/Geothermal and Hydropower Technologies Division

Research Area(s):

Geophysics-Other (Seismic)

Contract/Grant Number: AC08-79NV10054

Type of Research Activities:

Performing Organization:

Field Research

Data Analysis/Documentation

University of Nevada, Seismological Laboratory

Principal Investigators:

Alan S. Ryall

Ute R. Vetter

Objective:

Provide a baseline for assessment of changes in seismicity associated with future injection of geothermal fluid into deep wells in the Dixie Valley area.

Information/Status:

In recent years, Dixie Valley, north-central Nevada, has been the focus of geothermal exploration involving surface and drilling investigations by a number of oil companies. The area of most intensive study is between Dixie Hot Springs on the south and Sou or Seven Devils Hot Springs on the north. This area is a graben, capped by a gabbroic intrusive at a depth varying from approximately 1,500 to 2,000 feet.

A ten-station seismic network was operated in and around the Dixie Valley area from January 1980 to November 1981; three of these stations are still in operation. Data from the Dixie Valley network were analyzed through 30 June 1981, and results of analysis were compared with analysis of somewhat larger events for the period 1970-1979. Conclusions and recommendations are the following:

1. Seismicity in the Dixie Valley-Fairview Peak area is almost exclusively confined to the rupture zone of large earthquakes that occurred there in 1954. Thus, the area of most interest to geothermal exploration has been quiescent for at least a decade.

2. Earthquakes in northern Dixie Valley had focal depth of 7.2 km or less. This is quite shallow compared to mean depth of 11.3 km for the 1954 rupture zone to the south. Listric faulting may be occurring there, but much more data would need to be collected and analyzed to confirm this.

3. Focal mechanisms for larger events in the area of interest are consistent with regional extension in the NW-SE direction, as found by a number of previous investigators. There appears to be a correlation between the ratio of dip-slip to strike-slip motion and focal depth, with deeper events having primarily normal slip on NW- or SE-dipping faults. This may be explained by a relatively larger increase in vertical than in horizontal stress with depth, due to the overburden.

Information/Status: (continued)

the ratio of dip-slip to strike-slip motion and focal depth, with deeper events having primarily normal slip on NW- or SE-dipping faults. This may be explained by a relatively larger increase in vertical than in horizontal stress with depth, due to the overburden.

4. Perhaps unfortunately for this investigation, the level of seismicity in the Dixie Valley-Fairview Peak area was anomalously low during the period of operation of the Dixie Valley seismic network. In the Dixie Valley-Fairview Peak area, the period of quiescence has continued until the time of this writing.

5. A recurrence curve for events in the 1954 rupture zone for 1970-1981 indicates a b-value (related to the ratio of small-to-large earthquakes) that is high (1.3) for the western Great Basin. Such high b-values have been found to be characteristic of aftershock sequences, earthquake swarms and volcanic earthquakes. However, a running b-value calculation indicates that b increased from 1970 to 1974, and has since decreased during a period of generally reduced seismicity.

6. Evidence related to the possibility of a large earthquake in northern Dixie Valley is ambiguous, with the potential for an earthquake of magnitude 7+ in the near future.

On the other hand, some of the evidence argues against an impending large shock in this area.

7. Because of the ambiguity relative to the possibility of a future large earthquake in the area of primary interest to geothermal exploration, it is recommended that some level of monitoring be continued in the future. Probably the present level of effort, with two stations in northern Dixie Valley, will be sufficient for the time being.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Subsurface Fracture Mapping from Geothermal Wellbores

Sponsoring Organization: DOE/Division
of Geothermal Energy

Research Area(s):

Well Logging
Electrical Studies

Contract/Grant Number: ACO4-79-ET27013

Type of Research Activities:

Performing Organization:

Field Research
Laboratory Research-Experi-
mental

H-Tech Laboratories Inc.

Principal Investigators:

B.A. Hartenbaum
G. Rawson

Objective:

Assist in planning future experiments in the Hot Dry Rock Program by providing a review of 1) the use of radar to map far-field fractures, 2) the use of conventional well logging tools to map borehole-fracture intercepts, and 3) the use of magnetic dipole ranging to determine the relative positions of the injection and production well within the fractured zone.

Information/Status:

The emphasis in the radar study and magnetic ranging study is on basic physics; and the logging study is on experimental data analysis and interpretation. Research undertaken has indicated that the VHF backscatter radar has the potential for mapping fractures within a distance of 50+ 20 meters from the wellbore. The surveying of one borehole from another appears feasible at ranges of up to 200 to 500 meters by using a low frequency magnetic field generated by a solenoid located in one borehole, a sensitive B field detector that transverses part of the second borehole, narrow band filtering, and special data inversion techniques.

Topical Report on Subsurface Fracture Mapping From Geothermal Wellbores,
B.A. Hartenbaum, G. Rawson, Sept. 1980, NTIS No. DOE/ET/27013-TI.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Continuity and Internal Properties of Gulf Coast Sandstones and Their Implications for Geopressed Energy Development

Sponsoring Organization: DOE/Geothermal and Hydropower Technologies Division

Research Area(s):

Geochronology/Stratigraphy
Structural Geology

Contract/Grant Number: DE-AC08-79ET27111

Type of Research Activities:

Performing Organization:

Data Analysis/Documentation

University of Texas at Austin,
Bureau of Economic Geology

Principal Investigators:

R.A. Morton
T.E. Ewing
N. Tyler

Objective:

Provide systematic investigation, classification, and differentiation of the intrinsic properties of genetic sandstone units that typify many geopressed geothermal aquifers and hydrocarbon reservoirs of the Gulf Coast region.

Information/Status:

Sandstone facies models and regional structural fabric of the Gulf Coast Basin suggest that large and relatively continuous reservoirs should be found where barrier and strand plain sandstones parallel regional faults. These conditions should optimize the magnitude and rate of fluid production from geopressed geothermal aquifers and maximize the efficiency of primary and enhanced recovery of conventional hydrocarbons. Fluvial sandstones deposited by major streams that trend roughly normal to regional faults are probably less continuous than barrier sandstones, but together they serve as substantial targets for exploration and production of unconventional as well as conventional energy resources.

Continuity and Internal Properties of Gulf Coast Sandstones and Their Implications for Geopressed Energy Development, Annual Report for November 1, 1980 - October 31, 1981, R.A. Morton, et. al., The University of Texas at Austin, NTIS No. DOE/ET/27111-4, June 1982.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Raft River Well Stimulation Experiments - Geothermal Reservoir Well Stimulation Program

Sponsoring Organization: DOE/Division
of Geothermal Energy

Research Area(s):

Hydrology
Well Stimulation/Reservoir
Engineering

Contract/Grant Number: DE-AC-32-79AL10563

Type of Research Activities:

Performing Organization:

Republic Geothermal, Inc.
Maurer Engineering, Inc., and
Vetter Research

Field Research
Data Analysis/Documentation

Principal Investigators:

Objective:

Stimulate two production wells at the Raft River geothermal site using hydraulic fracture treatments and analyze and document the results to help identify stimulation problems and develop appropriate stimulation techniques.

Information/Status:

Well RRGP-4 was successfully stimulated using the dendritic fracture treatment method and well RRGP-5 was successfully stimulated using a conventional large hydraulic fracture treatment technique. Borehole televiewer surveys were used to examine the resulting downhole fractures. This experience will be valuable in high-temperature reservoir experiments.

Raft River Well Stimulation Experiments - Geothermal Reservoir Well Stimulation Program, Republic Geothermal, Inc., Maurer Engineering, Inc., and Vetter Research, NTIS No. DOE/AL/10563-T7, Aug., 1980.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Processing of Brines for Injection

Sponsoring Organization: DOE/Division
of Geothermal Energy

Research Area(s):
Brine/Gas Chemistry

Contract/Grant Number:

Type of Research Activities:

Performing Organization:
Lawrence Livermore Laboratory

Laboratory Research-Experi-
mental

Principal Investigators:

Objective:

Develop and demonstrate a process for treating Salton Sea geothermal brine effluents to produce wastes with high injectability.

Information/Status:

Process developed and bench-scale tested based on solids contact clarification (enhanced with an anionic coagulant) followed by polishing by sand or precoat pressure filtration.

Injectability tests indicated resulting effluents could be injected without significantly impairing injection wells.

"Processing of Geothermal Brine Effluents for Injection", R. Quong, et. al., Trans. Geothermal Resources Council Meeting, Hilo, 2, 1978, pp. 551-554.

"Geothermal Brine Injection Evaluation Methodology," Proceedings Second Invitational Well-Testing Symposium, Berkeley, CA, R. Quong, et. al., Lawrence Livermore Laboratory, Rept. UCID-17716, 1978.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Fluid Modeling for Deposition Prediction

Sponsoring Organization: DOE/Geothermal
and Hydropower Technologies Division

Research Area(s):

Corrosion/Scaling

Contract/Grant Number: 4-X29-9305X-1

Type of Research Activities:

Performing Organization:
University of California at San Diego

Modeling/Simulation
Theoretical Research

Principal Investigators:

Nancy Moller-Weare
John H. Weare

Objective:

Model multi-ion geothermal fluids to predict precipitation products, rates, and locations in energy conversion plants.

Information/Status:

A chemical equilibrium model has been developed for hydrothermal waters based on the semiempirical equations of aqueous electrolyte solutions recently introduced by Pitzer and co-workers. Accurate solubility predictions (usually within 5-10% of experimental results) can be made for ionic strengths 0-20m. Comparison with experimental data indicates that a theory parameterized by binary and ternary data can be used to accurately predict solubilities in much more complex mixtures. Mineral solubilities calculated with this model are compared with those calculated from other currently available models. Whereas our predictions are typically within 5%, the ion pairing models are substantially in error at low ionic strengths. Recent results parameterizing the H₂S and SiO₂ systems will be presented.

"Calculation of the Chemical Behavior of Highly Concentrated Geothermal Brines", N. Moller-Weare and J.H. Weare, in Proceedings of Geothermal Engineering and Materials (GEM) Program Conference, San Diego, CA, October 1982, sponsored by DOE/Geothermal and Hydropower Technologies Division.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Compilation of Data on Fluids From Geothermal Resources in the U.S.

Sponsoring Organization: DOE/Division of Geothermal Energy

Research Area(s):

Brine/Gas Chemistry

Contract/Grant Number: W-7405-ENG-48

Type of Research Activities:

Performing Organization:

Data Analysis/Documentation

Lawrence Berkeley Laboratory

Principal Investigators:

Objective:

Produce comprehensive, single-source compilation of geothermal fluid characteristics for important U.S. geothermal resources, to be stored in computerized database.

Information/Status:

A computerized file and hard-copy documentation of site-specific resource characteristics was produced in 1977.

"A Compilation of Data on Fluids From Geothermal Resources in the U.S.",
S.R. Cosner and J.A. Apps, Lawrence Berkeley Laboratory, NTIS No. LBL-5936,
May 1978.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Study of Using Surface Waters to Supplement Injection

Sponsoring Organization: DOE/Division
of Geothermal Energy

Research Area(s):

Brine/Gas Chemistry

Contract/Grant Number:

Type of Research Activities:

Performing Organization:

Laboratory Research-Experi-
mental

Lawrence Livermore Laboratory

Principal Investigators:

Objective:

Evaluate feasibility of using local surface waters as make-up water for geothermal brine injection at the Salton Sea geothermal resource.

Information/Status:

3 local sources of water (Salton Sea, New River, Alamo River) evaluated.

Direct injection of make-up not feasible because of high suspended-solids levels and because mixing of make-up with geothermal brine resulted in additional precipitation.

Mixtures of ambient temperature make-up and higher-temperature (80-90°C) brine effluent in a 1:4 mass ratio found to be potentially injectable following processing by reaction clarification and granular media filtration.

"Using Surface Waters for Supplementing Injection at the Salton Sea Geothermal Field, Southern, California," E. Raber, et. al., Trans. Geothermal Resources Council Meeting, Reno, 3, 1979, pp. 561-564.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Assessment of the Characterization (in situ-Downhole) of Geothermal Brines

Sponsoring Organization: DOE/Division of Geothermal Energy

Research Area(s):

Brine/Gas Chemistry
Well Logging

Contract/Grant Number: E (49-18) 2551

Type of Research Activities:

Performing Organization:

National Academy of Sciences
National Materials Advisory Board

Data Analysis/Documentation
Hardware/Instrumentation -
Development/Testing

Principal Investigators:

Objective:

Identify and quantify the physical and chemical properties of geothermal fluids and identify the downhole instrumentation needed to monitor changes in the values of these properties.

Information/Status:

General conclusions were made on the topics of packaging, data transmission, downhole sampler, and import physical and chemical measurements, and sampling as related to instrumentation needs.

Recommendations were made concerning a downhole sampler; standardized sampling; materials for insulation, jacketing, corrosion protection, and armoring; continuous temperature and pressure monitoring; integrated thermionic electronic circuits; development of a reference electrode for continuous downhole measurements; development of a H⁺ sensitive electrode for continuous downhole measurements; two-phase flow; partial pressure of CO₂; onset of heterogeneity; and a sulfide electrode.

"Assessment of the Characterization (in situ-Downhole) of Geothermal Brines", National Materials Advisory Board, National Academy of Sciences, NMAB-344, Jan. 1978.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Injection Well Stimulation Chemistry

Sponsoring Organization: DOE/Geothermal
and Hydropower Technologies Division

Research Area(s):

Corrosion/Scaling

Contract/Grant Number:

Type of Research Activities:

Performing Organization:

Laboratory Research/Experimental

Vetter Research

Principal Investigators:

Objective:

Identify chemical procedures and chemicals for reducing or removing scale
in geothermal fluid injection wells.

Information/Status:

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Measurement of Injectability of [Geothermal] Brines

Sponsoring Organization: DOE/Geothermal
and Hydropower Technologies Division

Research Area(s):

Fluid Migration

Contract/Grant Number:

Type of Research Activities:

Performing Organization:

Laboratory Research-Experimental

Lawrence Livermore Laboratory

Principal Investigators:

Objective:

Assess injectability of Imperial Valley geothermal brine by measuring the flow of brine through media which simulate downhole injection formations and correlate these measurements, as far as possible, with actual injection performance.

Information/Status:

On-line field tests of core flooding and membrane filtration with 70-102°C brine showed that injection would not be feasible unless particulates $\geq 1 \mu\text{m}$ were removed. Brines with pH lowered to retard scale formation were found to be not highly injectable without filtration.

- An Experimental Investigation of the Permeability of Kayenta and St. Peter Sandstones to Hypersaline Brine in the Temperature Interval 70-90°C at 10.3-MPa Confining Pressure, A.J. Piwinski and R. Netherton, Lawrence Livermore Laboratory, Rept. UCRL-52382, 1977.
 - Predicting the Rate by Which Suspended Solids Plus Geothermal Injection Wells, L.B. Owen, et. al., Lawrence Livermore Laboratory, Preprint UCRL-80529, 1977, presented at the 3rd Ann. Stanford Workshop on Geothermal Reservoir Eng., 1977.
 - "Development of Injection Criteria for Geothermal Resources," J.D. Tewhe, et. al., Trans. Geothermal Resources Council Meeting, Hilo, 2 (1978) pp. 649-652.
 - "Apparatus for the Field Evaluation of Geothermal Effluent Injection," R. Netherton and L.B. Owen, Trans. Geothermal Resources Council Meeting, Hilo, 2 1978 pp.
 - "An Automated System for Membrane Filtration and Core Tests," R.T. Hasbrouck, et. al., Trans. Geothermal Resources Council Meeting, Reno, 3 1979, pp. 301-304.
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Information/Status: (continued)

- "Processing of Geothermal Brine Effluents for Injection," R. Quong, et. al., Trans. Geothermal Resources Council Meeting, Hilo, 2 1978, pp. 551-554.
- An Assessment of the Injectability of Conditioned Brine Produced by a REaction Clarification--Gravity Filtration System in Operation at the Salton Sea Geothermal Field, Southern, California, L.B. Owen, et. al., Lawrence Livermore Laboratory, Rept. UCID-18488, 1979.
- Viscosity of Brines from the Salton Sea Geothermal Field, Imperial Valley, California, A.J. Piwinski, et. al., Lawrence Livermore Laboratory, Rept. UCRL-52344, 1977.
- Improving the Performance of Brine Wells at Gulf Coast Strategic Petroleum Reserve Sites, L.B. Owen and R. Quong, Lawrence Livermore Laboratory, Rept. UCRL-52829, 1979.
- "Evaluating Brine Injection for DOE's Strategic Petroleum Reserve Program", Energy and Technology Review, Lawrence Livermore Laboratory Rept. UCRL-52000-79-8, 1979 pp. 1-10.
- "An Evaluation of Geopressured Brine Injectability," L.B. Owen, et. al., presented at the 6th Annual Stanford Workshop on Geothermal Reservoir Engineering, 1980.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Geothermal Exploration in Trans-Pecos, Texas/New Mexico

Sponsoring Organization: DOE/Division
of Geothermal Energy

Contract/Grant Number: FC07-791D12080

Performing Organization:

Texas State Energy and Natural Resources
Advisory Council

Research Area(s):

Electrical Studies
Heat Flow Studies
Brine/Gas Chemistry
Structural Geology

Type of Research Activities:

Field Research
Laboratory Research-Analytical

Principal Investigators:

D.M. White

Objective:

Conduct a two-year field and laboratory investigation designed to explore and evaluate the geothermal resources of two selected subregions of Trans-Pecos, Texas/New Mexico.

Information/Status:

The Texas Energy and Natural Resources Advisory Council will be supported with subcontracts from the University of Texas at El Paso, University of Texas at Austin, and Southwest Research Institute. The Hueco Tanks subregion will be evaluated through electrical resistivity, gravity, microearthquake, thermal gradient, heat flow, geochemical and geologic investigations. The Presidio Bolson subregion will be evaluated through microearthquake, thermal gradient, heat flow, and geochemical investigations. Approximately 25 test holes will be drilled. This work will be combined with earlier work funded by the state and DOE to better define the resource potential in both subregions. Private funding will be used to accomplish research needs identified during the study, but for which funds have not been budgeted.

Contract from September 1979 to September 1981.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Seismic Monitoring at The Geysers Geothermal Field

Sponsoring Organization: DOE/Division
of Geothermal Energy

Research Area(s):

Geophysics-Other (Seismic)
Structural Geology

Contract/Grant Number: EG-77-A-36-1018

Type of Research Activities:

Performing Organization:
DOI/USGS

Field Research
Data Analysis/Documentation

Principal Investigators:

C.G. Bufe

Objective:

(1) Determine attenuation and source characteristics of earthquakes occurring at The Geysers; (2) differentiate between earthquakes natural to the geothermal area and those induced by production activities; and (3) define active faults at The Geysers, determine cumulative slip with time, and predict cumulative slip if microearthquake activity continues at its present level.

Information/Status:

The approach is to monitor seismic activity at The Geysers using The Geysers-Clear Lake automated seismograph network augmented by 3 additional stations; obtain wide band spectral information from 4 three-component seismographs; collect data over four-month period; and analyze results to determine possible seismic discriminants. A hypocenter map of earthquakes at The Geysers has been prepared. Comparisons of pre-production seismicity with present seismicity indicates an increase in earthquake activity at The Geysers.

Contract began in July 1977.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Monitoring Instrument Field Experiments

Sponsoring Organization: DOE/Division of
Geothermal Energy

Research Area(s):

Well Logging
Brine/Gas Chemistry

Contract/Grant Number: 80342; AC06-
76RL01830

Type of Research Activities:

Performing Organization:

Battelle Pacific Northwest Lab.

Hardware/Instrumentation -
Development/Testing

Principal Investigators:

D.W. Shannon
O.E. Koski
M.J. Danielson

Objective:

Information/Status:

A number of new chemical control sensors for geothermal applications have been developed (in other programs) at PNL and by subcontractors. These chemical sensor probes are expected to find wide applications to monitor geothermal power plant systems and for down hole logging tools, since the probes provide continuous electrical readout of chemical parameters important to geothermal scaling, corrosion, and environmental concerns. The probes include devices to measure salinity, oxygen content, acidity (pH), sulfide (H₂S), CO₂, and corrosion rate. A number of sensors have emerged from initial R and D to move to the next stage of development, namely, complete instrument systems ready for plant use. The objectives of the program in this FTP are to fabricate complete instruments using the new sensor probes, conduct laboratory scale calibrations and performance limits tests, conduct field performance and life tests on a geothermal brine system, and to document the design and performance specifications so commercial instrument vendors can consider manufacture and sale to the geothermal industry. This program will complete the development and demonstrate to the industry the useful applications of the devices. Without this program, the development of the sensors will be left at an incomplete stage. Period of performance is 10/80 to 7/83.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Cooperative Research DOE/ENEL Reservoir Engineering
(Field Products)

Sponsoring Organization: DOE/Division
of Geothermal Energy

Research Area(s):

Well Stimulation/Reservoir
Engineering

Contract/Grant Number: 005622

Type of Research Activities:

Performing Organization:

Lawrence Berkeley Lab.

Field Research
Hardware/Instrumentation
Development/Testing

Principal Investigators:

R.C. Schroeder
K. Pruess

Objective:

The objectives of this task are to: (1) conduct transient well tests at sites chosen to best support DOE/DGE programs and to analyze such data; the DOE-ENEL Corporation study on modeling of Vapor-dominated geothermal, and, (2) evaluate and improve existing downhole well testing tools and field techniques and transfer the resulting technological advances.

Information/Status:

The purpose of this research is to: (1) develop numerical simulation techniques; (2) develop a data base through direct contacts and technical reporting for a specific vapor-dominated reservoir; and (3) develop methodology for carrying out a large scale simulation of actual geothermal field behavior. Specific tasks include: (1) developing the LBL geothermal reservoir simulator SHAFT into a viable engineering tool and making it available to the U.S. geothermal community; (2) developing a quantitative description and history match for the Serrazzano zone of the Larderello Geothermal Reservoir in Italy; and (3) studying the effects of cold water injection on the behavior of the Italian field. Studies to date have concentrated on the Larderello Geothermal Field in Italy because it offers the opportunity to apply LBL developed models, using actual production data, to a vapor-dominated field to investigate future field behavior and optimum injection strategy.

Period of performance under this effort was 10/76 to 10/81. FY 80 funding was \$135,000.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Chemical Control and Monitoring Instrumentation
Subcontract

Sponsoring Organization: DOE/Division of
Geothermal Energy

Research Area(s):
Brine/Gas Chemistry

Contract/Grant Number: 80195

Type of Research Activities:

Performing Organization:
Battelle Pacific Northwest Lab.

Hardware/Instrumentation -
Development/Testing

Principal Investigators:

M.J. Danielson
G.A. Jensen

Objective:

The objective of this work is to subcontract to outside organization the development of sensors for measuring selected chemical and physical properties of geothermal fluids. This subcontracting program is in support of another PNL sensor program: the Development of Chemical Control and Monitoring Instrumentation. The funding is pass-through money that goes directly to the subcontractor.

Information/Status:

Subcontracts are in place for the development of the following instruments: (1) glass pH electrode - measures hydrogen ion concentration and two glass type electrodes are being developed based on modifications of present technology; (2) sulfide ion sensor - one device is being developed to measure sulfide ion concentration; (3) carbon dioxide sensor - one model is being developed to measure the amount of dissolved carbon dioxide in the brine; and (4) chemically sensitive semiconductor devices - advanced sensors are under development for measuring one or more chemical species. Devices are being developed to measure several species simultaneously. One additional subcontract will be let for the development of a nonglass pH electrode. The sensor is based on state-of-the-art science but is an advancement over glass models and holds promise for geothermal applications.

Work on these projects was initiated in October of 1978 with completion scheduled for September 1982. Funding during FY 81 was \$320,000.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: HDR Geothermal Energy Development Program

Sponsoring Organization: DOE/Division of
Geothermal Energy

Research Area(s):

Physical Properties Rocks/Liquids
Mass Heat Transport

Contract/Grant Number: 006089

Type of Research Activities:

Performing Organization:

Los Alamos Scientific Lab.

Field Research
Data Analysis/Documentation

Principal Investigators:

P. Oranke
G. Heiken
M. Smith

Objective:

The overall objective of the program is to determine the technical and economic feasibility of Hot Dry Rock (HDR) as a significant energy source and to provide a basis for its timely commercial development if such development is warranted.

Information/Status:

Principal operational tasks are those activities required to enable a decision of ultimate commercialization to be made by FY 1987. These include: (1) development and analysis of an HDR 20 to 50 MW thermal Phase 2 reservoir at Site 1 (Fenton Hill) with the ultimate construction of a pilot electric generating station (Phase 3); (2) selection of a second site with reservoir development and construction of a pilot electric plant or a direct heat plant of at least 30 MW thermal thereon; (3) the determination of the overall domestic HDR energy potential; and (4) the selection of 10 or more target prospect areas for future HDR plant development. Supporting technology and institutional tasks will involve: (1) design and testing of advanced instruments, equipment, and material; (2) drilling techniques, fracture studies, reservoir evaluation, and engineering studies; and (3) the requisite economic, environmental, legal, and regulatory studies to identify those factors necessary for widespread industrial utilization, along with aggressive transfer of technology and information to industry and academic and governmental organizations. Initial activities under the program began as early as 1972. Funding during FY 80 was \$24,455,000.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Fluid Chemistry and Computer Modeling

Sponsoring Organization: DOE/Division of
Geothermal Energy

Research Area(s):Brine/Gas Chemistry
Corrosion/Scaling

Contract/Grant Number: 006088

Type of Research Activities:

Performing Organization:

Los Alamos Scientific Lab.

Theoretical Research
Modeling/Simulation

Principal Investigators:R.C. Feber

Objective:

Assist DGE in the planning and coordination of national efforts in geothermal fluid chemistry.

Information/Status:

Activities are designed to anticipate and address potential chemical problems associated with the investigation and demonstration of the industrial usefulness of the geothermal energy resource. These potential problems derive from possible scaling, precipitation, or corrosion in surface utilization equipment or partial plugging of geothermal reservoirs when fluids are reinjected. Areas of particular interest include the theory of electrolyte solutions, thermodynamic data for pertinent solutions and solids, the kinetics and/or rate of precipitation of scale forming minerals, and computer modeling of energy extraction systems. The purposes of the task will be met by anticipating the need for and assuring the availability of information from these areas to predict systems degradation by precipitation/scaling and suggest operating regimes to minimize its effects.

Contract efforts were undertaken during FY 76 and the work is on-going. Funding during FY 80 was \$1,140,000.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Induced Seismicity

Sponsoring Organization: DOE/Resource
Applications

Research Area(s):

Geophysics-Other (Seismic)

Contract/Grant Number: 903205

Type of Research Activities:

Performing Organization:
University of Nevada, Reno

Field Research
Data Analysis/Documentation

Principal Investigators:

N/A

Objective:

The objective is to monitor microseismic activity at Dixie Valley, NV, due to the proximity of a large active fault and for future use in utilizing geothermal resources.

Information/Status:

The period of performance was August of 1979 through November of 1981 with FY 81 funding being \$100,000.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Targeting of Geothermal Resources in Delaware

Sponsoring Organization: DOE/Division of
Geothermal Energy

Research Area(s):

Heat Flow Studies
Well Logging

Contract/Grant Number: 006479

Type of Research Activities:

Performing Organization:
University of Delaware

Field Research
Data Analysis/Documentation

Principal Investigators:

H.D. Woodruff

Objective:

Assist DOE and its contractors in preliminary determination of the geothermal resources of Delaware.

Information/Status:

To date, work has included (1) administrative assistance to DOE contractors in preparation for the drilling of geothermal gradient holes, (2) temperature and other geophysical logging of gradient test holes, and (3) preparation of a Bouguer gravity map of portions of southern Delaware. Preliminary interpretations have been made of the gravity and other geophysical data from the standpoint of identifying structures or geologic features that would have geothermal implications. Final results would include recommendations for future drilling sites and prediction of temperatures that might be expected at given depths. Additional gravity mapping has been done and emphasis has been placed on interpretation of gravity data collected during the previous contract period. The work was initiated in July of 1978 and is on-going.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Geothermal Rock Mechanics

Sponsoring Organization: DOE/Division of
Geothermal Energy

Research Area(s):Physical Properties Rocks/Liquids

Contract/Grant Number: 000098

Type of Research Activities:**Performing Organization:**Laboratory Research-Experi-
mental

Terra Tek Inc.

Principal Investigators:D.O. Enniss

Objective:

Information/Status:

Material property testing of actual geothermal core materials will be performed at simulated in situ conditions of overburden pressure, temperature and pore fluid chemistry. The five geothermal development areas requiring such material properties at simulated conditions are exploration and assessment, drilling, reservoir engineering, stimulation and subsidence. Property measurements include: mechanical response, thermal conductivity, thermal diffusivity, thermal expansion, permeability, ultrasonic velocity and electrical resistivity. Additionally, procedures and techniques will be developed to allow the measurement of fracture conductivity and fracture toughness of core material at these same environmental conditions. This type of information is required for the accurate assessment of fractured reservoirs. A detailed source book containing the results of a test program conducted upon core materials retrieved from an East Mesa KGRA well has been completed and distributed to the geothermal community. Measurements included mechanical response, thermal properties, permeability, ultrasonic velocity and electrical resistivity. Core material from Raft River, Idaho KGRA has been obtained and a similar program has been initiated.

The project was undertaken during FY 81 with funding of \$160,000.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Standard Geothermal Sampling/Analysis Method Development

Sponsoring Organization: DOE/Office of Resource Application

Research Area(s):

Brine/Gas Chemistry
Other/Unknown

Contract/Grant Number: 005445

Type of Research Activities:

Data Analysis/Documentation

Performing Organization:

Battelle Pacific Northwest Lab.

Principal Investigators:

C.H. Hindle
D.W. Shannon
J.M. Creer

Objective:

Information/Status:

The effort was initiated in January of 1976 and scheduled for completion in September of 1982. During FY 80 the project was funded at \$100,000.

This contract will provide standardized, accepted, accurate sampling/analysis methods for use in geothermal resources exploration, utilization and monitoring. Standardization and acceptance will be accomplished through ASTM. The end result will be a manual of standardized recommended methods.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Geoplant Fluid Case Studies

Sponsoring Organization: DOE/Office of
Resource Application

Research Area(s):

Brine/Gas Chemistry
Corrosion/Scaling

Contract/Grant Number: 005446

Type of Research Activities:

Performing Organization:

Battelle Pacific Northwest Lab.

Field Research
Laboratory Research-Analytical
Data Analysis/Documentation

Principal Investigators:

D.W. Shannon
E.M. Woodruff

Objective:

The purpose of this program is to conduct case studies at two geothermal plants in order to establish historical records of brine chemistry, changes, materials performance, and scaling in order to document performance, achieve better plant control, anticipate problems, and estimate plant life.

Information/Status:

A number of new methods will be applied to these early plants to define the characteristics and interactions of geothermal fluids, gases, and materials of construction under full-scale operating conditions. Studies include analyses and monitoring of the chemistry of the system with special attention given to corrosion and heat transfer including film or scale characteristics, and fluid properties relating to disposal, such as suspended solids affecting injection well life. Data will be interpreted in terms of the significance of what is happening, why it occurs and how it impacts plant life, materials selection, operating efficiency, and maintenance. Emphasis in this program is on demonstrating new methods on-line or as close as possible to full scale operating geothermal systems and documenting the methods and results. The advantages in this approach derive from the quality of information obtained directly from the system, the opportunities to assist operators in defining conditions and formulating responses when necessary, and the effective transfer of new technologies of plant monitoring and process control directly to the geothermal industry. The period of performance for the effort is April 1978 through September 1983 with FY 80 funding being \$500,000.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Computer Simulation of Noncondensable Gas Behavior in Geothermal Power Plants Using Direct Contact Heat Exchange

Sponsoring Organization: DOE/Division of Geothermal Energy

Research Area(s):Mass Heat Transport
Brine/Gas Chemistry

Contract/Grant Number: 001166

Type of Research Activities:**Performing Organization:**

University of Tennessee

Modeling/Simulation
Theoretical Research

Principal Investigators:J.J. Perona

Objective:

Information/Status:

The transfer of energy, from a geothermal brine by direct contact with a working fluid, such as isobutane, permits transfer of noncondensable gases from the brine to the working fluid vapor. The noncondensable gases accompany the working fluid vapor from the direct contact boiler into the turbine, condenser and preheater. The prediction of the distribution of noncondensable gases between liquid and vapor phases in the various power plant components is a challenging problem in nonisothermal mass transfer. During FY 1979 a computer model was developed for carbon dioxide and hydrogen sulfide behavior in a direct contact geothermal power plant using isobutane as a working fluid. This computer model will be modified during FY 1980 to simulate the particular equipment characteristics of the 500 kw direct contact pilot plant at East Mesa. The computer model will then be used to help interpret experimental pilot plant runs. Modifications to the computer program have been completed. The effects of varying carbon dioxide levels in the inlet brine on vapor and liquid compositions are being ascertained. The project was completed in 1981 with funding of \$9,000.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Geochemical Engineering Reference Manual

Sponsoring Organization: DOE/Geothermal
and Hydropower Technologies Division

Research Area(s):
Geochemistry-Other

Contract/Grant Number: DE-AC-03815F-11520

Performing Organization:
Terra Tek, Inc.

Type of Research Activities:
Data Analysis/Documentation

Principal Investigators:

Objective:

Collect, consolidate, evaluate, and document geochemical-related information to assist the geothermal energy industry in optimizing energy utilization efficiency and safety.

Information/Status:

FY 1982 project.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Geochemistry of Geothermal Systems

Sponsoring Organization: DOE/Division of
Geothermal Energy

Research Area(s):

Brine/Gas Chemistry

Contract/Grant Number:

Type of Research Activities:

Performing Organization:

Pennsylvania State University

Data Analysis/Documentation
Modeling/Simulation

Principal Investigators:

Objective:

Collect geochemical data and model chemical systems for improving process engineering of geothermal plants.

Information/Status:

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Calorimetry of Geothermal Fluids and Related Materials

Sponsoring Organization: DOE/Division of Geothermal Energy

Research Area(s):

Mass Heat Transport
Brine/Gas Chemistry

Contract/Grant Number:

Type of Research Activities:

Performing Organization:

Arizona State University

Theoretical Research
Modeling/Simulation

Principal Investigators:

Objective:

Modify and apply an existing high-temperature, high-pressure calorimeter to measure enthalpies of dilution in concentrated NaCl-H₂O solutions and enthalpies of mixing, solution, and precipitation of solid phases in the systems NaCl - CaCl₂ - CaSO₄ - H₂O and NaCl - CaCl₂ - CaCO₃ - H₂O.

Information/Status:

Project completed.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Solubility and Kinetics of Precipitation of Minerals of Importance in Geothermal Applications

Sponsoring Organization: DOE/Division of Geothermal Energy

Research Area(s):

Corrosion/Scaling

Contract/Grant Number:

Type of Research Activities:

Performing Organization:

State University of New York, Buffalo

Laboratory Research-Experimental

Theoretical Research

Principal Investigators:

Objective:

Determine the thermodynamic solubilities and kinetics of scale-forming minerals in the presence of potential scale inhibitors.

Information/Status:

- Conducted studies on calcium carbonate polymorphs, calcium sulfate hydrates, barium sulfate, and silicates up to 300°C using a seeded growth technique.
- Influence of trace heavy metal ions on precipitation was also considered.

Project completed.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Calorimetric Determination of the Entropies and Gibbs Free Energies of Formation of Selected Scale-Forming Minerals

Sponsoring Organization: DOE/Division of Geothermal Energy

Research Area(s):

Corrosion/Scaling

Contract/Grant Number:

Type of Research Activities:

Performing Organization:

Laboratory Research-Analytical

DOI/USGS

Principal Investigators:

Objective:

Measure heat capacities and enthalpies of selected geothermal minerals which contribute to scale formation.

Information/Status:

- Measured heat capacities (between 5K and 600K) of chalcopyrite (CuFeS_2), siderite (FeCO_3), rhodochrosite (MnCO_3), fayalite (FeSiO_4), and tephroite (MnSiO_4) by combined adiabatic calorimetry and differential scanning calorimetry.
- Measured enthalpies of formation of siderite and rhodochrosite by HCl solution calorimetry.

Project completed.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Hydrodynamic/Kinetic Reactions in Liquid-Dominated Geothermal Systems

Sponsoring Organization: DOE/Division of Geothermal Energy

Research Area(s):

Corrosion/Scaling

Contract/Grant Number: LASL Subcontract 4-X29-9916F-1

Type of Research Activities:

Performing Organization:

Aerojet Energy Conversion Co.

Laboratory Research-Experimental

Hardware/Instrumentation-Development/Testing

Principal Investigators:

Objective:

- Evaluate hydrodynamic/kinetic mechanisms of geothermal scale buildup.
 - Identify methods to control or modify solids deposition.
-

Information/Status:

Designed, constructed, and tested a mobile well test unit to collect data on geothermal scale information and provide power plant design data.

Project completed.

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- "Mobile Well Site Test Equipment to Provide Hydrodynamic/Kinetic Reaction and Power Plant Design Data", J.P. Nesevich, et. al., Geothermal Resources Council Transactions, Vol. 5, 1981.
-

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Solubility of SrSO_4 in Aqueous Solutions

Sponsoring Organization: DOE/Division of
Geothermal Energy

Research Area(s):

Brine/Gas Chemistry

Contract/Grant Number:

Type of Research Activities:

Performing Organization:
Vetter Research

Laboratory Research/Experi-
mental

Principal Investigators:

Objective:

- Determine solubility of SrSO_4 in NaCl-free solution of CaCl_2 and MgCl_2 at 75°C and 95°C to identify solubility-temperature trends.
 - Determine SrSO_4 solubility in higher-temperature solutions containing NaCl.
-

Information/Status:

Project completed.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Injection, Injectivity, and Injectability in Geothermal Operations

Sponsoring Organization: DOE/Division of Geothermal Energy

Research Area(s):

Physical Properties Rocks/Liquids

Contract/Grant Number: ET-78-C-03-2444 or DE/AC03-79ET27146

Type of Research Activities:

Performing Organization:
Vetter Research

Indeterminable From-Project Description

Principal Investigators:

Objective:

Information/Status:

- Injection, Injectivity and Injectability in Geothermal Operations: Problems and Possible Solutions, O.J. Vetter and H.B. Crichlow, Vetter Research.
 - Particle Characterization for Geothermal Operations, O.J. Vetter and V. Kandarpa, Vetter Research, VR Report #81-01-06, Jan. 6, 1981.
-

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Sampling and Analysis Methods for Geothermal Fluids and Gases

Sponsoring Organization: DOE/Division of Geothermal Energy

Research Area(s):

Brine/Gas Chemistry

Contract/Grant Number: FY-76-C-06-1830

Type of Research Activities:

Performing Organization:

Data Analysis/Documentation

Battelle Pacific Northwest Laboratory

Principal Investigators:

Objective:

Develop accurate, reliable, and standardized sampling and analysis methods for geothermal fluid characterization and for supporting process monitoring activities.

Information/Status:

This project has been running since 1975 and has resulted in the publication of a comprehensive technical manual describing appropriate sampling and analysis methods for characterizing geothermal fluids. S&A methods developed in conjunction with ASTM are being used by industry.

Current R&D under this contract is developing S&A methods for detecting cross-leaks between geofluid and organic working-fluid streams in binary-cycle geothermal power plants.

- Sampling and Analysis Methods for Geothermal Fluids and Gases, J.C. Watson, Battelle Pacific Northwest Laboratory, PNL-MA-572, July 1978.
 - Appendices - Sampling and Analysis Methods for Geothermal Fluids and Gases, D.W. Shannon, Battelle Pacific Northwest Laboratory, PNL-MA-572, available from NTIS.
 - Field Evaluation of Sampling Methods for Pressurized Geothermal Liquids, Gases, and Suspended Solids, D.W. Shannon, et.al., Battelle Pacific Northwest Laboratory, PNL-3412, January 1980, available from NTIS.
 - Techniques for Geothermal Liquid Sampling and Analysis, C.E. Kindle and E.M. Woodruff, Battelle Pacific Northwest Laboratory, PNL-3801, July 1981, available from NTIS.
 - Standardizing Sampling and Analysis Methods for Geothermal Fluids and Gases, J.C. Watson, Pacific Northwest Laboratory, PNL-6847A, Presented at American Nuclear Society National Meeting, San Diego, CA, June 1978.
-

Information/Status: (Continued)

- Round Robin Evaluation of Geothermal Brine Analytical Methods, J.C. Watson, Pacific Northwest Laboratory, PNL-SA-7359A, to be presented at Joint American Chemical Society-Chemical Society of Japan Chemical Congress, Honolulu, HI, April 1979.
- Geothermal Water and Gas - Collected Methods for Sampling and Analysis; Comment Issue, J.G. Douglas, R.J. Serne, D.W. Shannon, E.M. Woodruff, BNWL-2094, August 1976.
- 1979 Field Test Report - East Mesa, California, D.W. Shannon, et. al., August 1980.
- Geothermal Release Points of Environmental Contaminants, C.H. Kindle, PNL-SA-8501, May 1980.
- "Institutional Standardization of Geothermal Fluid Characterization Techniques", C.H. Kindle, to be published in Geothermal Resources Council Transactions, September 1980.
- Geothermal Sampling/Analysis: Summary Document on Techniques, C.H. Kindle and E.M. Woodruff, to be published.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Silica Scale Kinetics

Sponsoring Organization: DOE/Division of
Geothermal Energy

Research Area(s):

Corrosion/Scaling

Contract/Grant Number:

Type of Research Activities:

Performing Organization:
Lawrence Berkeley Laboratory

Laboratory Research-Experi-
mental

Principal Investigators:

Objective:

Study and document the kinetics of SiO_2 scaling in geothermal conditions to enhance understanding and control of the scaling process.

Information/Status:

- Large amount of high-quality experimental data generated over 23-100°C temperature range.
- SILNUC computer code developed which quantitatively models and extrapolates to untested conditions the nucleation and growth of colloidal SiO_2 particles.

Project completed.

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- Kinetics of Silica Polymerization, O. Weres, et. al., Lawrence Berkeley Laboratory, LBL-7033, May 1980, available from NTIS.
-

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Scale Formation and Suppression

Sponsoring Organization: DOE/Division of
Geothermal Energy

Research Area(s):

Corrosion/Scaling

Contract/Grant Number: DE-AC0879ET27255

Type of Research Activities:

Performing Organization:
mental
Dow Chemical Co.

Laboratory Research-Experi-

Principal Investigators:

Objective:

- Evaluate scale control methods for heat exchangers.
 - Provide experimental testing of fluid chemistry models developed by LASL to identify R&D needs for scale inhibitors.
 - Provide quantitative data on scaling and scaling rates in pilot-plant size equipment.
-

Information/Status:

- Lowering pH of simulated brine to pH 6 or less found to be effective in S&T HX; not economic approach, though, due to increased corrosion.
- Calgon CL-165 and Monsanto Dequest 2060 found to be promising and deserving further testing. (Further testing conducted by Vetter Research confirmed the promise of Dequest 2060 and is now being commercially used.)
- Experiments with seeding, turbulence promotion, and electrostatic and electromagnetic devices were unsuccessful.

Project completed.

- Study on Scale Formation and Suppression in Heat Exchange Systems for Simulated Geothermal Brines, Final Report, J.S. Wilson, et. al., Dow Chemical Co., COO/2833-1, Final Report for Period 1/12/76 - 3/5/78.
-

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Scale Inhibition in Geothermal Operations

Sponsoring Organization: DOE/Division of
Geothermal Energy

Research Area(s):

Corrosion/Scaling

Contract/Grant Number:

Type of Research Activities:

Performing Organization:

Laboratory Research-Experi-
mental

Vetter Research

Principal Investigators:

Objective:

Test commercially-available scale control additives for CaCO_3 at the East Mesa geothermal site to evaluate the additives' technical effectiveness, any undesirable side effects, and economics of use at that site.

Information/Status:

- Monsanto's Dequest 2060 product identified as very effective carbonate scale inhibitor.
 - Estimated cost of use determined to be on the order of .3 mills/kWhr.
- Project completed.

- Scale Inhibition in Geothermal Operations-Experiments with Dequest 2060 Phosphonate in Republic's East Mesa Field, O.J. Vetter and D.A. Campbell, Vetter Research, VR Report No. 79-5-27, May 27, 1979.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Silica Scaling Study

Sponsoring Organization: DOE/Division of
Geothermal Energy

Research Area(s):

Corrosion/Scaling

Contract/Grant Number: EY-786-C-02-2607

Type of Research Activities:

Performing Organization:

Data Analysis/Documentation
Modeling/Simulation

EIC Corporation

Principal Investigators:

Objective:

Collect data and prepare models for SiO_2 scaling and kinetics in
geothermal brines.

Information/Status:

Project completed in April 1978.

- Study of Silica Scaling From Geothermal Brines, Final Report, EIC Corp.,
Report No. C00-2607-5.
 - "Condensation of Silica From Supersaturated Silicate Acid Solutions",
Journal of Colloid Interface Science.
-

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Precipitation and Scaling in Dynamic Geothermal Systems

Sponsoring Organization: DOE/Division of Geothermal Energy

Research Area(s):

Corrosion/Scaling

Contract/Grant Number: W-7405-ENG-26

Type of Research Activities:

Performing Organization:

Oak Ridge National Laboratory

Laboratory Research-Experimental

Modeling/Simulation

Principal Investigators:

Objective:

- Collect basic scaling data for model development
 - Develop scaling models for application in pilot plants
-

Information/Status:

- 100 gpm Ti corrosion test loop modified to provide dynamic facility for studying formation of SiO_2 deposits, their properties, and fates as a function of brine composition, temperature, and flow conditions.
 - Scale formation studied in segmented HX under realistic conditions.
 - Project terminated after minimal progress.
 - Silica Scaling in Simulated Geothermal Brines, E.G. Bohlmann, et. al., Oak Ridge National Laboratory, April 1981, available from NTIS.
 - Silica Precipitation and Scaling in Dynamic Geothermal Systems, E.G. Bohlmann, et. al., Oak Ridge National Laboratory, Workshop on Scale Control in Geothermal Energy Extraction Systems, Los Alamos, NM, Oct. 6, 1977.
-

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Hydrodynamic/Kinetic Reactions and Morphology Changes of Scale-forming Materials

Sponsoring Organization: DOE/Division of Geothermal Energy

Research Area(s):

Corrosion/Scaling

Contract/Grant Number: 29-99165-2

Type of Research Activities:

Performing Organization:

Laboratory Research-Experimental

University of Delaware

Principal Investigators:

Objective:

Examine hydrodynamic effects on scale formation kinetics and morphology with scales produced in the lab at atmospheric pressure, low shear stresses, and temperatures from 26-100°C.

Information/Status:

- Electron microanalysis shown to be a sensitive method to determine composition of scale deposits.
- Seems possible to modify scale structure by changing the fluid mechanics of the brine.

Project completed.

- Application of a Rotating Disc Contactor to Scale Deposition, A.B. Metzner, et. al..
 - "Microanalysis and Electron Microscopy of Geothermal Scale", F.D.S. Marques and J.U. Edington, Proceedings of the 7th Congress on Electron Microscopy.
 - "Microstructure of the Scale Formed in a Geothermal Well in the Salton Sea", F.D.S. Marques and J.U. Edington, Proceedings of the 7th Congress on Electron Microscopy.
-

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Geothermal Brine Modeling

Sponsoring Organization: DOE/Division of
Geothermal Energy

Research Area(s):

Brine/Gas Chemistry

Contract/Grant Number:

Type of Research Activities:

Performing Organization:

University of California,
La Jolla

Theoretical Research
Modeling/Simulation

Principal Investigators:

Objective:

Develop an activity coefficient model for geothermal fluids and determine the single electrolyte parameters for binary aqueous solutions of NaOH, KOH, $Mg(OH)_2$, and $Ca(OH)_2$.

Information/Status:

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Geochemistry Modeling and Fluid Chemistry

Sponsoring Organization: DOE/Division of
Geothermal Energy

Research Area(s):

Corrosion/Scaling
Brine/Gas Chemistry

Contract/Grant Number:

Type of Research Activities:

Performing Organization:

Los Alamos Scientific Laboratory

Data Analysis/Documentation
Modeling/Simulation

Principal Investigators:

Objectives:

Assist DOE in planning and coordination of efforts in geothermal fluid chemistry and computer modeling of scaling, including preparation of codes and comparison of prediction with experimental data.

Information/Status:

Developed and modified computer code to predict locations of deposition of various chemical species in geothermal systems. Although techniques for sampling did not yield sufficiently accurate measurements, empirical data were consistent with general predictions.

- LASL's Relationships to the Modeling of Geochemical Systems, T.J. Merson, Los Alamos Scientific Laboratory, Workshop on Scale Control in Geothermal Energy Extraction Systems, Los Alamos, N.M., Oct 6, 1977.
-

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Geophysical Logging Case History of the Raft River Geothermal System, Idaho

Sponsoring Organization: DOE/Division of Geothermal Energy

Research Area(s):

Well Logging

Contract/Grant Number: W-7405-ENG-36

Type of Research Activities:

Performing Organization:

Data Analysis/Documentation

LASL-Subcontract to Boise State University
No. L28-1932E-2

Principal Investigators:

J.H. Applegate
T.A. Moens

Objective:

Review commercial geophysical logs from wells drilled in the Raft River geothermal area to determine 1) if adequate logs were made, 2) whether the logs responded as normally anticipated, and 3) whether the data were useful in the evaluation of the geothermal reservoir.

Information/Status:

The log responses for complex rocks, including tuffaceous sediments, metamorphics, and quartz monzonite are more complicated than those in typical sedimentary rocks. Cross-plotting techniques clearly delineate the complex rock types and zones of increased alteration and increased fracturing.

The cross plots indicate that the quartz monzonite, schist, and siltstone are fractured in RRGE No. 1. In RRGE No. 2, the quartzite, quartz monzonite, and sandstone appear fractured. In both wells, the fracturing may have enhanced the intergranular porosity in the siltstone and sandstone and, hence, improved production. The quartzite appears altered in RRGE No. 1, whereas in RRGE No. 2 the quartzite and schist are more altered in the quartzite than in the schist. In RRGE No. 4, fracturing must be minimal, and the schist and quartzite appear to be altered. The lack of fracturing in the schist, quartzite, and siltstone, and the partial sealing of the siltstone with alteration products contributes to the lack of production from RRGE No. 4.

The production in the Raft River geothermal system comes from several formations near the sediment-basement complex. Fracturing may enhance the normal production from the intergranular porosity. Alteration products could be reducing effective porosity in some of the units. Multiple stages of faulting (older thrusts, followed by younger normal faults) may have controlled the distribution of faulting.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Case History on Geothermal Well Log Interpretation
Surprise Valley, California

Sponsoring Organization: DOE/Division of
Geothermal Energy

Research Area(s):

Well Logging

Contract/Grant Number: W-7405-ENG 36

Type of Research Activities:

Performing Organization:

Data Analysis/Documentation

LASL-Subcontract to SAI-4-L-29-77516-1

Principal Investigators:

T.A. Rigby

G.P. Zebal

Objective:

Aid in reservoir evaluation and improved well siting in California's
Surprise Valley.

Information/Status:

Two wells (one by Magma Energy, Inc. and one by Gulf Oil) were drilled in the early 1970's to investigate the geothermal potential of Surprise Valley. The log data from these wells were supplied by the companies so that this study could be undertaken. This case history study for the Surprise Valley points out several concerns encountered in geothermal reservoirs of the Basin and Range.

Analyses included stratigraphy, porosity, lithologic properties and an examination of fractures and porosity through SP and Resistivity, and Density and Neutron Log Response. The work was initiated in September of 1980 and the final report issued in June of 1981.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: CO/sub 2/ and Carbonate Chemistry applied to Geothermal Engineering

Sponsoring Organization: DOE/Geothermal and Hydropower Technologies Division

Research Area(s):

Brine/Gas Chemistry

Contract/Grant Number: W-7405-ENG 48
LBL Subcontract

Type of Research Activities:

Performing Organization:

Data Analysis/Documentation

Republic Geothermal, Inc.

Principal Investigators:

D.E. Michels

Objective:

Provide guidance for interpreting and using chemical data about geothermal resources.

Information/Status:

The chemistry of high-HCO/sub 3/resources is emphasized because they present special complications about data interpretation, development of vapor, and potential for scale deposition. Solubility of CO/sub 2/and its exsolution from liquids is treated according to the unique context presented by geothermal resources. Contrasts between this approach and the treatment of CO/sub 2/solubility in physical chemistry and other geochemical contexts are presented. Dimensional units for solubility coefficients different from those of physical chemists are presented to favor engineering application. The effects of CO/sub 2/on wellbore flow, initiation of flashing, and depth of the 2-phase zone are described and illustrated with examples. To aid the understanding of fluid behavior and the interplay with the design process, specially constructed charts - chemical maps - are presented, examples given for their use, and directions given for their construction. The information resulting from this effort was published in January of 1981.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Regional Strategy for Geothermal Exploration with Emphasis on Gravity and Magnetotellurics

Sponsoring Organization: DOE/Geothermal and Hydropower Technologies Division

Research Area(s):
Electrical Studies

Contract/Grant Number: N/A

Performing Organization:
University of Texas
Los Alamos Scientific Laboratory

Type of Research Activities:
Field Research
Data Analysis/Documentation

Principal Investigators:

C.L. Aiken
M.E. Ander

Objective:

Information/Status:

Part of the resource evaluation Program conducted by Los Alamos Scientific Laboratory for the national Hot Dry Rock (HDR) Geothermal Program, a regional magnetotelluric (MT) survey of New Mexico and Arizona is being performed. The MT lines are being located in areas where the results of analysis of residual gravity anomaly maps of Arizona and New Mexico, integrated with other geologic and geophysical studies indicate the greatest potential for HDR resources.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Geothermal Direct Heat Resource Assessment
in Hawaii

Sponsoring Organization: DOE/Division
of Geothermal Energy

Research Area(s):

Structural Geology
Electrical Studies
Gravity/Magnetic
Geophysics-Other (Seismic)

Contract/Grant Number: 001181

Type of Research Activities:

Performing Organization:

Field Research
Data Analysis/Documentation

Principal Investigators:

D.M. Thomas

Objective:

Identify and characterize potential geothermal resource areas throughout Hawaii.

Information/Status:

The techniques used in the exploratio program include: geological mapping, soil and groundwater sampling for mercury, radon, and other elements sensitive to alterations in geothermal systems, resistivity soundings, time domain electromagnetic soundings, and gravity, magnetic and seismic surveys. Upon completion of all applicable surface geochemical and geophysical surveys in each of the identified potential geothermal areas, an attempt will be made to determine the probability for the existence of a geothermal resource in each study area and an estimate made of its temperature and size. Geothermal exploration surveys are expected to be completed during the coming 12 months for the following areas: Kawaihae and North the Haleakala Northwest rift system on Maui. Geochemical soil surveys have been conducted in Lahaina-Kaanapali, Olowalu-Ukumehame Canyon and the Haleakala Northwest rift on Maui and in Kawaihae on Hawaii, groundwater sampling has been conducted on the above areas and chemical and isotopic analysis is presently underway. Detailed gravity and magnetic surveys have been conducted along the West-Maui southwest coast area and on the Haleakala Southwest and Northwest rift systems; reduction of this data is presently underway. Time domain electromagnetic and Schlumberger soundings have been conducted in West Maui, on the Haleakala Northwest rift on Maui and in Kawaihae on Hawaii.

The period of performance for the efforts was February 1978 through January 1982 with FY 82 funding of \$200,000.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Materials of Construction for Geobrine Operations

Sponsoring Organization: DOI/Bureau of
Mines

Research Area(s):

Corrosion/Scaling

Contract/Grant Number: B-15-I

Type of Research Activities:

Performing Organization:

Hardware/Instrumentation
Development/Testing

DOI/Bureau of Mines

Principal Investigators:

D.R. Flinn

J.P. Carter

F.X. McCawley

R.P. Walters

S.D. Cramer

Objective:

Develop an understanding of corrosion and scaling processes in geothermal fluids at the Salton Sea resource, as applied to commercially available alloys.

Information/Status:

The largest geothermal system in the United States containing substantial quantities of potentially recoverable minerals is located in the Imperial Valley of California. The Salton Sea known geothermal resource area (KGRA) contains brines that have a high mineral content and are among the most corrosive natural fluids. The Bureau of Mines initiated steps towards eventual recovery of these minerals with a research and development program to find solutions to the severe corrosion and scaling problems presently delaying construction of geothermal resource recovery plants in the Imperial Valley. This program, developed at the Avondale Metallurgy Research Center, consists of a combination of laboratory research and field testing. The laboratory research is directed towards understanding the basic corrosion processes in, and the thermodynamics of, geothermal brines so that the corrosion and scaling observed in the field can be controlled. The field testing is designed to study the corrosion of selected commercially available alloys in flowing brines from the Salton Sea KGRA, and chemistry of such brines. Current studies include the corrosion of alloys, the solubility of gases, sampling and analyses of two-phase flow, and electrochemical measurements in geothermal brines.

Contract began July 1974 and is continuing.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Chemistry of the Springs of the Ozark Mountains, Northern Arkansas

Sponsoring Organization: DOI/Office of Water Research and Technology

Research Area(s):
Brine/Gas Chemistry

Contract/Grant Number: A-055-ARK

Performing Organization:
University of Arkansas

Type of Research Activities:
Laboratory Research-Analytical

Principal Investigators:
K.F. Steele

Objective:

1) evaluate the effect of zinc, lead copper and uranium mineralization on groundwater composition in a carbonate terrain; 2) test the validity of the use of trace metal concentrations in groundwater for geochemical exploration in the Ozarks of Arkansas; 3) evaluate the potential geothermal water resources of the Ozarks of northern Arkansas.

Information/Status:

The north-central portion of the Arkansas Ozark Mountains is highly mineralized with possible commercial amounts of zinc and associated cadmium, and lead, copper and uranium. Necessary baseline trace metal water quality data for this area of the Ozark Mountains will allow determination of the effect of mineralization of the groundwater chemistry. It will be necessary to determine other parameters such as pH, NO₃, SO₄, Cl and others to adequately understand the trace metals behavior. Therefore the knowledge of water quality for this area will be greatly expanded. By calculations based on solubility of silica the maximum temperature of the groundwater can be made which will allow an evaluation of the geothermal potential of this region.

Work on this project was initiated in 1981.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Control of Scale and Heavy Metal Recovery in Geothermal Systems

Sponsoring Organization: DOI/Bureau of Mines

Research Area(s):

Brine/Gas Chemistry
Corrosion/Scaling

Contract/Grant Number: J0295068

Type of Research Activities:

Performing Organization:
Penn State University

Laboratory Research-Analytical

Principal Investigators:

H.L. Barnes

Objective:

The goal of this work shall be to understand the chemistry first of Salton Sea geothermal brines well enough to control scale deposition and simultaneously to recover valuable heavy metals from solution. Ideally, the recovery process for these metals should also make possible the recovery of soluble salts like NaCl, KCl, LiCl and MgCl₂ in a state uncontaminated by heavy metals.

Information/Status:

Work was initiated on the project in September of 1979 and completed in Sept. of 1981. During FY 80 the project was funded at \$96,000.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Recovery of Heavy Metals from High Salinity Geothermal Brine

Sponsoring Organization: DOI/Bureau of Mines

Research Area(s):

Brine/Gas Chemistry

Contract/Grant Number: J0188076

Type of Research Activities:

Performing Organization:

Laboratory Research-Experimental

SRI International

Principal Investigators:

E.P. Farley
E.L. Watson
D.D. MacDonald

R.W. Bartlett
G.N. Krishnan

Objective:

Investigate the technical feasibility of recovering heavy metals from high-salinity Salton Sea geothermal brines by sulfide precipitation.

Information/Status:

High salinity geothermal brines typically contain several hundred parts per million of valuable heavy metals, and because of the large potential flow of geothermal brines, metal production as a by-product could be significant. The heavy metals, in order of decreasing abundance, are usually manganese, zinc, iron, lead, copper, and silver. All but manganese and iron are valuable as by-products.

A process scheme to recover the valuable heavy metals from spent geothermal brines was developed at SRI. In this process the brine is treated with a sulfiding agent, such as Na_2S or H_2S to precipitate the metals as sulfides. In the first year of a two-year investigation, SRI predicted the recovery of heavy metals under different conditions of pH, temperature, and PH_2S , using extensive computer modeling. Batch experiments using spent brines from Magmamax and Woolsley wells in the Salton Sea area were performed to confirm the results of the computer simulation. In the second year, a continuous 14 liter per hour flow apparatus was used with brine from a Niland well in the Salton Sea area to obtain process engineering data and physical and chemical characteristics of the precipitates.

Laboratory results indicate that, generally, 80-90% of the Pb and Zn, 30-40% of the Fe, and 20% of the Mn can be recovered as sulfide. The Fe and Mn are considered unwanted products.

- o Recovery of Heavy Metals From High Salinity Geothermal Brine, E.P. Farley, et. al., SRI International, Bureau of Mines, OFR 91-81, NTIS #PB 81-222218, Dec. 1980.
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Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Operation of a Mineral Recovery Unit on Brine From the Salton Sea Known Geothermal Resource Area

Sponsoring Organization: DOI/Bureau of Mines

Research Area(s):

Brine/Gas Chemistry

Contract/Grant Number: D-4-I-9449-8

Type of Research Activities:

Performing Organization:

Laboratory Research-Experimental
Hardware/Instrumentation
Development

DOI/Bureau of Mines

Principal Investigators:

L.E. Schultze
D.J. Bauer

Objective:

Investigate the technical feasibility of recovering heavy metals from high-salinity geothermal brine.

Information/Status:

The Bureau of Mines operated a mineral recovery unit to recover metal values from post-flash geothermal brines from the Salton Sea known geothermal resource area as part of its research into the use of plentiful resources. The brine was available for metals recovery after its heat content had been used to generate electricity. The brine source was treated with lime to precipitate the contained iron, manganese, lead, and zinc before injection of the heat-depleted brine into the underground reservoir. Major factors investigated were the effects of process variables, such as rate and method of lime addition and air oxidation versus air exclusion. Variations in precipitation of metal values, composition of precipitates, effectiveness of slurry thickeners, and methods of treating the precipitates to recover metal values are discussed in the associated reports (see below).

- Operation of a Mineral Recovery Unit on Brine from the Salton Sea Known Geothermal Resource Area, L.E. Schultze and D.J. Bauer, Bureau of Mines, Report of Investigations #8680, 1982.
 - Process Technology for Recovering Geothermal Brine Minerals, C.E. Berthold, et. al., Hazen Research, Inc., Bureau of Mines, OFR 35-75, NTIS #PB-241 867, Feb. 1975.
 - Magmax No. 1 Geothermal Brine Bulk Solids Precipitation Pilot Plant - Engineering Design, C.E. Berthold and F.M. Stephensen, Bureau of Mines, OFR 127-78, 1978.
 - The Recovery and Separation of Mineral Values from Geothermal Brines, D.H. Christopher, et. al., Bureau of Mines, OFR 81-75, NTIS #PB 245 686/AS, 1975.
-

Information/Status: (Continued)

- Mineral Content of Selected Geothermal Waters, J.W. Sanders and M.J. Mills, Bureau of Mines, OFR 14-75, NTIS # PB 240 419/AS, 1975.
- Research on a Geothermal Mineral Extraction Complex. Phase I. Preliminary Technical and Economic Assessment, M.W. Urbanek, et. al., Bureau of Mines, OFR 51-79, 1979.
- Extracting Minerals from Geothermal Brines: A Literature Study, R.L. Blake, Bureau of Mines, IC 8638, NTIS #PB 240 681, Dec. 1974.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: High Frequency Electromagnetic Borehole Techniques

Sponsoring Organization: DOE/Office of
Nuclear Energy

Research Area(s):

Well Logging

Contract/Grant Number:

Type of Research Activities:

Performing Organization:

USGS

Hardware/Instrumentation Develop-
ment

Principal Investigators:

T. Frischknecht

Objective:

To determine capabilities and limitations of high frequency techniques for exploration of evaporites and crystalline rocks, to develop borehole equipment from radar and point-to-point transmission measurements, and to test this equipment at several sites to guide further development.

Information/Status:

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Development of a Single Hole Electromagnetic Probe

Sponsoring Organization: DOE/Office of
Nuclear Energy

Research Area(s):

Electrical Studies
Well Logging

Contract/Grant Number:

Type of Research Activities:

Performing Organization:
Lawrence Livermore Laboratory

Hardware/Instrumentation Develop-
ment

Principal Investigators:

R.J. Lytle

Objective:

To develop and test an electromagnetic borehole probe that is capable of locating anomalies in the vicinity of a deep borehole (size, distance from the hole, and direction).

Information/Status:

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Brine Migration

Sponsoring Organization: DOE/Office of
Nuclear Energy

Research Area(s):

Fluid Inclusions

Contract/Grant Number:

Type of Research Activities:

Performing Organization:
Sandia

Laboratory Research-Experi-
mental

Principal Investigators:

H.C. Shefelbine
S.J. Lambert
A.R. Slattler

Objective:

To determine the physiochemical properties of fluid inclusions in native rock and in artificially imposed heat fields. To evaluate the potential of fluid inclusions for waste-form degradation and radionuclide migration by performing laboratory, bench-scale, and in situ experiments for assessment of brine migration phenomena.

Information/Status:

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Optical Fiber Logging Cable Development

Sponsoring Organization: DOE/Office of
Nuclear Energy

Research Area(s):

Well Logging

Contract/Grant Number:

Type of Research Activities:

Performing Organization:

Optelecom

Hardware/Instrumentation Develop-
ment

Principal Investigators:

G. Gould

Objective:

Information/Status:

An optical fiber logging cable to increase the data transmission capabilities of logging systems many times over industry's standard four-conductor logging cable was studied. The fabricated prototype cable was tested and proved to be feasible for borehole logging.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Geothermal Well Stimulation

Sponsoring Organization: DOE/Office of
Nuclear Energy

Research Area(s):

Well Stimulation
Reservoir Engineering

Contract/Grant Number: 006090

Type of Research Activities:

Performing Organization:

University of California
Los Alamos National Lab.

Hardware/Instrumentation Develop-
ment

Principal Investigators:

R.J. Hanold

Objective:

Utilize existing hardware and experience developed in the oil and gas industry for stimulation experiments in lower temperature geothermal wells and then extend the state of the art to higher temperature applications.

Information/Status:

The geothermal reservoir well stimulation program will consist of two concurrent phases: the first phase will be devoted to the development of the required specialized geothermal hardware, stimulation treatment designs, and data analysis interpretation from existing well stimulation treatments. While the second phase will directly address and provide for site-specific and technique-specific field demonstration experiments. Emphasis will be on (but not necessarily limited to) hot water-dominated hydrothermal system reservoir stimulation by hydraulic fracturing techniques.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Continental Scientific Drilling Program:
Thermal Regimes

Sponsoring Organization: DOE

Research Area(s):

Well Logging

Contract/Grant Number: DE-AC04-76DP00789

Type of Research Activities:

Hardware/Instrumentation Development

Performing Organization:

Sandia National Laboratories

Principal Investigators:

O.E. Jones
R. Traeger
H.C. Handee
J. Dunn

Objective:

Develop appropriate drilling, logging and instrumentation technology by conducting broad-based generic research.

Information/Status:

a) Drilling, Logging, Instrumentation - plans are underway for the drilling of shallow test holes at Mono Craters for the purpose of shallow logging and for instrumentation test and evaluation. High temperature (1200°C) thermal probes and associated cables are being developed for logging high temperature holes. Compressional-wave and shear wave (P&S) sources have been developed, and a swept-frequency periodic source is currently under development.

b) Thermal Geophysical Techniques - research is concentrating on the design of a convective heat flow sensor for use in permeable convecting surface zones; initial tests are planned at Long Valley and Mono Craters.

c) Hydrothermal-Magma Geoscience Research - develop an understanding of mass and energy transport within and between hydrothermal and magma systems. Research activities include geochemical and mineralogical studies on silicic and basaltic natural and synthetic magma systems.

d) Mono Craters Geophysical Study - surface and near surface geophysical and geological observations including gravity change measurements, heat flow measurements, petrologic studies of volatiles in rapidly quenched glasses, and tectonic modeling.

"Drilling, Instrumentation and Sampling Consideration for Geoscience Studies of Magma-Hydrothermal Regimes", Sandia National Laboratory, May 1981.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Magma Energy Research

Sponsoring Organization: DOE

Research Area(s):

Contract/Grant Number: DE-AC04-76DP00789

Mass Heat Transport
Physical Properties Rocks/
Liquids

Performing Organization:

Type of Research Activities:

Sandia National Laboratories

Field Research

Principal Investigators:

H.C. Hardee

Objective:

Assess the scientific feasibility of directly extracting energy from buried magma sources.

Information/Status:

a) Testing at the Kilauea Iki site has indicated:

1. Boreholes to the melt can be kept open and are stable to 10km depth at near-molten temperatures.
2. Materials can survive and function in a magma environment.

b) Petrologic studies of Kilauea Iki cores are defining the vertical structure, liquid and mineral evolution, and the mineral-liquid relationships through the melt zone.

c) Investigations are underway to determine the effects of high pressure and dissolved gases on convective heat transfer in a magma.

The program is nearing completion with scientific feasibility having been established.

"Drilling, instrumentation and sampling consideration for geoscience studies of magma-hydrothermal regimes", May, 1981 (available thru NTIS).

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Geophysics Research

Sponsoring Organization: DOE

Research Area(s):

Structural Geology
Physical Properties Rocks

Contract/Grant Number: DE-AC04-76P00789

Type of Research Activities:

Performing Organization:
Sandia National Laboratories

Theoretical Research
Modeling/Simulation

Principal Investigators:

O.E. Jones
J. Rundle
W. Wawersik

Objective:

Conduct research activities leading to a more soundly based understanding of geophysical processes in the earth's crust and mantle.

Information/Status:

a) Crustal Strain Program - develop methods and techniques for interpreting time - dependent deformation of the earth's crust. Numerical computer codes have been developed which compute time - dependent surface deformation due to faulting in layered, inelastic earth models.

b) Time-Dependent Deformation and Fracture of Brittle Rock - experimental and analytical efforts are underway to develop a basic understanding of the mechanics of microcrack growth and how this is expressed in the continuum response of the material. Experimental work is concentrating on the relationship between crack velocity, applied driving forces, and environmental conditions.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Continental Scientific Drilling Program

Sponsoring Organization: DOE

Research Area(s):

Brine/Gas Chemistry

Contract/Grant Number: 005982

Type of Research Activities:

Performing Organization:

Data Analysis/Documentation
Laboratory Research-Experimental

University of California
Lawrence Berkeley Laboratory

Principal Investigators:

J.A. Apps
A. White

Objective:

Information/Status:

Support of the Geosciences group at LBL to the Continental Drilling Program for Scientific Purposes will consist of both service functions and associated research. Service functions will include continual participation in the Interlaboratory Working Group with emphasis in geochemistry. The function of the group will be to continually evaluate specific geothermal sites as targets for deep drilling in terms of new data available from drilling programs and support research, to coordinate such research programs, and to work with other agencies and groups related to the Continental Drilling Program. In addition the Geothermal Fluids Data Base will be updated and expanded with new information from sites selected for possible drilling. Supporting research will consist of theoretical and experimental studies that will aid in interpreting the chemistry of gas and water samples and core material in terms of ongoing geochemical processes in the thermal regime. Work will include experimental evaluation of temperature, pressure and kinetic effects on dissolution, sorption and precipitation mechanisms in geochemical systems applicable to selected sites. In addition evaluation of thermodynamic data at high temperatures and pressures including aqueous complexation and hydration, and aqueous activity coefficients will be conducted along with methods to extrapolate available data to higher temperatures. Development will begin on a downhole geochemical sampler which can be used to obtain accurate environmental pH, eH and trace element data.

Work on the contract was initiated during 1980, with FY 80 funding of \$175,000.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Thermal Regimes

Sponsoring Organization: DOE

Research Area(s):

Contract/Grant Number: W-7405-ENG-36

Mineralogy/Alterations
Brine/Gas Chemistry
Geophysics-Other (Seismic)

Performing Organization:

Type of Research Activities:

Los Alamos National Laboratory

Field Research
Laboratory Research-Analytical

Principal Investigators:

J.T. Whetton
O. Goff
K.H. Olsen

Objective:

- 1) Characterize the Sulphur Springs System (west side of Valles Caldera)
 - 2) Investigate detailed geochemical and geologic characteristics of Valles Caldera, Ojo Caliente, and Lucero Volcanic Field
 - 3) Provide information and models applicable for use in the Continental Scientific Drilling Program.
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Information/Status:

a) At Sulphur Springs the waters, gases, and altered rocks are characterized geochemically; detailed mapping of alteration and fracture zones within and near the system is performed; and the compositions of alteration phase assemblages and fluids present are studied.

b) In hydrothermal systems research, thermal and nonthermal waters of the Valles Caldera are collected for chemical and isotopic analysis; local geologic and tectonic features are mapped; the resulting geologic, geochemical, and geophysical data are integrated; and geothermal potential is evaluated.

c) Refracting seismic profiling research in Northern New Mexico attempts to improve understanding of the third dimension of the Valles Caldera and its relationship to the Rio Grande rift. Determine whether or not there is a magma body beneath the Valles Caldera, and establish the causes for earthquakes near Espanola, New Mexico, the second most seismic active location in the state. These research tasks directly support needs of the Continental Scientific Drilling Program which designated the Valles Caldera as prime drill site, geothermal exploration, and nuclear test verification programs.

d) Research on the Paliza Canyon formation in the Valles Caldera provides explanation of the evolution of the caldera and is critical to assessment of potential drill sites for the Continental Scientific Drilling Program.

e) The geology, petrology, and geochemistry of the Zuni and Lucero volcanic fields are being studied. Research focuses on origin of magmas, their residence in the crust, and their effect on the hydrologic regime. This research will lead to an understanding of causes of magmatism, evolution of magmas, and their relation to rift tectonics.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Geophysics

Sponsoring Organization: DOE

Research Area(s):

Physical Properties Rock/Liquids
Heat Flow Studies

Contract/Grant Number: W-7405-ENG-36

Type of Research Activities:

Performing Organization:

Laboratory Research-Experi-
mental

Los Alamos National Laboratory

Principal Investigators:

J.T. Whetten
J.D. Blacic
T.J. Shankland

Objective:

Conduct Geophysics Research in Creep Deformation of Rock, Radiative Heat Transfer in Minerals, Glasses, and Metals, and Electrical Conductivity and Temperature in the Upper Mantle

Information/Status:

- 1) Study of creep deformation of basalt, granite, and tuff at simulated in situ conditions. Emphasis is placed on evaluating the effects of water on creep of intact versus fractured samples. Results of the experiments will be used for predictive computer models of repository designs.
 - 2) Determine the contribution to total thermal conductivity from the radiative component in a variety of materials that figure in geothermal studies and nuclear waste isolation.
 - 3) Measure the thermoelectric effect in the mantle minerals olivine and pyroxene as a function of temperature, orientation, oxygen fugacity, and iron content and investigate the effect of Mg/Si nonstoichiometry on mineral conductivity.
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Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Geochemistry

Sponsoring Organization: DOE

Research Area(s):

Physical Properties Rocks/Liquids

Contract/Grant Number: W-7405-ENG-36

Type of Research Activities:

Performing Organization:

Laboratory Research-Experimental

Los Alamos National Laboratory

Theoretical Research

Principal Investigators:

R.W. Charles

T.M. Benjamin

Objective:

Information/Status:

a) Rock-water interaction studies involving experimental and theoretical studies to model reactions using cold seal pressure vessels, agitating vessels and dynamic systems.

b) Investigation into location, mobility, and deposition of trace elements in rock reservoirs.

c) Expand the usefulness of the chemical geothermometer to more varied rock reservoirs.

d) Facilitate an understanding of inter- and intracrystalline major and trace element fractionation trends.

e) Electron probe microanalysis, scanning electron microscopy, fluorescent and visible microscopy and bulk analysis of sulfur in order to establish relationships between modes of sulfur occurrence, types of peat, and depositional environments.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Physical Processes of Subsidence in Geothermal Systems

Sponsoring Organization: DOE

Research Area(s):

Structural Geology
Physical Properties Rocks

Contract/Grant Number: 6711502

Type of Research Activities:

Performing Organization:

Theoretical Research

University of Illinois

Principal Investigators:

J.W. Rudnicki

R.E. Johnson

Objective:

Information/Status:

Ground subsidence near geothermal system may be due, in part, to the time-dependent deformation of near crustal rocks. Experiments have suggested that this time dependence of nominally brittle rock is due to slow, environmentally assisted microcrack growth. In one portion this study, an internal variable approach is used to formulate a constitutive theory for time dependent deformation of brittle rock based on the microscale mechanism of slow crack growth.

A second aspect of this study concerns the role that small scale reservoir inhomogeneities, i.e., cracks, cavities, fissures, and inclusions, play in the mechanical response of permeable rock mass subjected to a pumping environment. The study attempts to evaluate the effects to hydrodynamic loads exerted on the rock mass by rapid fluid flow through such inhomogeneous porous material. As a first step, the solution has been developed for flow through a porous medium containing an elliptical cavity. Preliminary results indicate that for slender elliptical cavities rather large hydrodynamic loads are present near the cavity tip.

The effort was conducted during 1979 and funded at \$14,000.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Alaska Peninsula Telemetered Seismic Network

Sponsoring Organization: DOE

Research Area(s):

Geophysics-Other (Seismic)

Contract/Grant Number: EY-76-S-06-229-006

Type of Research Activities:

Performing Organization:

Data Analysis/Documentation
Field Research

University of Alaska
Geophysical Institute

Principal Investigators:

H. Pulpan

Objective:

Increase the fundamental knowledge about the subduction process and provide a better basis for assessing the geothermal potential of the Alaska Peninsula and offshore islands.

Information/Status:

The project involves operating a network of eleven short-period vertical-component seismographs on the Alaska Peninsula and surrounding islands.

Data analysis presently focuses on:

- Determining the stress distribution in the subducting slab from fault plane solutions of regionally recorded earthquakes and from the determination of the moment tensor of teleseismically recorded events.
 - Inverting regional and teleseismic travel time data into a three-dimensional crustal and upper mantle seismic velocity structure.
-

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Aqueous Chemistry and Geosciences

Sponsoring Organization: DOE

Research Area(s):

Brine/Gas Chemistry

Contract/Grant Number:

Type of Research Activities:

Performing Organization:

Laboratory Research-Experimental

Oak Ridge National Laboratory

Principal Investigators:

Objective:

Information/Status:

Research included investigating aqueous systems (thermodynamics of electrolytes, cation hydrolysis, solubility of amorphous silica) and other geo-science investigations.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Continental Scientific Drilling Program (CSDP)

Sponsoring Organization: DOE

Research Area(s):

Volcanology

Contract/Grant Number: W-7405-ENG-48

Type of Research Activities:

Performing Organization:

Data Analysis/Documentation

Lawrence Livermore National Laboratory

Principal Investigators:

A.G. Duba

N.W. Howard

A.J. Piwinski

L.W. Yeunker

Objective:

Provide information and data management services.

Information/Status:

Provide a data bank for drill hole data.

Testing of a petrologic model at the Elkhorn Mountain Volcanics/Boulder Batholith and at Valles Caldera. The work will lead to either improved models for the evolution of magma bodies or to greater confidence in the models presently used.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Geosciences Program: a) thermochemistry of geothermal materials; b) trace element transport by fluid flow; c) migration of heavy element species in geologic strata.

Sponsoring Organization: DOE

Research Area(s):

Physical Properties Rocks/Liquids

Contract/Grant Number: 109ENG38

Type of Research Activities:

Performing Organization:

Laboratory Research-Experimental

Argonne National Laboratory

Principal Investigators:

J.A. Cofasso

M.J. Steindler

Objective:

a) Obtain reliable thermodynamic quantities for zeolites and minerals related to them; b) provide fundamental geochemical knowledge on transport of dissolved material by fluid flow; c) determine the geochemical factors upon which mobility of radionuclides in geologic strata depend.

Information/Status:

a) Systems chosen for study are those of importance in vapor-dominated, hot dry rock geothermal systems. Experimental goals are achieved by using several techniques, namely, reaction, high-temperature drop, low-temperature adiabatic and differential scanning calorimetry. Current studies are concerned with the estimation of thermodynamic quantities of natrolite, scolecite mesolite, pollucite, and heulandite.

b) Infiltration of rock cores is used to study solid/liquid interactions within the rock matrix. The infiltration experiments allow study of trace element transport with all the complications of ion exchange, leaching, dissolution and precipitation, differences in major element concentrations, and diffusion in the rock, under flow conditions.

c) The particular area of interest is the mobility of the actinides and the fission products. Important chemical properties under investigation include the oxidation states, the nature and stability of the complexes formed, solubility of compounds in ground waters, self-diffusion in rock strata and a study of hydrolysis reactions. The dynamics of reactions of the radionuclides with the rock matrix as well as with ground waters are being studied because they affect the patterns and rates of migration.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Physical Chemistry of Magmas

Sponsoring Organization: DOE

Research Area(s):**Physical Properties Rocks/Liquids**

Contract/Grant Number: ANL 57802

Type of Research Activities:**Performing Organization:****Laboratory Research-Experimental****Argonne National Laboratory**

Principal Investigators:**F.A. Caffaso****M. Blander**

Objective:

Information/Status:

This program will involve physicochemical studies of magmas essential to understanding bubble nucleation and violent gas evolution (as, e.g., contact-vapor explosions)--two related phenomena that may be important in extraction of heat from magmas by injection of water or with water-cooled heat exchangers. Preliminary studies of magmas have revealed that large kinetic barriers must be overcome and large supersaturations of dissolved water or other volatiles must be attained before these substances can be evolved at a significant rate from a large magma body. Understanding the mechanisms for bubble evolution using concepts of bubble nucleation developed in this laboratory will be one of the principal objectives of this program. When a hot substrate such as magma (or rocks derived from magma) contacts water, there is the possibility of explosive interactions called contact-vapor explosions. In addition, the cooling of gas-saturated magmas can lead to the violent evolution of bubbles. Theories of these phenomena will be used to define conditions under which they might occur during heat extraction efforts. These conditions will then be investigated along with means for avoiding these dangerous and violent events.

Initial efforts were undertaken during 1978 and are on-going.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: IVEP Geothermal Subsidence and Seismicity

Sponsoring Organization: DOE/Office of
Health and Environmental Research

Research Area(s):

Structural Geology
Geophysics-Other (Seismic)

Contract/Grant Number: RPIS-2341; W-7405-
ENG-48

Type of Research Activities:

Performing Organization:
Lawrence Livermore Laboratory

Field Research
Data Analysis/Documentation

Principal Investigators:

N.B. Crow

Objective:

Document the naturally occurring levels of subsidence and seismicity in the Imperial Valley of California and identify any increase in these processes due to the development of geothermal resources.

Information/Status:

Included are development of criteria for distinguishing natural subsidence from induced movement, and natural seismic activity from induced activity. A geological model of the Imperial Valley will be developed as well as a predictive model of potential subsidence due to geothermal production activity. Subsidence detection is based upon precise leveling networks, surveyed to first- or second-order standards. Repeated surveys at intervals of one or two years will show any changes in elevation of points on the network, thus measuring land-surface elevation changes. A regional seismographic network and microseismic network will be utilized to determine baseline seismic activity in the Valley.

Contract began November 1975.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Assessment of Subsurface Injection for Western Hydrothermal Resources

Sponsoring Organization: EPA

Research Area(s):

Brine/Gas Chemistry

Contract/Grant Number: 68-03-3051

Type of Research Activities:

Performing Organization:

Modeling/Simulation

Energy Resources Co., Inc.

Principal Investigators:

J. Kopecek

Objective:

Assess the environmental effects of geothermal brine injection disposal associated with expected geothermal energy resources in the western U.S.

Information/Status:

The project entailed:

- Assembling site characterization data and development plans for U.S. hydrogeothermal sites and loading this into a computerized database.
- Determining the toxicological risks of brine constituents.
- Assessing injection technology and associated technical risks.
- Modeling injection plume over 30 years at selected sites.
- Evaluating regulatory issues, especially the Underground Injection Control regulation of SDWA.

Six sites were originally identified for detailed examination and modeling studies, but only one (Raft River) was investigated in depth.

Contract from Jan. 1981 to Jan. 1982.

Contract amount: \$197,314.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Wetlands Disposal of Geothermal Wastewater

Sponsoring Organization: EPA/ORD

Research Area(s):

Brine/Gas Chemistry

Contract/Grant Number: D9-X0657;
BC2J-00863

Type of Research Activities:

Performing Organization:

Data Analysis/Documentation

DOI/Fish and Wildlife Service

Principal Investigators:

L. Ischinger

Objective:

To determine the feasibility of using spent geothermal waters for the creation or enhancement of waterfowl wetland habitats in the arid western U.S.

Information/Status:

The approach is to evaluate existing chemical and physical data, waterfowl and foodstock tolerances, legal and institutional implications, and physical changes associated with the objective, and select sites based upon developed criteria.

Contract from Jan. 1979 to June 1980. FY 1980 funding was \$31,000.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Assessment of Subsurface Injection For Western Geothermal Resources

Sponsoring Organization: Environmental Protection Agency

Research Area(s):

Well Stimulation/Reservoir Engineering

Contract/Grant Number: 68-03-3051

Type of Research Activities:

Performing Organization:
Energy Resources Co., Inc.

Data Analysis/Documentation

Principal Investigators:

J. Kopecek
R. Beck
J. Hager

Objective:

The purpose of this project is to assess the adequacy of EPA's Underground Injection Control Regulations in protecting the environment from the subsurface injection of brines from future geothermal facilities in the western United States. This ongoing project is divided into three phases as described below.

Information/Status:

Phase I assesses the potential consequences of geothermal wastewater injection. This phase includes a review of existing data on the injection of various wastewaters, the characterization of western geothermal resources and likely developments, and the development representative scenarios for analysis.

Phase II evaluates the adequacy of existing injection control regulations. This work includes the review of existing injection control regulations and the identification of regulations that pertain to aquifer contamination.

Phase III produces recommendations for changes in injection system design, monitoring of injections, and injection control regulations. This task follows from a synthesis of work performed under the first two phases.

The project was begun in 1981.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Geothermal Studies of Passive Continental Margins

Sponsoring Organization: DOC/National
Oceanic and Atmospheric Administration

Research Area(s):

Heat Flow Studies

Contract/Grant Number: R/C-2

Type of Research Activities:

Performing Organization:
Woods Hole Oceanographic Institution

Laboratory Research-Analytical
Data Analysis/Documentation

Principal Investigators:

R. von Herzen

Objective:

Determine reliable (plus or minus 5%) values of geothermal flux on passive continental margins.

Information/Status:

Data and samples from the COST drill holes will be used to obtain vertical temperature gradients and thermal conductivity to depths of 4 km or more at 2 sites on the Atlantic shelf and slope. Downhole logs will be evaluated for equilibrium temperature gradients, and samples of drill cuttings will be obtained for thermal conductivity measurements.

ANTICIPATED BENEFITS: 1) provide industry and governmental agencies (BLM, USGS) with another method and data for evaluation of hydrocarbon potential in shelf sediments; 2) provide geologists and geophysicists with accurate values of heat flux at known sites for calibration of other survey techniques under development; 3) assist in planning of multiple (and sometimes conflicting) uses of continental shelves by developing accurate geological models and resource estimates of passive continental margins; 4) determine the usefulness of the technique of measuring thermal conductivity on drill cuttings for other drill holes.

Contract from Nov. 1977 to June 1980. FY 1980 funding was \$15,000.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Electrolyte Thermodynamic Data

Sponsoring Organization: DOC/National
Bureau of Standards

Research Area(s):

Brine/Gas Chemistry

Contract/Grant Number: 3165156

Type of Research Activities:

Performing Organization:

Laboratory Research/Experi-
mental

DOC/National Bureau of Standards

Principal Investigators:

B.R. Staples

Objective:

Provide engineers and scientists with standard references data on thermodynamic properties of electrolyte solutions. These data are required in the analysis of problems in water quality control, geothermal energy production, corrosion, sewage treatment desalination, industrial processes and in the interpretation of chemical, biochemical and geochemical systems.

Information/Status:

PROJECT APPROACH: Prepare and publish evaluated data on the osmotic and activity coefficients of electrolytes in water and in selected thermodynamic properties of important constituents on natural water systems. Develop and test methods for evaluating data. Provide information services.

PRIOR YEAR ACCOMPLISHMENTS: Assessment of energy related invention and tests of accuracy of solution thermodynamics data, leading to proof of compatibility of enthalpies of dilution based on the first and second laws of thermodynamics.

Contract from Oct. 1976 to Dec. 1979. FY 1978 funding was \$82,000.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Hydrology, Geochemistry, and Microbiology of Geothermal Systems on the Submarine Rift Zones of Kilauea, Mauna Loa and Kaleskala Volcanoes

Sponsoring Organization: DOC/National Oceanic and Atmospheric Administration

Research Area(s):

Brine/Gas Chemistry

Contract/Grant Number: ME/R-4

Type of Research Activities:

Performing Organization:

Field Research

University of Hawaii

Principal Investigators:

G.M. McMurtry

D.M. Harl

Objective:

1) To better understand the hydrology of the rift zones of Hawaiian volcanoes and how groundwater interacts with geothermal systems in the rift zones. 2) To determine if hydrothermal vents are currently active or were active in the recent past on the submerged sections of the rift zones and, if so, to characterize the chemistry, microbiology, and hydrography of the submarine hydrothermal system. 3) To study evidence of recent submarine eruptions that will enhance our understanding of the magma plumbing of the rift zones and the processes of submarine eruption.

Information/Status:

The data from this project will provide new information on submarine geothermal reservoirs, on fresh and seawater movements through the rift zones (both subaerial and submarine), and on submarine eruptions and magma plumbing, all of which are important to the emerging alternate energy industry in Hawaii. The data will provide information on submarine mineral resources which would aid in the development of new mineral industries, as well as comparative information on hydrothermal vent ecosystems at intraplate rift zones with those recently discovered at midplate spreading centers, both of which are important to public education on the origins of life.

The project began in April of 1981 and is scheduled for completion in May of 1983. Funding during FY 81 was \$24,000.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Waste Heat Rejection From Geothermal Power Plants

Sponsoring Organization: EPRI
California State Energy Commission

Research Area(s):
Mass Heat Transport

Contract/Grant Number: RP927

Type of Research Activities:

Performing Organization:
R.W. Beck Co.

Data Analysis/Documentation

Principal Investigators:

Objective:

- 1) identify sources of and demand for make-up water for geothermal power production
 - 2) develop analytical techniques and perform a comparative analysis of waste heat rejection options
-

Information/Status:

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Mobile Geothermal Fluids, Materials, and Components Test Laboratory

Sponsoring Organization: EPRI

Research Area(s):

Brine/Gas Chemistry

Contract/Grant Number: RP741

Type of Research Activities:

Performing Organization:

Field Research

Atomics International

Laboratory Research-Analytical

Principal Investigators:

Objective:

- 1) Support field testing of geothermal fluids and components
 - 2) develop detailed knowledge of geothermal fluid characteristics
-

Information/Status:

The project is a 3 year effort with completion scheduled during 1982. The mobile laboratory was designed to have extensive capabilities for the analysis of geothermal brine, steam condensate, and non-condensable gases. A portable fluid sampling system is operated in conjunction with the laboratory. The system has been used at East Mesa, Ca., Brazoria County, TX., and Brawley, Ca.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Method of Producing Self-Propping Fluid -
Conductive Fractures in Rock

Sponsoring Organization: E.I. DuPont
DeNemours and Co.

Research Area(s):

Physical Properties Rocks/
Liquids

Contract/Grant Number: None

Type of Research Activities:

Performing Organization:

Theoretical Research

Principal Investigators:

D.L. Coursen
G.R. Cowan

Objective:

Information/Status:

A fracture that conducts fluid within the confines of an underground rock formation without the need for particulate proppant materials to hold opposing fracture faces apart is created by a method in which a long portion of a hole drilled into the formation has its axis slanted with respect to the directions of the principal stresses, and is pressurized rapidly over its entire length with fluid, preferably by detonating an explosive therein. A hypothetical fracture plane is defined as that plane containing the axis of the hole which is under the least compressive normal stress. When the orientation of the hole axis is such that there is a substantial shear stress on the hypothetical fracture plane, but the normal stress thereon does not greatly exceed the minimum principal stress, the fracture created lies close to the hypothetical fracture plane, and is conductive to fluids. The fracture is conductive because it is held open by the misfit between the opposing faces which arises from the shear displacement of the faces that occurs when the existing shear stress is released by the formation of the fracture.

Patent No. US4,220,205, File Date 28 Nov. 1978.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Thermal Aureoles of Igneous Intrusions: Some Possible Indication of Hydrothermal Convective Coding

Sponsoring Organization: N/A

Research Area(s):

Heat Flow Studies
Geology-Other (Unknown)

Contract/Grant Number: N/A

Type of Research Activities:

Performing Organization:

Modeling/Simulation
Field Research

Brown University

Principal Investigators:

E.M. Parmentien
A. Schedl

Objective:

Information/Status:

The size and shape of metamorphic aureoles is investigated as a possible indicator of hydrothermal convective cooling of epizonal igneous intrusions. A simple family of numerical models illustrates the effect of convective cooling on maximum temperatures attained in the country rock surrounding an intrusion. Boundary layer approximations have also been applied to describe convection of vaporizing groundwater near the contact of an intrusion early in its cooling history. Maximum temperature isotherms are taken to reflect the width and shape of thermal aureoles defined by preserved mineral assemblages as appears to be reasonable based on several well-studied conductively cooled intrusions. The thermal aureoles of intrusions for which oxygen and hydrogen isotope data indicate convective groundwater circulation have been examined on the basis of the simple numerical and boundary layer models. The shape of the low temperature alteration aureole of the well-mapped El Salvador porphyry copper deposit suggests convective cooling of a permeable intrusion. The width of the low temperature (greenschist) aureole of the Mull intrusive complex can be explained by convective cooling of permeable intrusive rock. The narrow high temperature (amphibolite) aureole of the Cuillin gabbro on Skye can be explained by strong convective cooling; but the low temperature (greenschist) aureole is wide enough to be consistent with conductive cooling, thus suggesting decreasing permeabilities during the cooling history. This is consistent with oxygen isotope sampling and other geologic observations.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Water Geochemistry at Castle Hot Springs, Arizona

Sponsoring Organization:

Research Area(s):

Brine/Gas Chemistry

Contract/Grant Number:

FI07-79ID12009

Type of Research Activities:

Performing Organization:

Laboratory Research-Analytical

Arizona State University

Principal Investigators:

R.L. Satkin
K.H. Wohletz
M.F. Sheridan

Objective:

Information/Status:

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Regional Geothermal Assessment

Sponsoring Organization: DOE

Research Area(s):

Fluid Tracer Studies

Contract/Grant Number:AS07-78ID01713

Type of Research Activities:**Performing Organization:**

Field Research

University of Hawaii

Principal Investigators:

Objective:Assess geothermal energy potential in Hawaii.

Information/Status:

Regional assessment for geothermal potential in Hawaii indicated thermal alteration of shallow groundwater in northeast Maui. Studies within the area, the lower north rift of Haleakala volcano, include the measurement of ground Rn emanation, soil Hg concentration and soil pH. Anomalous results from these geochemical techniques are reasonably coincident, and are located over the western boundary of the rift structure. These studies suggest anomalous subsurface temperatures associated with the rift and consequent enhancement of ground gas outgassing. Further surveys, both geochemical and geophysical, are currently being carried out to confirm these conclusions.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Fault Zone Controlled Charging of a Liquid - Dominated Geothermal Reservoir

Sponsoring Organization: N/A

Research Area(s):

Mass Heat Transport

Contract/Grant Number: N/A

Type of Research Activities:

Performing Organization:

Theoretical Research

University of Colorado

Principal Investigators:

H.P. Goyal

D.R. Kassay

Objective:

Information/Status:

A mathematical model is developed for the fault zone controlled charging of a geothermal reservoir. The model is used to describe a reservoir of finite vertical extent with an impermeable upper boundary. A quasi-analytic theory is developed for high Rayleigh number convection of liquid in a rigid porous medium. In this approximation, liquid rises up the fault and spreads into the near regions of the reservoir isothermally. The cooling effect of the surface on the fault flow is confined to a thin layer near the surface. This layer grows with distance from the fault. In the far field of the aquifer the full depth of the reservoir is cooled by the surface. A study is made of the effect of various parameters such as mass flow rate, Rayleigh number, and fault width on the pressures, velocities, temperatures, and their gradients at different locations in the fault and in the aquifer. This analysis can be applied to geothermal systems where the thickness of the impermeable reservoir cap is quite small compared to the reservoir depth.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Variation of Continental Heat Flow With Age and the Thermal Evaluation of Continents

Sponsoring Organization: N/A

Research Area(s):

Heat Flow Studies

Contract/Grant Number: N/A

Type of Research Activities:

Performing Organization: Univ. of Michigan, Dept. of Geology & Mineralogy

Modeling/Simulation
Theoretical Research

Principal Investigators:

I. Vitorello
H.N. Pollack

Objective:

Information/Status:

The observed decrease of continental heat flow with tectonic age is interpreted in a three-component model. The first component is radiogenic heat from the zone of crustal isotopic enrichment, which yields about 40% of the observed heat flow in terrains of all tectonic ages. Because the surface heat flow varies with age between about 90 and 45 mW m/sup -2/, this radiogenic component also varies with the age between about 36 and 18 mW m/sup -2/, a net decrease of some 18 mW m/sup -2/. The absolute decrease with time of this component is achieved by erosional removal of radioisotopes from the surface; the erosion, exponentially decreasing with age, has a characteristic time of some 300--400 Ma (m.y. B.P.). The second component of surface heat flow is residual heat from a transient thermal perturbation associated with tectogenesis. This transient yields approximately 30% of the heat flow (27 mW m/sup -2/) in Cenozoic tectonic zones, diminishing effectively to zero in late Precambrian to mid-Precambrian terrains. The decay of this component has been fitted with temperature perturbation models that show a maximum perturbation to a cool shield geotherm of 750/sup 0/-800/sup 0/C at a depth of 80--100 km. From the analysis of this transient component we conclude that for residual heat to be observable up to and beyond 500 Ma, conductive cooling likely extends at least to depths as great as 300--350 km, implying that the continental crust and upper mantle beneath 500-Ma and older terrains has remained as a single conductive unit to such depths for at least the age of the terrain. For younger terrains the residual heat is yet sufficient to weaken them and make them vulnerable to recurrent tectonism. The third component of surface heat flow is a background flux of 27 mW m/sup -2/. Some 15 mW m/sup -2/ arises within the thick continental conductive root and is likely to be radiogenic.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Porous Media Studies

Sponsoring Organization: University
of Illinois

Research Area(s):

Fluid Migration

Contract/Grant Number:

Type of Research Activities:

Performing Organization: University
of Illinois

Theoretical Research

Principal Investigators:

J.W. Rudnicki

Objective:

Develop solutions to equations governing deformation of linear
fluid-infiltrated porous solids.

Information/Status:

Although the equations governing deformation of linear fluid-infiltrated porous solids are formally analogous to those of linear thermoelasticity, relatively few solutions to the porous media equations exist. One reason for this situation is that the coupling of deformation with diffusion, which can often justifiably be neglected in thermoelasticity, must be retained in the porous media case. Solutions to these equations which are relevant to problems of faulting, hydraulic fracture, aquifer mechanics, and geothermal energy recovery are being sought.

Work on the project began in 1978.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Helium Content of Fumarolic and Well Gases

Sponsoring Organization: Hawaii State
Government

Research Area(s):
Fluid Tracer Studies

Contract/Grant Number:

Performing Organization: University
of Hawaii

Type of Research Activities:
Data Analysis/Documentation
Field Research

Principal Investigators:

J.J. Naughton

Objective:

Determine the effectiveness of the helium content of fumarolic and well gases as a predictor of the long-term potential of a site.

Information/Status:

Field sampling apparatus and techniques have been developed, and a large number of gas sample collected in the Kilauea area on the rifts of the 1971 and 1974 eruptions, and at the Sulphur Bank Fumarole. Collection from the Puna geothermal well is planned once drilling has reached a level where there are indications of proximity to a hot body of lava. Thus far analyses have shown great differences in the helium content of gases from various fumaroles and drill holes at Kilauea, which seems to be related to the extent and age of the hot lava body feeding these fumaroles. Collections and analyses are continuing.

Contract began 1975.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Experimental Verification of Trace Metal Speciation in Soil Solutions Affected by Geothermal Brines

Sponsoring Organization: California State Government

Research Area(s):

Fluid Tracer Studies

Contract/Grant Number: CA-R-SES-3920

Type of Research Activities:

Performing Organization: University of California, Riverside

Laboratory Research-Experimental Modeling/Simulation

Principal Investigators:

S.V. Mattigad

Objective:

Verify experimentally, trace metal speciation in soil solution-geothermal brine mixture as predicted by a computer program: GEOCHEM.

Information/Status:

Saturation extracts from two different soils from Imperial Valley will be mixed with two or three different brines in ratios, 1:1, 5:1 and 10:1. Resulting partitioning of the elements between the solid and the solution phase will be measured. Results of the computer simulations will be compared with the experimental data. Validity of computer predictions for speciation of each element will be examined. In cases of discrepancies, additions or corrections to the thermodynamic data in the computer program: GEOCHEM will be made.

The period of performance for the project is 12/79 through 9/84.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Improved Rock Type Discrimination

Sponsoring Organization: NASA/Office of
Space & Terrestrial Applications

Research Area(s):

Petrology

Contract/Grant Number: 677-41-03

Type of Research Activities:

Performing Organization:

California Institute of Technology,
Jet Propulsion Laboratory

Hardware/Instrumentation Develop-
ment Testing

Principal Investigators:

Objective:

Improve our abilities in mineralogic and lithologic discrimination by remote sensing.

Information/Status:

The approach is to acquire data in the field, in the laboratory, from aircraft, and from satellite, to develop new instruments for data acquisition and to refine techniques for data analysis. Three types of data are to be systematically studied: (1) very high spectral resolution reflected infrared data (1 to 2.5 microns); (2) moderate resolution mid-infrared emission data (3-14 microns); and (3) surface thermal properties such as thermal inertia, derivable from temperature measurements. The newly completed 10 channel hand-held rationing radiometer (HHRR) will be used in the field at the Shuttle Multispectral Infrared Radiometer (SMIRR) and other test sites to test the value of very narrow band filters (.02 microns) in the 2-2.5 microns region for mineralogic discrimination, particularly among the clays and carbonates. Results will be related to data acquired during the SMIRR aircraft flight tests. Construction will begin on a new high resolution spectrometer head for the PFRS. The instrument will have a resolution of 0.005 microns and cover the range 1.5-2.5 microns. The existing spectral measurements from the laboratory will be augmented with a high resolution spectrometer covering the 0.4-2.5 microns range. The JPL Portable Field Emission Spectrometer (PFES) will be operated at various test sites in Arizona, Nevada and Utah to obtain in situ spectra in the 3-14 microns region. Data will be correlated with multiband thermal images of the Tintic mining district and analyzed during FY-79. Statistical analysis techniques will be applied to the field spectra to determine the best spectral bands for discrimination among silicate and carbonate rocks. Thermal inertia measurements of a number of natural surfaces will be taken in the field. A simple device has been constructed to make measurements independent of insolation. Results will be compared to data acquired by aircraft and HCM.

Contract began in 1980.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Chemistry and Materials in Geothermal Systems

Sponsoring Organization: N/A

Research Area(s):

Brine/Gas Chemistry
Corrosion/Scaling

Contract/Grant Number: N/A

Type of Research Activities:

Performing Organization: Edgerten,
Germeshausen, and Grier, Inc.

Indeterminable from Description

Principal Investigators:

R.L. Miller

Objective:

Information/Status:

The development of a geothermal fluid is traced, from its origin as meteoric water precipitating on the earth's surface, as it flows through the soils and rocks of geological formations, to the point where it returns to the surface as a hot spring, geyser, well, or other form. Water of magmatic origin is also included. The tendency of these hydrothermal fluids to form scale by precipitation of a portion of their dissolved solids is noted. Information required for materials selection for energy systems utilizing geothermal fluids, including pH, temperature, the speciation of the particular geothermal fluid (especially its chloride, sulfide, and carbon dioxide content), and various types of corrosive attack on common materials was analyzed.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Geothermal in situ experiments in the Asse salt-mine.

Sponsoring Organization: Federal

Republic of Germany

Research Area(s):

Heat Flow Studies

Contract/Grant Number:

Performing Organization:

Type of Research Activities:

Theoretical Research
Laboratory Research-Experi-
mental

Principal Investigators:

J. Hopfety

R. Jung

Objective:

Information/Status:

The effort concentrated on the conduct of in situ experiments in the Asse salt-mine in Germany. With reference to model calculations of the temperature field which is produced in salt formations by radioactive waste, temperature measurements in the area of electrical heating elements and in situ measurements of thermal conductivity have been performed. The measured temperatures are in good accordance with the theoretical prediction. Preliminary results of the thermal conductivity measurements correspond with the data of single NaCl crystals published by Birch and Clark. At present a heating experiment is being conducted in the Asse mine to investigate thermo-mechanical effects of a cylindrical heat source upon the surrounding rock salt. Possible thermal induced fractures monitored by permeability changes and seismoacoustical phenomena are the main objects of this experiment.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Atlas of Subsurface Temperatures

Sponsoring Organization: Commission of
the European Communities

Research Area(s):

Heat Flow Studies

Contract/Grant Number: N/A

Type of Research Activities:

Performing Organization:

Data Analysis/Documentation

Principal Investigators: N/A

Objective:

Information/Status:

The temperature distribution in the subsurface to a depth of 500 m and by increments of 500 m is clearly displayed in a multicolour printed atlas covering the territory of the European Community. The atlas also contains maps of the terrestrial flow density and on the mean temperatures at the earth's surface. The compilation of temperature data is the basis for exploration of geothermal energy and a planning reference for administrative decisions. In addition, this document is of great value for the oil industry, the water resources agencies and for all geosciences. (45 maps)

"Atlas of Subsurface Temperatures in the European Communities", CEC, 1980.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Improved Geologic Interpretation at NTS
Using Electric Logs

Sponsoring Organization: DOE/Defense
Programs

Research Area(s):

Well Logging

Contract/Grant Number:

Type of Research Activities:

Performing Organization:

Data Analysis/Documentation

Los Alamos National Lab.

Principal Investigators:

N. Marusck

R. Batra

Objective:

Aid in the interpretation of seismic data at the Nevada test site; give a more accurate regional interpretation of the geologic problems of the area.

Information/Status:

Electric logs have been used successfully to identify a missing rock sequence (geologic fault) enhance stratigraphic interpretation and aid in accurate definition of new site selections for future emplacement holes. The project was funded at \$20,000.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Geothermal Assessment and Reservoir Definition in Alaska

Sponsoring Organization: DOE/Office of Energy Technology

Research Area(s):

Structural Geology
Geophysics-Other (Unknown)

Contract/Grant Number: FC07-79ET27034

Type of Research Activities:

Performing Organization:

Field Research

University of Alaska

Principal Investigators:

D.L. Turner

Objective:

Provide geological and geophysical field studies of selected geothermal areas in Alaska.

Information/Status:

Geologic mapping and seismic temperature, resistivity/magnetotellurics, geochronologic and gravity surveys will be combined as appropriate to attempt to define the nature of the geothermal reservoirs studied. Assessment of Alaskan geothermal resources will proceed concurrently with the resource definition work. A final technical report will be produced which will integrate and interpret all geological and geophysical data for each site.

Contract from March 1979 to March 1980.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Sulfur Gas Geochemical Detection of Hydrothermal Systems

Sponsoring Organization: DOE

Research Area(s):

Fluid Tracer Studies

Contract/Grant Number: FC07-79ID12063

Type of Research Activities:

Performing Organization:

Field Research

Earth Science and Engineering, Inc.

Principal Investigators:

G.E. Rouse

Objective:

Utilize three different survey techniques for determining the sulfur gas concentrations in soils over Roosevelt Hot Springs, Utah to demonstrate the usefulness of this approach for identifying geothermal reservoirs and identify the best of the three techniques.

Information/Status:

Approaches to the problem will include: determining the sulfur gas concentration in soil gas with an instrument capable of instantaneous readout; determining the sulfur gas flux of the area by accumulating the vapors over several weeks with collecting devices; and determining the sulfur gas flux by collecting and analyzing soil samples for adsorbed sulfur gases. The method of surveying which works best at Roosevelt Hot Springs will be tested at two other known geothermal sites. The product of this work will be a report detailing each sampling and analytical procedure for each of the three methods as well as a series of maps showing the distribution of sulfur gases as determined by each method for each area surveyed.

Contract from Oct. 1979 to April 1980.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Analysis of Three Dimensional Inverse Electrical Methods

Sponsoring Organization: DOE/Office of Energy Technology

Research Area(s):

Electrical Studies

Contract/Grant Number: FC07-79ID12066

Type of Research Activities:

Performing Organization:

Modeling/Simulation

LuTech, Inc.

Principal Investigators:

F.M. Tesche

Objective:

Apply the highly efficient unimoment method using the hybrid solution of the Finite Element Method and analytical expansions to modeling the realistic 3-D geologic structures for convective hydrothermal resources.

Information/Status:

This project studies an innovative approach employing electrical measurements in the frequency domain for characterizing geothermal objects/reservoirs. This improved 3-D analysis will aid the design of more effective electrical survey techniques and the interpretation of field data. The various inversion schemes in frequency domain are also being studied. The goal of transferring the results of this study to industry is being used as a guide in performing this research and recommendations for such transfer will also be made as a part of this work.

Contract from Sept. 1979 to Sept. 1980.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Low Temperature Geothermal Resource Assessment

Sponsoring Organization: DOE

Research Area(s):

Structural Geology
Heat Flow Studies

Contract/Grant Number: FC07-79ET27220

Type of Research Activities:

Performing Organization:

Field Research

Oregon State Department of Geology and
Mineral Industries

Principal Investigators:

D.A. Hull

Objective:

The objective is the detailed testing of various previously identified geothermal sites in Oregon for direct-use application.

Information/Status:

The following tasks were planned: data compilation; geologic mapping; temperature gradient drilling; and geochemistry. Completion of geologic mapping of eight low-temperature geothermal resource areas identified earlier in the project and temperature gradient drilling at Lakeview and Craig Mountain-Cove (La Grande) are planned.

Contract from May 1979 to Dec. 1980.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Geothermal Resource Assessment of the Western and Central Cascades, Oregon

Sponsoring Organization: DOE/Idaho Operations

Research Area(s):

Structural Geology
Heat Flow Studies

Contract/Grant Number: FC07-79ID12044

Type of Research Activities:

Performing Organization:

Field Research

Oregon State Department of Geology and Mineral Industries

Principal Investigators:

D.A. Hull

Objective:

Assess the geothermal resources of the Western and Central Cascades in Oregon

Information/Status:

The following tasks were planned: geology and lineament study, tectonic framework study, thermal gradient drilling, and geochemistry. Expected results are identification of potential geothermal resource area(s), and recommendation(s) for deep exploratory drilling.

Contract from May 1979 to July 1980.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Terrain Effects in Resistivity and Magnetotelluric Surveys

Sponsoring Organization: DOE/Office of Energy Technology

Research Area(s):
Electrical Studies

Contract/Grant Number: FC07-79ID12038

Type of Research Activities:

Performing Organization:
University of New Mexico

Modeling/Simulation

Principal Investigators:

G.R. Jiracek

Objective:

Develop a documented computer algorithm which calculates the electrical and electromagnetic response of an arbitrary three-dimensional topographic effect in dipole-dipole resistivity and magnetotelluric surveys; and to provide case studies on existing field data to test the utility of the algorithms.

Information/Status:

The approach taken will be to adapt proven modeling techniques for a three-dimensional flat earth to include terrain. Existing finite difference resistivity modeling programs will be adapted using geometric weighting of coupling coefficients. Existing finite element techniques for both resistivity and electromagnetic modeling will be adapted using isoparametric finite elements. The case studies will analyze resistivity and magnetotelluric data obtained by our group. The resistivity data are from the Los Alamos Scientific Laboratory Hot Dry Rock Geothermal Site in the Jemez Mountains. Magnetotelluric data are from the Rio Grande rift and bordering mountains and uplands.

Contract from Sept. 1979 to Sept. 1980.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Calcite Cap Rock in Shales to Predict Occurrence of Reservoirs Composed of Leached Secondary Porosity in the Geopressured Zone

Sponsoring Organization: DOE/Nevada Operations Office

Research Area(s):

Geochronology/Stratigraphy

Contract/Grant Number: AC08-79ET27111

Type of Research Activities:

Performing Organization:

University of Texas

Laboratory Research-Analytical
Data Analysis/Documentation

Principal Investigators:

W.R. Kaiser

K. Magara

Objective:

Information/Status:

Diagenetic studies on Gulf Coast Tertiary rocks, funded by DOE and conducted at the Bureau of Economic Geology since 1977, have produced a large quantity of data on the regional variations in detrital and authigenic mineralogy. This information has been applied to understanding the occurrence of deep subsurface reservoirs, which is vital for assessing the geopressure geothermal energy potential of the region. This study proposes to combine the above sandstone consolidation data with maps, field samples, and well log information to produce tools for porosity exploration and to then compare the occurrence of deep reservoirs composed of secondary porosity to calcareous shale caps at shallower depths. To better assess the suggested relationship between leaching and cap rocks, the origin of authigenic carbonate minerals in Tertiary sandstones and shales should be understood. For this we need to obtain more geochemical information on authigenic phases and formation waters.

The project was a one and a half year effort that was completed in Oct. of 1980.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Heat Flow and Geothermal Evaluation of the Cascade Range of Oregon and Washington

Sponsoring Organization: DOE/Idaho Operations Office

Research Area(s):

Heat Flow Studies

Contract/Grant Number: 5-27526-000;
AS07-79ID12037

Type of Research Activities:

Performing Organization:

Field Research

Southern Methodist Univ.

Principal Investigators:

D.D. Blackwell

Objective:

Information/Status:

As part of a cooperative effort with the Oregon Dept. of Geology and Mineral Industries and the Washington Dept. of Natural Resources, a heat flow and geothermal evaluation program will be carried out for the states of Oregon and Washington, with particular emphasis on the Cascade Range of Oregon and Washington and the Basin-and-Range province of Oregon. Specifically, as part of this study, technical support and equipment for field heat flow measurements will be provided by personnel from SMU for the field program planned by the state agencies. The state groups will contract drilling and perform various geological and geophysical studies necessary for a complete program. Field measurements of temperature and in situ well parameters such as natural gamma activity, SP, resistivity, and sonic velocity will be obtained. Samples will be collected for thermal conductivity determination. In the laboratory, the data collected by the state groups and by SMU personnel will be reduced (thermal conductivity determinations, terrain corrections, etc.) and complete heat flow values calculated for geothermal interpretation of the regional heat flow and geothermal potential of the target areas. The final outcome of the combined studies of all three groups will be detailed estimates of the magnitude and location of the geothermal resources in the Cascade Range and in the Basin-and-Range province of Oregon. Period of performance for the effort was 6/79 through 5/81.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Well Test Analysis and Reservoir Performance Predictions for Geopressured Geothermal Systems in the Texas/Louisiana Gulf Coast Region

Sponsoring Organization: DOE/Nevada
Operations Office

Research Area(s):

Well Stimulation/Reservoir
Engineering

Contract/Grant Number: AC08-80NV10150

Type of Research Activities:

Performing Organization:

Field Research

Systems, Science and Software, Inc.

Principal Investigators:

S.K. Garg

Objective:

Apply existing reservoir simulation techniques to assist DOE in interpreting data generated from geopressured wells in the Gulf Coast Region. Estimate energy recoverability and rates of energy production for a suite of systems that are representative of the Gulf Coast geopressured resource base.

Information/Status:

Systems, Science and Software (S3) will support the reservoir analysis groups at the University of Texas at Austin (UTA) and Louisiana State University (LSU) which have the primary responsibility for the analysis of the design test wells drilled in their respective states under the DOE Deep Drilling Program. Well test data will be analyzed to estimate formation properties and reservoir limits. Long term performance characteristics of the specific geopressured reservoir systems will be predicted using simulation models based on the results of the well test analysis. The period of performance for the effort is Aug. 1980 through Aug. 1983.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Geothermal Reservoir Site Evaluation in Arizona

Sponsoring Organization: DOE/Idaho
Operations Office

Research Area(s):

Electrical Studies
Brine/Gas Chemistry

Contract/Grant Number: 000102

Type of Research Activities:

Performing Organization:
University of Arizona

Field Research
Data Analysis/Documentation

Principal Investigators:

W.R. Hahman

Objective:

Information/Status:

The project involves exploration for and evaluation of the geothermal energy resources in Arizona. The program combines exploration geology, geophysics and geochemistry in the location and evaluation of geothermal anomalies. The results of this program will ultimately be the utilization of geothermal energy to assist Arizona, a net energy importer, in meeting its greatly expanding energy needs. The location of 37 areas suitable for direct use of geothermal energy applications plus the location of several areas with the potential for the utilization of geothermal energy for electrical generation were identified. Work on the effort was initiated in May of 1977 and completed in January 1981. Funding for FY 81 was \$300,000.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Seismic Studies: Austin Bayou and Cuero Geopressured Geothermal Prospects

Sponsoring Organization: DOE/ORNL

Research Area(s):

Geophysics-Other (Seismic)
Geochronology/Stratigraphy

Contract/Grant Number: AS05-76ET28461

Type of Research Activities:

Performing Organization:

Field Research
Data Analysis/Documentation

University of Texas

Principal Investigators:

R.A. Morton

Objective:

The objectives of this study are to obtain and interpret pre-existing and new seismic data from the Frio Formation of the Austin Bayou Prospect, Brazoria County, and the Wilcox Group of the Cuero Prospect, Dewitt County, Texas. Specific objectives of the proposed seismic studies are: (1) to locate and map faults, determine their growth history, and recognize geometry of sandstone beds near the faults where well control is typically sparse; (2) to verify lateral continuity of sandstone beds now carried on electric-log sections; (3) to determine the seismic signature of thick sandstones within geopressured shale from synthetic seismograms and modelling, and to recognize these sandstones beyond the limit of well control; (4) to attempt to distinguish porous from non-porous sandstones; and (5) to locate and map the top of geopressure.

Information/Status:

Work was completed on this effort in October of 1980.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Geothermal Resource Assessment in Oklahoma

Sponsoring Organization: DOE/Idaho
Operations Office

Research Area(s):

Heat Flow Studies

Contract/Grant Number: 001163

Type of Research Activities:

Performing Organization:

Data Analysis/Documentation

University of Oklahoma
State Geological Survey

Principal Investigators:

W.E. Harrison

Objective:

Information/Status:

The Oklahoma Geological Survey will perform two tasks under the terms of the contract. The project will produce a geothermal gradient map of the State at a scale of 1:500,000. The project will also conduct field studies or site confirmation investigations to test the accuracy of the gradient map. Included in the latter will be a study to investigate the relation between gradient conditions and geologic factors (structure, stratigraphy, petrophysics, etc.). The work was initiated in Sept. of 1980 and completed in October of 1981. The project was funded at \$119,000 and a gradient map of the state was produced as well as a report describing the geologic work.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Geothermal Assessment of the MX Deployment Area in Nevada

Sponsoring Organization: DOE/Nevada
Operations Office

Research Area(s):

Structural Geology
Heat Flow Studies

Contract/Grant Number: AC-08-81NV10187

Type of Research Activities:

Performing Organization:
University of Nevada

Data Analysis/Documentation
Field Research

Principal Investigators:

D.T. Trexler
J.L. Bruce

Objective:

Information/Status:

A preliminary geothermal resource assessment of the MX deployment area in Nevada focused on Coyote Spring Valley in southeastern Nevada. Initially, an extensive literature search was conducted and a bibliography consisting of 750 entries was compiled covering all aspects of geology pertaining to the study area. A structural study indicates that Coyote Spring Valley lies in a tectonically active area which is favorable for the discovery of geothermal resources. Hot water may be funneled to the near-surface along an extensive fracture and fault system which appears to underlie the valley, according to information gathered during the literature search and aerial photo survey. A total of 101 shallow temperature probes were emplaced in Coyote Spring Valley. Three anomalous temperature points all lying within the same vicinity were identified in the north-central portion of the valley near a fault. A soil-mercury study also identified one zone of anomalous mercury concentrations around the north end of the Arrow Canyon Range. A literature search covering regional fluid geochemistry indicated that the three fluid samples taken from Coyote Spring Valley have a higher concentration of Na + K. During field work, seven fluid samples were collected in Coyote Spring Valley which also appear to be derived from volcanic units due to the presence of Ca-Mg or Na-K carbonate-bicarbonate. A temperature gradient study of six test water wells indicates that only one geothermal well with a temperature of 35.5/sup O/C (96/sup O/F) exists in the central portion of the valley at the north end of Arrow Canyon Range near the zone of anomalous soil-mercury points. A cultural assessment of Coyote Spring Valley was performed prior to field work.

Geothermal Assessment of the MX Deployment Area in Nevada, Final Report, April 1, 1981 through April 30, 1982, Trexler, D.T., et. al., University of Nevada, June 1982.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Identification of Geopressured Occurrences Outside of the Gulf Coast

Sponsoring Organization: DOE/Nevada
Operations Office

Research Area(s):

Well Logging
Other/Unknown

Contract/Grant Number: AC08-80NV10133

Type of Research Activities:

Performing Organization:
Science Applications, Inc.

Data Analysis/Documentation

Principal Investigators:

O. Strongin

Objective:

Information/Status:

The work focused on the occurrences of geopressures in Appalachia and selected California basins. In the former region, where geopressures have been observed, the pressure gradients for the most part were only slightly above normal as in the case of the Oriskany formation of Devonian age; this unit was also characterized by extremely high salinity. The one notable exception was in the Rome trough of West Virginia where Cambrian beds at depths below 10,000 feet display very high geopressure, approaching the lithostatic gradient, and the waters are only moderately saline. Though the geothermal gradient throughout Appalachia is relatively low, even in the Rome trough, the pressure, temperature and salinity values in this area indicate that the methane content of the Cambrian formation waters is in the range of 30 to 35 SCF/barrel. The two California areas researched included the contiguous Sacramento and San Joaquin Valleys. In the first, geopressures have been principally encountered in the Forbes formation of Cretaceous age, often at very shallow depths. Further waters are invariably characterized by very low salinity, far below the salinity of normal sea water, while the geothermal gradient is apparently higher in geopressured than in normally pressured zones. In the San Joaquin Valley, geopressures are particularly noteworthy in at least two formations of Miocene age at depths generally greater than those of the Forbes. The formation waters are likewise low in salinity; however, the geothermal gradient, especially in the geopressured zones on the west side of the valley, can be extremely high, up to twice as much as the normal temperature gradient. In view of these conditions, it is estimated that in the western San Joaquin Valley the methane content of geopressured formation waters will range from 30 to 40 SCF/barrel while in the Sacramento Valley, the methane content is estimated to be 20 to 25 SCF/barrel.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Exploration of Volcanic Geothermal Energy Resources Based on Rheological Techniques

Sponsoring Organization: DOE

Research Area(s):

Geophysics-Other (Earth Tide Tilt)
Gravity/Magnetic Studies

Contract/Grant Number: AT06-76ET28453

Type of Research Activities:

Performing Organization:

Field Research

Oregon State University,
Portland State University

Principal Investigators:

G. Bodvarsson
G. Axelsson
A. Johnson

Objective:

Information/Status:

Tidal strain and tilt field observations were carried out during the period February 1978 to December 1979 at the Klamath Graben and Newberry Caldera in Oregon and at Krafla in Northern Iceland. Moreover, tilt observations were made at M.t St. Helens, Washington, during the summer of 1980. Two strainmeters of the same type as now is used by the U.S. Geological Kinematics model TM-1B biaxial tilt meters. The instruments were placed at depths of approximately one to two meters below the ground surface. Both strain and tilt fields turn out to be heavily contaminated by noise that is mostly of thermoelastic origin. In spite of considerable efforts, it has not been possible to process the strain field data to obtain sufficiently clear tidal signals. The tilt data are less contaminated and rather clear tidal signals were observed at Newberry in Oregon and Krafla in Iceland. A local magnification by a factor of about 3 of the EW component of the theoretical solid earth and ocean load tilt was observed at one station at Krafla. Moreover, the tidal tilt component across the ring fault at Newberry appears to be magnified by a factor of 1.4 to 1.9. The phenomena at the Krafla may possibly be due to a local magma chamber. These results are a clear indication of a tilt field modification by local structure and indicate the possibility of using tilt data to locate subsurface magma bodies.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Seismological Investigation of Crack Formation In Hydraulic Rock Fracturing Experiments

Sponsoring Organization: DOE/Office of Basic Energy Sciences

Research Area(s):

Geophysics/Other (Seismic)

Contract/Grant Number:

EY-76-S-02-2534

Type of Research Activities:

Performing Organization:

Modeling/Simulation

Massachusetts Institute of Technology

Principal Investigators:

K. Aki

Objective:

Develop a comprehensive interpretation theory based on a quantitative model of geothermal systems and test it against a variety of data from different geothermal resources sites.

Information/Status:

The present research program was originated from our involvement in two major geothermal projects, namely, the Hot Dry Rock project at Los Alamos Scientific Laboratories and the Magma Tap project of Sandia. Our main conclusion from these studies is that a multiple approach is essential for exploring a complete geological body like a geothermal system. We need both conventional and unconventional techniques, based on both active experiments (using artificial signal sources such as seismic waves generated by buried explosions) and passive experiments (using signals generated by the geothermal system itself) or by the natural process outside the system. To put this multiple approach on a sound scientific basis, we are developing a comprehensive interpretation theory based on a quantitative model of a geothermal system and testing it against a variety of data from different geothermal areas. We will continue to collect and analyze data from our own Hawaii seismic network, the LASL Hot Dry Rock experiments, and our own digital event-recorders at the Newberry Peak volcano. Interpretation methods will be refined for more quantitative analysis of seismic data from geothermal areas. In the past year, we worked on the following subjects: (1) analysis and interpretation of seismic data obtained from the bore holes at the LASL Hot Dry Rock geothermal site; (2) collection, analysis, and interpretation of data on deep volcanic tremors at the USGS Hawaii Volcano Observatory; (3) development of a new method for determining seismic attenuation at frequencies higher than 1 Hz; (4) installation of 3-component digital event recorders at four stations in the Newberry Peak Volcano, Oregon; and (5) development of a computer program for calculating seismic motion generated by the vibration of fluid-filled crack in a layered medium.

Contract from Jan. 1975 to Dec. 1979.

Aki, K., Attenuation of Shear Waves in the Lithosphere for Frequencies from 0.05 to 25 Hz. J. Phys. Earth Planet. Int., 1979. Fehler, M., and K. Aki, Diffraction of Plane Elastic Waves by a Finite Crack with Application to Location of a Magma Lens, Seis. Soc. Amer. 68: 573-598(1978).

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Silicate, Aluminosilicate and Borosilicate and Melts:
Thermochemical Studies by High Temperature Calorimetry

Sponsoring Organization: DOE/Office of
Basic Energy Sciences

Research Area(s):

Petrology

Contract/Grant Number:

AC02-80ER10765

Type of Research Activities:

Performing Organization:

Arizona State University

Laboratory Research-Experi-
mental

Principal Investigators:

A. Navrotsky

Objective:

Collect basic thermochemical data on silicate glasses and melts by high temperature solution calorimetry and use the data to construct thermodynamic models of mixing properties and to calculate phase equilibria.

Information/Status:

The result, a better fundamental understanding of melt structure and properties, will have applications in volcanology, magma energy generation, geothermal energy, nuclear waste disposal, and materials science.

Contract from Sept. 1980 to Aug. 1981.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Geothermal Scaling and Corrosion Research

Sponsoring Organization: DOE/Office of
Basic Energy Sciences

Research Area(s):

Corrosion/Scaling

Contract/Grant Number:

Type of Research Activities:

Performing Organization:

Idaho National Engineering Laboratory

Laboratory Research-Experi-
mental

Principal Investigators:

D.E. Michels

Objective:

Investigate scaling and corrosion phenomena in geothermal fluids.

Information/Status:

The following topics are being studied: chemical mechanisms in scaling and corrosion; tests in simulated geothermal brines; crystal growth from solutions on selected substrates; rotated-disc electrode apparatus used to establish preselected hydrodynamic conditions on substrates; deposition of calcite on metallic substrates; corrosion of iron alloys in solutions containing silica and ionic salts; deposition of silica on Fe; effects of stress and trace elements; and x-ray diffraction, LEED, AES, and acoustic emission.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Aqueous Chemistry and Thermodynamics to Elevated Temperatures and Pressures

Sponsoring Organization: DOE/Office of Basic Energy Sciences

Research Area(s):

Brine/Gas Chemistry

Contract/Grant Number:

AK-01-03-02-1; W7405-ENG-26

Type of Research Activities:

Performing Organization:

Laboratory Research-Experimental

Oak Ridge National Laboratory

Principal Investigators:

H.F. Holmes
M.H. Lietzke
W.L. Marshall

Objective:

Major current thrusts of the program are on the solubilities of oxides to provide information on the speciation and thermodynamics of metal ions at high temperatures and the isopiestic and heat-flow calorimetric methods to advance the knowledge of thermodynamics of electrolytes at high temperatures.

Information/Status:

Thermodynamics of aqueous systems at elevated temperatures and pressures for DOE technological applications using potentiometry, conductance, isopiestic experiments, heat flow microcalorimetry, and solubility measurements; understanding of effects of temperature and pressure on equilibria, acid-base buffering systems, and electrolyte behavior; basis for accurate equations of state; hydrolysis and solubility of metal ions; solutions of alkali and alkaline earth halides; impact on steam generators, reactor coolants, geothermal chemistry, environmental chemistry, and processing chemistry. Equilibrium models are useful guides in understanding complex practical and natural processes. Physical chemical methods are being developed and applied to measurements of ionization association, complexing, and phase behavior of many metal ions and buffering systems. Techniques and results from this program have contributed greatly to the data base existing on the ionization behavior acids and bases to 300 degrees, the association behavior of 1:1 electrolytes to 800 degrees C and 4000 bars, the phase behavior of sulfates and oxides to 300 degrees C, thermodynamics of electrolytes and mixtures to 200 degrees, hydrolysis of metal ions as yet principally below 100 degrees C.

Contract began 1977 and is continuing. FY 1978 funding was \$384,000.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Localized Corrosion And Stress Cracking Phenomena Related To Energy Technologies

Sponsoring Organization: DOE/Office of Basic Energy Sciences

Research Area(s):

Corrosion/Scaling

Contract/Grant Number:

AK-01--2-03-3; W7405-ENG-2C

Type of Research Activities:

Performing Organization:

Laboratory Research-Experimental

Oak Ridge National Laboratory

Principal Investigators:

A.L. Bacarella
E.J. Kelly
A.A. Palko

Objective:

Continue to investigate localized corrosion and stress cracking phenomena related to energy technologies, with emphasis on corrosion of metallic materials in restricted geometries in the presence of normally acidic, concentrated solutions which are maintained by coupled electrochemical, hydrolytic, and mass-transport processes.

Information/Status:

These investigations are a redirection of our previous studies on mechanisms of general or uniform corrosion reactions to emphasis on localized corrosion, including stress corrosion cracking, pitting, and crevice corrosion, of susceptible metals in aqueous media. Localized corrosion is a deleterious, pervasive, and complex phenomenon important in the design of all present or future energy systems, and examples abound in highly developed technologies (nuclear reactors, coal gasification systems, MHD power generation, geothermal energy extraction, and processes of all sorts involving heat exchangers) where initiation and propagation of localized corrosion (stress corrosion cracking in particular) have led to materials failures and even premature plant shutdown. Although research on localized corrosion has been carried out by numerous investigators for many years, our examination of the literature has revealed one area of study which has been virtually neglected, but which we feel is crucial to the further development of the science at this point. And yet no systematic studies exist on the influence of pH, temperature, and the concentration, speciation, and electrochemical reactivity of corrosion products and other solution constituents on the kinetics of the anodic and cathodic partial processes which take place in the concentrated aqueous solutions formed by corrosion under geometric constraints. Furthermore, kinetic information of this type is required not only for increasing our understanding of the specific reactions which are important in localized corrosion, it is necessary to know detailed reaction kinetics in these concentrated media before any realistic theoretical models of localized corrosion can be developed.

Information/Status: (Continued)

- E.J. Kelly, Magnetic Field Effects on Electrochemical Reactions Occuring at Metal/Flowing-Electrolyte Interfaces, J. Electrochem. Soc., 124 (7), 987-94 (1977); J. Braunstein, A.L. Bacarella, B.M. Benjamin, L.L. Brown, and C.A. Girard, Proton Spin Relation and Mobility in Hydrous Melts, J. Electrochem. Soc., 124 (6), 844-49 (1977).

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Porosity with Fluids: Origin and Effect on Physical Properties of Crustal Rocks

Sponsoring Organization: DOE/Office of Basic Energy Sciences

Research Area(s):

Physical Properties Rocks/Liquids

Contract/Grant Number:

EY-76-S-03-0326 045

Type of Research Activities:

Performing Organization:

Laboratory Research-Experimental

Stanford University

Principal Investigators:

A. Nur

Objective:

Measure in the laboratory, compressional and shear wave velocities and attenuation in porous rock with water undergoing a vapor/fluid transformation, compare laboratory and theoretical results with reflection data gathered in the field at The Geysers, and investigate the physics of wave energy loss in reservoir rocks in an attempt to better characterize reservoirs.

Information/Status:

Results in Berea Sandstone indicate strong attenuation and abnormally low velocities in the region of transition from steam to hot water. Strong reflections from fracture zones in the field appear to be related to high fracture porosity and high permeability. In the laboratory we are measuring very carefully the effects of pore pressure, temperature, confining pressure, degree of saturation, clay content and rock type on wave attenuation. In parallel, we develop theoretical models for the physics of wave attenuation in situ. Preliminary results suggest that thermoelastic effects coupled with pore pressure are dominant in geothermal environments. We are investigating the coupled mechanical and chemical processes which lead to the reduction of pore and fracture volume in rocks. In the laboratory we are attempting to determine the relations between temperature, stress, chemical potential, solubility and transport and changes in configuration of porosity in shallow crustal rocks. Preliminary results suggest that active tectonics are required to continuously create new fracture porosity, against the sealing effects of solution and deposition. This may explain the usefulness of micro-earthquake surveys as a geothermal exploration method.

Contract began 1978.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Magma Energy Research

Sponsoring Organization: DOE/Office of
Basic Energy Sciences

Research Area(s):

Mass Heat Transport

Contract/Grant Number:

2910789

Type of Research Activities:**Performing Organization:**

Sandia Laboratory

Field Research

Theoretical Research

Principal Investigators: P.J. Modreski
H.M. Stoller M.J. Davis
J.L. Colp H.C. Hardee
E.J. Graeber D.W. Lawson
T.M. Gerlach D.O. Lee
P.C. Montoya

Objective:

Investigate the feasibility of extracting energy directly from buried circulating magma sources.

Information/Status:

Typically, these magma deposits have temperatures on the order of 1000° C and represent great concentrations of high quality thermal energy. The current concept involves locating a suitable magma source, drilling into the liquid magma, and installing a heat exchanger to continually transfer the heat from the magma to a conventional power plant on the surface. Ideally, natural convection power flow in the magma would circulate the liquid around the exchanger in such a way that the cooled material would settle to the bottom of the chamber. The system would be fully closed and, thus, assures no leakage of water or other working fluid. Preliminary studies have shown that the concept may be both technically and economically feasible if the magma source is within the upper five kilometers of the crust and if the heat extraction rate from the magma is at least five kilowatts (thermal) per square meter of heat exchanger surface.

Contract began 1978.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Thermodynamic Properties of Magmas

Sponsoring Organization: DOE/Office of
Basic Energy Sciences

Research Area(s):

Physical Properties Rocks/Liquids

Contract/Grant Number:

W-7405-ENG-48

Type of Research Activities:

Performing Organization:

Lawrence Berkeley Laboratory

Laboratory Research-Experimental

Principal Investigators:

J.S. Carmichael

Objective:

Measure the partial molar volumes and expansivities in a wide range of silicate liquids and measure the compressibilities of silicate liquids at 1 bar containing pressure using sound wave velocities to better evaluate the physical properties of magma.

Information/Status:

This is part of a continuing project to investigate the high temperature properties of silicate liquids, and their low temperature metastable equivalents, silicate glasses. Naturally occurring silicate liquids, or magmas, are ultimately responsible for a wide range of geologic phenomena, including a great part of the crust of the earth, geothermal activity and related ore deposits. However, very little is known of the physical properties of magma although its chemistry can be deduced, within limits, from its consolidation products, the igneous rocks. As natural silicate liquids vary over a considerable, but finite, range, it is necessary to express the pertinent physical properties in terms of partial molar quantities, which require experiments in temperature and composition space.

Contract began 1978.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Geosciences Relating to Geothermal Energy

Sponsoring Organization: DOE/Office of
Basic Energy Sciences

Research Area(s):

Brine/Gas Chemistry

Contract/Grant Number:

W-7405-ENG-48

Type of Research Activities:

Performing Organization:

Lawrence Berkeley Laboratory

Indeterminable from Project
Description

Principal Investigators:

P.A. Witherspoon

C.F. Tsang

W.H. Somerton

Objective:

Apply the principles of thermodynamics, hydrodynamics and geochemistry to support investigations of geothermal systems.

Information/Status:

The investigations are a necessary part of the LBL program to develop geothermal energy from low salinity high temperature brines. However, the results of the investigations will have broader impact in geothermal energy development from other sources. Four areas are being investigated: (1) reservoir dynamics; (2) rock fluid systems properties; (3) thermodynamics of high temperature brines; and (4) geochemistry and mass transfer in geothermal systems.

This project was started in FY 75.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Isotopic Studies on Rare Gases in Terrestrial Samples and in Natural Nucleosynthesis

Sponsoring Organization: DOE/Office of Basic Energy Sciences

Research Area(s):
Isotope Geochemistry

Contract/Grant Number:

EY-76-S-03-0034 032

Type of Research Activities:

Performing Organization:
University of California, Berkeley

Hardware/Instrument Development
Laboratory Research-Analytical

Principal Investigators:

J.H. Reynolds

Objective:

Conduct research in rare gas mass spectrometry where the broad objective is to read the natural record which the isotopes of the rare gases comprise as trace constituents of natural gases, rocks, and meteorites.

Information/Status:

In terrestrial samples it is observed that subterranean rare gases occur as recycled atmospheric gases, as radiogenic gases from natural radioactivity in the rocks and sediments, as much rarer radiogenic gases from extinct radioactivities, and possibly as a primordial component more ancient than the earth itself. Rocks similarly contain atmospheric gases, radiogenic gases, and sometimes primordial gas. A new program with us is to design, construct and operate apparatus which will analyze the elemental and isotopic composition of rare gases from fluid sources in the field, at or near the sampling site. Long-range scientific goals are to search for additional manifestations of primordial gases and to see how they relate to convection patterns within the earth. The rare gases from steam wells and other geothermal energy sources will also be examined with particular interest in assaying the proportions of recycled atmospheric field studies on fluids is being fabricated, we are working with volcanic xenoliths and suboceanic volcanic basalts where we have already observed interesting elemental and isotopic patterns.

Contract began 1978.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Isotopic Studies on Rare Gases in Terrestrial Samples and in Natural Nucleosynthesis

Sponsoring Organization: DOE/Office of
Basic Energy Sciences

Research Area(s):
Isotope Geochemistry

Contract/Grant Number:

DE-AS03-76F00034

Type of Research Activities:

Performing Organization:
University of California

Laboratory Research-Analytical
Laboratory Research-Experi-
mental

Principal Investigators:

J.H. Reynolds

Objective:

Read the natural record that isotopes of the rare gases comprise as trace constituents of natural gases, rocks, and meteorites.

Information/Status:

The RARGA system was used for making elemental and isotopic analyses of the rare gases in terrestrial fluids. Samples, both water and gas, from Yellowstone National Park and the Lardarello geothermal field were studied. Plans are to operate the RARGA system at a field location in California. Another effort, recently begun is the measurement of solubilities of the rare gases in silicate liquids at various temperatures and compositions. Work will also be undertaken in investigating isotopic equilibria in mineral separates from mantle xenoliths.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: The Relationship of Rock Physics to Geothermal Energy Technology

Sponsoring Organization: DOE/Office of Basic Energy Sciences

Research Area(s):

Physical Properties Rocks/Liquids
Other (Seismic)

Contract/Grant Number:

EY-76-S-03-0034

Type of Research Activities:

Performing Organization:

Laboratory Research-Experimental

University of California, Los Angeles

Principal Investigators:

D.L. Anderson
N.W. Warren

Objective:

Under this renewal grant, we propose to continue the work of our original program on the microstructure of rock and the physics of cracks by characterizing and quantifying rock microstructure using acoustic and petrographic methods and application to characterizing permeability and its pressure derivative in terms of microstructure.

Information/Status:

Properties of the earth's crust at low overburden pressure are controlled to a great extent by the rock fracture and microstructure. Elucidation of the effects of microstructure, therefore, applies directly to such problems as HOT DRY ROCK geothermal systems. Two aspects of research are proposed. The results of our investigations should be able to give us more detailed understandings of fracture growth under geological conditions and of the effects of detailed crack spectra or bulk physical properties, as well as new methods for measuring or estimating averaged microstructure distributions in rock.

RESULTS: Study of correlation of rock groups based on microstructure (petrographic study) to groups based on velocity properties; extension of the inverse problem of obtaining crack spectra from velocity data; stress corrosion experiments with crack growth rates of 2 times 10 to the minus 10th power m/sec; new velocity and strain data for three suites of rock including Conway granite, New Hampshire; setup of permeameter and velocity and permeability of identical samples; generation of microphoto library for structure study; extension of study relating permeability to elastic moduli through dependence on crack networks; three papers.

Contract from Nov. 1977 to Oct. 1978. FY 1978 funding was \$50,000.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Physical Chemistry of Geothermal Solutions

Sponsoring Organization: DOE/Office of
Basic Energy Sciences

Research Area(s):

Brine/Gas Chemistry

Contract/Grant Number:

05-ENG-26

Type of Research Activities:

Performing Organization:

Laboratory Research-Analytical

Oak Ridge National Laboratory

Principal Investigators:

R.E. Mesmer

C.F. Baes

R.H. Busey

W.L. Marshall

H.F. Holmes

Objective:

Provide physical/chemical information on processes occurring in geothermal solutions in support of the governmental and industrial efforts to harness geothermal energy from the hydrothermal sources in the western U.S.

Information/Status:

We conduct potentiometric, isopiestic, conductance, calorimetric and theoretical modeling studies on the properties of the brines and their interactions with minerals. Among the homogeneous equilibria upon which the program focuses are: the ionization of water in brines, ionization of silicic acid and polysilicate equilibria, fluorosilicate equilibria, carbonate ionization, and hydrolysis. Processes involved in silica transport are a principal focus. The thermodynamics of the major components NaCl, KCl, and CaCl₂ and their mixtures are being determined to 250 deg C by the isopiestic method.

Contract began 1978.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Interactions of Aqueous Media With Constituents of Natural Formations

Sponsoring Organization: DOE/Office of Basic Energy Sciences

Research Area(s):
Brine/Gas Chemistry

Contract/Grant Number:

004533

Type of Research Activities:

Performing Organization:
ORNL

Laboratory Research-Experimental

Principal Investigators:

J.W. Dickson

Objective:

The objective of the program is to provide fundamental data relevant to migration of constituents of solids and solutions in the earth's crust.

Information/Status:

Detailed physical chemical data can lead to greater understanding of rock alteration, and the transport and deposition processes involved in scientific questions (geochemical cycling, origin of ores, metamorphic reactions) and practical problems (underground storage, geothermal energy extraction, solution mining, enhanced oil recovery, etc.). Equilibrium and kinetic studies are being made in high temperature-high pressure apparatus (500 degrees C, 1 kbar) on pure mineral solubilities and rock-solution kinetics. Solutions of interest will be principally aqueous NaCl although other brines will be included. In the first experimental work on this project the special facilities and expertise of the Laboratory in electrical conductance at high temperatures and pressures have been applied to the study of the association behavior of alkaline earth chlorides in solution under supercritical conditions.

Activities under the effort were initiated in FY 80 with funding of \$163,000.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Thermal Regimes of Major Volcanic Centers -
Magnetotelluric Constraints

Sponsoring Organization: DOE/Office of
Basic Energy Sciences

Research Area(s):

Electrical Studies
Volcanology

Contract/Grant Number:

AS02-79ER10401

Type of Research Activities:

Performing Organization:

Field Research

Brown University

Principal Investigators:

J.J. Hermance

Objective:

Information/Status:

The proposed research studies processes through which the genesis of basaltic magma on a regional scale is coupled to the development of major volcanic centers in the western U.S.. This involves: (1) the completion of our magnetotelluric/geomagnetic variation field system; (2) the analysis and intercomparison of existing geophysical/electromagnetic data from major tectono/volcanic centers; (3) the acquisition of new magnetotelluric field data from volcanic centers along the eastern front of the Sierra Nevadas, particularly Long Valley; and (4) the integration of this activity into the Continental Scientific Drilling Program. The research is a four year effort with completion scheduled for April of 1983.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Porosity With Fluids: Origin and Effects on Physical Properties of Crustal Rocks

Sponsoring Organization: DOE/Office of Basis Energy Sciences

Research Area(s):

Physical Properties Rocks/Liquids
Geophysics-Other (Seismic)

Contract/Grant Number:

000164

Type of Research Activities:

Performing Organization:

Stanford University Dept. of Geophysics

Modeling/Simulation
Theoretical Research

Principal Investigators:

A.M. Nur

Objective:

Information/Status:

A plan to further develop the model which describes the physical processes actually responsible for wave attenuation in the crust including fluid squirt and thermal relaxation will be studied. Particular attention will be paid to partially saturated rocks. Q and V for P and S waves will be measured as a function of pore pressure, confining pressure, pore fluid type, temperature and rock type. The results are essential for inferring the state of underground reservoirs from seismic waves, used in geophysical exploration and well logging. The relationship between Q and hydraulic permeability in rocks, in order to determine whether permeability can be estimated from seismic measurement will be studied. Models relating these properties for compliant cracks, subject to pore and confining pressure, with partial water saturation will also be developed. The results will enable us to better estimate permeability of rocks under in situ conditions. A plan to develop simple crustal models involving cracking and healing to constrain the distribution of pore pressure in situ will be studied. This is essential for determining deep geothermal potential, earthquake prediction and formation of ore deposits. The project was initiated in 1976 and is on-going. Funding for FY 81 was \$140,000.

Microcracking and Healing in Granites, Sprunt, E., and Nur, A., 1979.

Compressional and Shear Wave Velocities in Water Filled Rocks During Water-Stream Transition, Ito, H., DeVilbiss, J., and Nur, A., 1979.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Hydrologic Reconnaissance of Geothermal Areas in Nevada and California

Sponsoring Organization: USGS

Research Area(s):

Hydrology (Other)
Heat Flow Studies

Contract/Grant Number: NA

Type of Research Activities:

Performing Organization:

USGS

Field Research
Modeling/Simulation

Principal Investigators:

Franklin H. Olmsted

Objective:

To develop and evaluate geohydrologic reconnaissance techniques chiefly related to shallow test drilling for exploration of several hydrothermal systems in northern and central Nevada. To formulate conceptual models of the systems for which the most data are available.

Information/Status:

This project began in early 1972 with a hydrologic reconnaissance of 7 hydrothermal systems in northern and central Nevada: Brady Hot Springs, western Carson Desert (Soda Lakes), Stillwater, Leach Hot Springs, Gerlach Hot Springs, Buffalo Valley, Hot Springs, and Sulphur Hot Springs (Ruby Valley). The release of USGS Open-File Report 75-56 ended the first stage of the project. The second stage involved the selection of 3 of the 7 systems for more intensive investigation: Brady Hot Springs, western Carson Desert (Soda Lakes), and southern Grass Valley (Leach Hot Springs and vicinity). A short time later, the Beowawe hydrothermal system and the Upsal Hogback system (northeast of Soda Lakes in the western Carson Desert) were added to the list of study areas. In addition, evaluations were made of the utility of temperature measurements at 1-m depth in delineating thermal anomalies at greater depths, using both conventional methods (thermistor measurements) and the Fallmann (sugar-solution) method of temperature integration.

Work on the project was completed in 1981.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: GEOTHERM - Geothermal Resources File

Sponsoring Organization: USGS

Research Area(s):

Hydrology-Other

Contract/Grant Number: NA

Type of Research Activities:

Performing Organization:

Data Analysis/Documentation

USGS

Principal Investigators:

James D. Bliss

Objective:

To maintain a computerized data base on geothermal systems for use by the Geothermal Research Program, state and other government agencies, and the general public.

Information/Status:

Computerized methods of filing data on (1) geothermal fields, (2) thermal wells/springs and (3) geothermal wells have been designed and implemented. The computer-stored data may be manipulated and retrieved in various ways, and were used extensively in the assessment of geothermal resources that resulted in the publication of USGS Circular 790. The GEOTHERM project, in the past, collaborated with the Department of Energy in its state-coupled program of resource assessment. All the thermal well and spring data compiled for that program are being added to GEOTHERM. Preliminary designs have been completed for a heat-flow file and a file on references to data in GEOTHERM. In December 1979 the data file on thermal wells/springs was entered into the General Electric Information Services Network where it is available directly to subscribers of that network.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Geothermal Geophysics

Sponsoring Organization: USGS

Research Area(s):

Resource Evaluation/Identification

Contract/Grant Number: NA

Type of Research Activities:

Performing Organization:

Data Analysis/Documentation

USGS

Principal Investigators:

Don R. Mabey

Objective:

To coordinate a Federal-State program to assess the geothermal resources of southern Idaho (1978-1980 period). To review all data relating to geothermal resources of the northern Basin and Range Province and to recommend a program to complete assessment of the resources of this region (1981 - ongoing).

Information/Status:

Some report writing remains to complete the work in southern Idaho. Reports are planned on the Raft River geothermal system, the Blackfoot lava field, and the Snake River Plain. A gravity map of southern Idaho will be prepared. The northern Basin and Range program will begin with a review of data obtained through the Department of Energy's Industry-Coupled Program.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Physics of Geothermal Systems

Sponsoring Organization: USGS

Research Area(s):

Heat Flow Studies

Contract/Grant Number: NA

Type of Research Activities:

Performing Organization:

Data Analysis/Documentation
Modeling/Simulation

USGS

Principal Investigators:

T. C. Urban

Objective:

To obtain a better understanding of the physics of geothermal systems through measurement of temperatures and other geophysical parameters that appear appropriate and practical. To integrate these data and other geological, geophysical and hydrological information in order to develop models suitable for describing specific geothermal systems and geothermal systems in general. To examine geological and geophysical data on a more regional basis to determine the nature and causes of the existence of geothermal systems.

Information/Status:

An average-elevation map of the conterminous United States at a scale of 1 to 2.5 million is in the final drafting stage for publication. This map and future modified versions will be compared to geologic and geophysical maps. A chapter on the geology and geophysics of geothermal systems was prepared for a book on the Production of Electricity from Geothermal Energy, edited by J. Kestin of Brown University. Equilibrium temperature logs were obtained in 24 holes at Raft River, Idaho. Analysis of these data should be completed within the next year. Temperature data obtained in intermediate depth holes in the eastern part of Long Valley Caldera, California, show that there is pervasive lateral subsurface spreading of hot water that rises from depth along deeply penetrating conduits.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Analytical and Numerical Methods

Sponsoring Organization: DOE/Office of
Energy Research

Research Area(s):

Fluid Migration
Mass Heat Transport

Contract/Grant Number: W-7405-ENG-48

Type of Research Activities:

Performing Organization:

Theoretical Research

Lawrence Berkeley Laboratory

Principal Investigators:

N. Albright
A. Chorin
P. Concus
F.A. Gruenbaum

Objective:

Construct realistic models that are suitable for comparison with experiments and are capable of being used for engineering purposes.

Information/Status:

The Analytical and Numerical Methods program at LBL encompasses the areas of applied analysis, computational mathematics, and numerical methods for partial differential equations. The main thrust, which covers all the above areas, is the development of numerical techniques for obtaining solutions that are discontinuous or nearly discontinuous for hyperbolic and parabolic partial differential equations. These techniques find application in the development of computational techniques for analyzing turbulent combustion phenomena, such as those that occur in an internal combustion engine, and multiphase porous flow phenomena, such as occur in petroleum or geothermal reservoirs. The techniques are unique in that they use sampling procedures and dictionaries of known phenomena as building blocks in the numerical schemes. Other topics of primary interest include the development of methods for the numerical solution of elliptic partial differential equations and the analysis of particular classes of equations arising in the study of capillary phenomena. Methods are also being developed for the reconstruction of images of objects from projection data of their transverse sections.

FY 1980 funding was \$400,000.

Albright, N., P. Concus, and W. Proskurowski, "Numerical Solution of the Multidimensional Buckley-Leverett Equation by a Sampling Method", Paper SPE 7681 presented at the Society of Petroleum Engineering 5th Symposium on Reservoir Simulation, Denver, CO., Feb 1979. Avila, J.H., and P. Concus, "Update Methods for Highly Structured Systems of Nonlinear Equations", SIAM J. Num. Anal. 16: 260-269 (1979).

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Kinetics and Mechanisms of Chemical Processes
Related to the Development and Use of Energy

Sponsoring Organization: DOE/Office of
Energy Research

Research Area(s):

Chemistry-Other (Unknown)
(Chemical Reactions)

Contract/Grant Number: 20

Type of Research Activities:

Performing Organization:

Theoretical Research

Brookhaven National Laboratory

Type of Research Activities:

Principal Investigators:

J.W. Sutherland

Objective:

Develop basic kinetic and mechanistic information about selected chemical systems which are associated with the development and use of energy sources and for which present data are inadequate or unavailable.

Information/Status:

Short-lived transient chemical species are characterized by flash photolytic and pulse radiolytic techniques, while steady-state photolytic, steady-state radiolytic and standard kinetic methods are used to identify and measure yields of final products of a particular overall reaction. Principal topics being investigated are the photochemistry of selected molecules absorbed on high surface area solids and the chemistry of transient nitrogen compounds. Some aspects of the reactivity of sulfur dioxide are also being studied. Information developed in this program is relevant to investigations into systems being considered for the photochemical conversion and storage of solar energy, into methods for nitrogen fixation, and to problems in sulfur chemistry associated with the development and use of geothermal energy sources and of fossil fuels. The results of this investigation, in addition to their intrinsic value to the general field of chemical kinetics, are available as quantitative input data for models designed to assess the impacts of using various energy sources.

Contract began in 1977.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Superconductivity, Superconducting Devices, and 1/f Noise

Sponsoring Organization: DOE/Office of Energy Research

Research Area(s):

Electrical Studies

Contract/Grant Number: 005930

Type of Research Activities:

Performing Organization:

Hardware/Instrumentation Development

University of California
Lawrence Berkeley Lab.

Principal Investigators:

J. Clarke

Objective:

Information/Status:

Non-equilibrium properties of superconductors are being studied. These include the enhancement of the superconducting energy gap by microwave and phonon irradiation and by tunneling extraction of quasiparticles, the measurement of electron-phonon scattering rates, an investigation of quasiparticle branch imbalance under pulsed conditions, and a study of the relaxation of branch imbalance in the presence of magnetic impurities. Superconducting Quantum Interference Devices (SQUIDs) for measuring tiny voltages and small fluctuations in magnetic fields and magnetic field gradients are being fabricated in highly reliable thin-film configurations. Recent work has demonstrated that the sensitivity and response time of these devices can be substantially improved by reducing the area of the Josephson tunnel junctions, and further techniques for improvements are being investigated. One application of SQUIDs is to the magnetotelluric measurement of the apparent resistivity of the earth's crust. New and improved techniques for acquiring and analyzing magnetotelluric data are being studied, to improve both the speed of surveying and the accuracy of the method. These techniques are being applied to magnetotelluric studies of geothermal sources. The 1/f noise in thin metal films is being studied. Work on the project was initiated in FY 80 with funding of \$255,000.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Evaluation of the Salina Salt Basin

Sponsoring Organization: DOE/Office of
Nuclear Energy

Research Area(s):
Geology-Other (Unknown)

Contract/Grant Number:

Type of Research Activities:

Performing Organization:

Field Research

Stone and Webster

Principal Investigators:

J. H. Peck

Objective:

To evaluate the regional geologic and hydrologic environment of the Salina Salt Basin, New York and Ohio, where extensive bedded salt occurs; to select study areas for detailed characterization; and to inventory the natural resources of the Salina Basin.

Information/Status:

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Operations of Initial Seismic Network for Basalt
Waste Isolation Project

Sponsoring Organization: DOE/Office of
Nuclear Energy

Research Area(s):
Geophysics-Other (Seismic)

Contract/Grant Number:

Type of Research Activities:

Performing Organization:
Rockwell/Hanford
University of Washington

Field Research
Data Analysis/Documentation

Principal Investigators:

Objective:

To continue operation of the eastern Washington seismic network to provide
continuing information on seismic events and travel times.

Information/Status:

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Evaluation of Gulf Coast Salt Domes

Sponsoring Organization: DOE/Office of
Nuclear Energy

Research Area(s):

Structural Geology

Contract/Grant Number:

Type of Research Activities:

Performing Organization:

Data Analysis/Documentation

Texas Bureau of Economic Geology
Louisiana State University
Law Eng. and Testing Company

Principal Investigators:

D.E. Pauls
C.W. Kreitlev
J.D. Martinez

Objective:

To evaluate the regional geologic and hydrologic environment of the Gulf Interior Region where numerous salt domes occur; to select study areas for detailed characterization; and to inventory the natural resources of the basin.

Information/Status:

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Seismic Reflection Applications

Sponsoring Organization: DOE/Office of
Nuclear Energy

Research Area(s):

Geochronology/Stratigraphy
Geophysics-Other (Seismic)

Contract/Grant Number:

Type of Research Activities:

Performing Organization:
Geophysical Services, Inc.

Field Research

Type of Research Activities:

Principal Investigators:

R. Maxwell

Objective:

Information/Status:

This work will investigate the subsurface lithology and structure of the Westwater Canyon Member of the Jurassic Morrison Formation in the San Juan Basin near Crown Point, New Mexico. The project is funded at \$118,000.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Evaluation of West Texas Bedded Salt

Sponsoring Organization: DOE/Office of
Nuclear Energy

Research Area(s):

Geochronology/Stratigraphy
Structural Geology

Contract/Grant Number:

Type of Research Activities:

Performing Organization:

Data Analysis/Documentation

Texas Bureau of Economic Geology

Principal Investigators:

C.R. Hanford

Objective:

To evaluate the regional geologic and hydrologic environments of the Palo Duro and Dalhart Basins of West Texas where extensive bedded salt occurs; to assist in selecting study areas for detailed characterization; and to inventory the natural resources of the basins. The effort was funded at a level of \$2.5M in FY 80.

Information/Status:

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Water Use Information System

Sponsoring Organization: DOE/Office of
Nuclear Energy

Research Area(s):

Hydrology-Other (Unknown)

Contract/Grant Number: 903162

Type of Research Activities:

Performing Organization:

Data Analysis/Documentation

Westinghouse Hanford Co.

Principal Investigators:

J.T. Fletchen

Objective:

Develop a computerized system whereby it is possible to predict where and when deficiencies in power plant cooling water availability may occur.

Information/Status:

The objective is met through the establishment of: a data bank on water availability (ground, surface, estuarine) and its associated characteristics; power plant operating characteristics, with primary emphasis on water withdrawals and consumptive use; and a predictive model for central station power plant growth and associated water usage. To date, the basic data bank is operational and is being used by a number of groups, and the predictive model has been developed. Supporting water requirements studies for geothermal and high temperature reactors were undertaken in 1979 - 1980.

The effort was funded at \$80,000 during FY 81.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Geothermal Studies (Geysers)

Sponsoring Organization: DOE/Office of
Health & Environmental Research

Research Area(s):

Biologic Environmental Studies

Contract/Grant Number: 003232

Type of Research Activities:

Performing Organization:

Data Analysis/Documentation

Lawrence Livermore Laboratory

Principal Investigators:

J. Shinn

Objective:

Conduct research studies to evaluate the environmental impacts of geothermal energy development on geology, hydrology, and ecology at The Geysers - Calistoga Area and the Imperial Valley area of California.

Information/Status:

Key issues include: (1) slope stability, subsidence and seismicity; (2) surface water, groundwater, and geothermal reservoir interrelationships; (3) biogeochemical cycling of geothermal effluents, e.g., boron, ammonia, arsenic, mercury, in the soil, water, sediment, and vegetation, and in terrestrial and aquatic organisms; and (4) effects and toxicities of geothermal effluents on terrestrial and aquatic ecosystems. Extensive baseline and effects information have been established by the Imperial Valley Environmental Program (IVEP). Expertise gained in the IVEP will be applied to new research areas at The Geysers-Calistoga Area. Field projects will be established in the first year.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Nutrient and Radionuclide Cycling

Sponsoring Organization: DOE/Office of
Health and Environmental Research

Research Area(s):

Geochemistry-Other (Unknown)

Contract/Grant Number: 000683

Type of Research Activities:

Performing Organization:

Indeterminable from Description

University of California,
Los Angeles

Principal Investigators:

E.M. Romney

Objective:

Gain a better understanding of the following processes involving environmental pollutants: (1) radionuclide cycling in the desert ecosystem with emphasis on the transuranic elements Pu-239/Pu-240 and Am-241; and (2) stable element cycling in soils and vegetation with emphasis upon trace elements of concern as environmental pollutants when released in the burning of fossil fuels and in the development and application of geothermal energy resources as a source of power generation.

Information/Status:

Several interacting studies form the basis of this research program. Work is proceeding along the following lines in response to mission needs of DOE: (a) define the manner in which plants function in the vegetation-carrier transport of plutonium and other transuranic elements through the food chain from contaminated soil; (b) characterize the patterning, association, and distribution of desert vegetation as influenced by nutrient gradients and other edaphic factors; (c) investigate the cycling of non-nuclear trace element pollutants in soils and vegetation; and (d) establish baseline assessments of such elements in natural ecosystems near geothermal resource areas (KGRA's) in the Imperial Valley, CA. Plant concentrations indicate that Am is more mobile than Pu in this desert environment.

Contract started in July 1975. FY 1980 funding was \$90,000.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Ecological Investigation of Dry Geothermal Energy Demonstration

Sponsoring Organization: DOE/Office of Health and Environmental Research

Research Area(s):

Biologic Environmental Studies

Contract/Grant Number: W-7405-ENG-36

Type of Research Activities:

Performing Organization:

Field Research

Los Alamos Scientific Laboratory

Principal Investigators:

K.H. Rea

Objective:

(1) Develop an environmental resource data base at the site, (2) determine differences in composition and quantity of ecosystem components near the facility and at adjacent control sites, and (3) identify in effluent waste water solid chemical constituents and other materials that might degrade the water quality of the area.

Information/Status:

Permanent sampling stations will be set up to follow both the biotic and abiotic components of the ecosystem through time. Eventually it should be possible to compare the environmental consequences of hot dry rock utilization to other forms of geothermal energy (i.e., hydrothermal and geopressured).

Contract began in January 1976.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Imperial Valley Environmental Project Geothermal -
Water Quality

Sponsoring Organization: DOE/Office of
Health and Environmental Research

Research Area(s):

Biologic Environmental Studies

Contract/Grant Number: RPIS-1944; W-7405-
ENG-48

Type of Research Activities:

Performing Organization:

Laboratory Research-Analytical

Lawrence Livermore Laboratory

Principal Investigators:

K.D. Pimentel

Objective:

Accumulate baseline data on water quality in Imperial Valley, California; detect and evaluate any impacts of geothermal development on water quality; participate in evaluation of alternate heat sinks for geothermal power; participate in regional water resource analysis; and explore ways that geothermal resources could be used to improve water quality in Imperial Valley.

Information/Status:

These objectives will be accomplished by accumulating water quality data already available from many federal, California, and local agencies, collecting additional data specific to our needs, and integrating these data into an overall assessment. Water quality sampling networks were established to monitor baseline chemistry in surface waters and groundwaters.

Contract began October 1976.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: National Geothermal Information Resource

Sponsoring Organization: DOE/Office of
Health and Environmental Research

Research Area(s):

Biologic Environmental Studies

Contract/Grant Number: 002159; W-7405-
ENG-48

Type of Research Activities:

Performing Organization:

Data Analysis/Documentation

Lawrence Berkeley Laboratory

Principal Investigators:

S.L. Phillips

Objective:

Collect and disseminate information relevant to environmental aspects of geothermal energy.

Information/Status:

The main issues are: hydrogen sulfide; subsidence; induced seismicity; monitoring; toxic trace metals; and noise. Information is collected from various sources (e.g., published literature), organized into appropriate categories, stored on computer tapes, evaluated, and disseminated (e.g., Federal, State, local government agencies, the private sector) on a worldwide basis.

Contract started July 1975.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Atmospheric Boundary Layer Studies

Sponsoring Organization: DOE/Office of
Health and Environmental Research

Research Area(s):

Biologic Environmental Studies

Contract/Grant Number: 004548

Type of Research Activities:

Performing Organization:

Modeling/Simulation

Battelle Pacific Northwest Laboratory

Principal Investigators:

T.W. Horst

Objective:

Provide improved environmental assessment tools for atmospheric transport, dispersion, and deposition.

Information/Status:

The research emphasis for the near future will be pollutant transport and dispersion in complex terrain (mountains, valleys, canyons, etc.). Simple models will be sought for the prediction of the depths, speed and direction of gravity-controlled drainage flows and for the prediction of pollutant dispersion within these flows. Models will be based on and verified by an extensive multi-lab observational program initially located in The Geysers Geothermal Area of California. The resultant atmospheric transport model will be applicable to the siting of energy-generating facilities in complex terrain. The capability for reliable impact analysis in complex terrain is particularly required for the development of geothermal, coal, and oil shale resources.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Radiation Instrumentation

Sponsoring Organization: DOE/Office of
Health and Environmental Research

Research Area(s):

Brine/Gas Chemistry

Contract/Grant Number: 902868

Type of Research Activities:

Performing Organization:

Battelle Pacific Northwest Lab.

Hardware/Instrumentation Develop-
ment

Principal Investigators:

N. Wagman

Objective:

Information/Status:

This program is primarily concerned with the development of radiochemical instrumentation and analytical technology for the measurement of low levels of radionuclides which enter the environment from the nuclear industry and from nuclear testing operations. It is also concerned with the development and refinement of neutron activation analysis technology for the analysis of trace elements released to the environment from fossil fuel combustion, coal conversion, oil shale retorting, and geothermal power generation. Coupled with neutron activation analysis, techniques are developed to define the pathways of natural or waste radioisotopes and toxic, stable elements in the environment. The program was funded during FY 81 at \$103,000.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Solar, Geothermal, and Energy Conservation

Sponsoring Organization: DOE/Office of
Health and Environmental Research

Research Area(s):

Other/Unknown

Contract/Grant Number: W-7405-ENG-82

Type of Research Activities:**Performing Organization:**

Data Analysis/Documentation

Iowa State University

Principal Investigators:N/A

Objective:

Identify water-related problems and water-related environmental control options.

Information/Status:

This work package covers three closely related subtasks as follows. Subtask A involves assessment of the water-related environmental control technology requirements associated with the conversion of urban solid waste to energy. Subtask A was completed in FY 1980. Subtask B involves assessment of waterrelated environmental control technology associated with biomass-to-energy conversion processes using solar derived fuels as input. Subtask C involves assessment of water-related environmental control technology associated with production of alcohol fuels from solar derived material (biomass). Emphasis will be placed on evaluating plants designed specifically for production of alcohol for use as a fuel or fuel additive. The task work involves quantification of water use and wastewater production, analysis of the treatability of wastewaters produced at operating energy production or conversion facilities, and assessment of the availability and practicality of conventional and advanced treatment processes to produce an effluent meeting existing and proposed future state, local and federal discharge standards. Solid residues produced during processing or sludges produced during wastewater treatment are analyzed to determine potential water related environmental impacts caused by leaching or undesirable components.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Environmental Assessment - HDR Geothermal Systems

Sponsoring Organization: DOE/Office of
Health and Environmental Research

Research Area(s):

Biologic Environmental Studies

Contract/Grant Number: 006043

Type of Research Activities:

Performing Organization:

Data Analysis/Documentation

University of California

Principal Investigators:

F.R. Miera

Objective:

Information/Status:

Programmatic efforts are focussed on evaluating impacts to water quality, air quality, ecology and resources. Studies to date have emphasized establishing biotic and abiotic baseline inventories and measurements, characterization of source terms and identifying pathways by which residuals and emissions may potentially reach the environment. Where applicable, tests are conducted under controlled environmental conditions using proven methodologies and validated through field test comparisons. These efforts will provide a longterm predictive capability for monitoring impacts from HDR technology development and an evaluation of appropriateness of methodologies currently used for gathering baseline data and their application in geothermal environmental assessment.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Geothermal Environmental Research

Sponsoring Organization: DOE/Office of
Health and Environmental Research

Research Area(s):

Biologic Environmental Studies

Contract/Grant Number: 902894

Type of Research Activities:

Performing Organization:
Los Alamos National Lab.

Indeterminable From Description

Principal Investigators:

E. Wewerka

Objective:

Examine the environmental concerns associated with geothermal energy development.

Information/Status:

The work examines a number of environmental concerns in the areas of air quality, water quality, subsidence, and induced seismicity. The research addresses these areas in a generic manner by using the hydrothermal demonstration plant at Baca, New Mexico as a suitable site. Work was initiated in 1981 with funding of \$150,000.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Engineering Foundations Conference on Geotechnical and Environmental Aspects of Geopressure Energy, Sea Island, Georgia, Jan. 13-18, 1980.

Sponsoring Organization: National Science Foundation, Directorate for Engineering and Applied Science

Research Area(s):

Geology
Hydrology
Geochemistry

Contract/Grant Number: CME79-21127

Type of Research Activities:

Performing Organization:

Data Analysis/Documentation

United Engineering Trustees, Inc.

Principal Investigators:

S.K. Saxena

Objective:

Assess the status and needs of geopressure energy activities and provide direction to fulfill those needs.

Information/Status:

This conference brought together geotechnical and other engineers and scientists from universities, industry and government, including some foreign participants.

Specifically, the first task was to review the current state of the art and then to identify which procedures work best and what are the shortcomings of each. The second task was to identify the cross-technology transfer from geothermal to geopressure and from shallow to deep reservoirs. The final task was to assess the future impact of research in progress and to identify areas where further research and development is needed.

The topics covered research in the disciplines of geomechanics, geology, geohydrology and geochemistry and the conclusions and recommendations are published in a formal proceedings.

Contract from Dec. 1979 to May 1981. FY 1980 funding was \$6,000.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Structure and Metamorphism of the Merrimack Synclinorium - Geochemistry of the Ossipee Mountains

Sponsoring Organization: National Science Foundation, Directorate for Astronomical Atmospheric Earth & Ocean Sciences

Research Area(s):
Geochronology/Stratigraphy
Structural Geology

Contract/Grant Number: EART77-20085

Performing Organization:
Dartmouth College

Type of Research Activities:
Field Research

Principal Investigators:

J.B. Lyons

Objective:

Studies will be continued on the stratigraphic, structural, igneous, and metamorphic geology of the Merrimack synclinorium in central New Hampshire.

Information/Status:

Lower and middle Paleozoic rocks that originated as a sedimentary clastic wedge have been involved in three episodes of intense deformation and injected by sheet-like plutons ranging in age from about 400 million to 350 million years. Further work will include completion of detailed mapping, gravity measurement, and petrologic and mineralogical studies. Microprobe analyses will be aimed at refining the metamorphic zonation and locating heat sources responsible for regional metamorphism. The project will furnish information needed for interpreting the history of the Appalachian origin in terms of plate-tectonic models as well as contributing to the understanding of thermal controls in regional metamorphism. The study will also include work on the chemistry and mineralogy of the Ossipee Mountains intrusive, one of the plutonic bodies in the White Mountain magma series.

Contract from March 1978 to Aug. 1980.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Shock Wave Measurements on Lower Mantle Minerals

Sponsoring Organization: National Science Foundation/Directorate for Astronomical Atmospheric Earth & Ocean Sciences

Research Area(s):
Physical Properties Rocks/Liquids

Contract/Grant Number: EAR79-06766

Type of Research Activities:

Performing Organization:
California Institute of Technology

Laboratory Research-Experimental

Principal Investigators:

T.J. Ahrens
M.R. Somerville

Objective:

This project will continue shock wave measurements of the equation of state of mantle minerals, including single-crystal for stericite, single-crystal bronzite, nearly single-crystal olivine, and porous MgO in the pressure regime of the lower mantle of the earth.

Information/Status:

The question to be addressed is whether the high pressure phases of the lower mantle can have the same composition as the upper mantle (a necessary condition for mantle-wide convection) by comparing equation-of-state models with seismic data. Data will also be obtained on the behavior of the Gruneisen parameter of the lower mantle. The latter constrains the geothermal gradient (as well as the melting point) which in turn strongly affects the viscosity gradient and hence the conditions required for the onset of Rayleigh-Benard flow.

Contract from July 1979 to Dec. 1980. FY 1979 funding was \$76,700.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Training and Research in Tectonophysics

Sponsoring Organization: National Science Foundation, Directorate for Science Education

Research Area(s):
Structural Geology

Contract/Grant Number: SER76-18206

Type of Research Activities:

Performing Organization:
Brown University

Data Analysis/Documentation

Principal Investigators:

T.E. Tullis

Objective:

Develop a strong, coherent tectonophysics program for training and research at the university, to include colloquia and a symposium.

Information/Status:

The purpose of the project is to strengthen an emerging interdisciplinary program in tectonophysics at Brown University. Tectonophysics deals with the physics of deformation in the earth. There are many practical applications of tectonophysics, including the understanding and prediction of earthquakes, aiding in the recovery of geothermal energy and non-renewable resources, and ground subsidence and liquefaction resulting from earthquakes.

The program recognizes an existing interest in tectonophysics by students and faculty in the Geological Sciences Department and the Engineering Division. The principal goal of this project is to solidify these growing interests into a strong, coherent program for the training and research of young scientists. This will be done by providing the equipment needed for interdisciplinary activities, by bringing in scientists to provide meetings and laboratories, and by conducting biweekly colloquia in tectonophysics and a symposium during the final year of the project.

Contract from July 1976 to Nov. 1980.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Geothermal Impact - A Systems Approach to Monitoring Environmental Impacts From Development, Conversion, and Waste Disposal

Sponsoring Organization: EPA

Research Area(s):

Biologic Environmental Studies

Contract/Grant Number: R806457; JC27-60

Type of Research Activities:

Performing Organization:

Modeling/Simulation

University of Nevada

Principal Investigators:

J. Hess

Objective:

Develop and validate a systematized methodology for monitoring the long term environmental implications of geothermal resource development, conversion and waste disposal.

Information/Status:

The resultant methodology will be useful for developing site-specific water, air soil and biologic monitoring plans. The system will be developed using the Roosevelt Hot Springs, Utah KGRA as data source. Elements of system development include: 1) Fault tree analysis of geothermal failure modes; 2) Assessment and testing of physical, chemical, air quality, and biological models; 3) Development and testing of computer-based monitoring plan design system; and 4) Design of site-specific monitoring plan for Roosevelt KGRA.

Contract from April 1979 to Oct. 1983. FY 1980 funding was \$80,000.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Monitoring Changes in Groundwater Quality as a Result of Geothermal Development, Conversion and Waste Disposal

Sponsoring Organization: EPA/ORD

Research Area(s):

Hydrology-Other

Contract/Grant Number: 68-03-2755; JC2J-01

Type of Research Activities:

Performing Organization:

Data Analysis/Documentation

Harding Lawson Associates

Principal Investigators:

F.C. Kresse

R.B. Weiss

Objective:

Develop guideline for monitoring changes in groundwater quality due to the escape of geothermal fluids as a result of extraction, conversion and waste disposal processes in the development of geothermal energy.

Information/Status:

Data on 11 selected western U.S. KGRA's were compiled. A compilation of environmental and regulatory restraints related to geothermal energy development was made. Pollution control technology was surveyed. A general groundwater monitoring methodology that can be applied to any geothermal development was prepared.

Final Output: The following reports were published: 1) a Decision Maker's Handbook, geared toward laypersons in planning agencies; 2) a KGRA Survey report, 3) a Waste Control Technology report, 4) a Groundwater Monitoring Methodology report.

Contract from May 1978 to Oct. 1979.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Hydrologic Interpretation of Shallow Subsurface Temperature Data

Sponsoring Organization: DOI/Office of Water Research and Technology

Research Area(s):

Heat Flow Studies
Hydrology (General)
Other (Ordinance)

Contract/Grant Number: A-094-NEV

Type of Research Activities:

Performing Organization:

Field Research

University of Nevada

Principal Investigators:

M.E. Campana
R.L. Jacobson

Objective:

Utilize shallow temperature data to determine the following for a portion of Dixie Valley, Nevada: 1) Spatial and temporal distribution of recharge; 2) Relationship between thermal and non-thermal springs; 3) Nature of the geologic controls on the shallow groundwater flow system.

Information/Status:

Resolution and synthesis of the results of the thermal anomaly study with those of other studies (e.g., hydrogeochemical, isotopic, hydrologic and geologic). The results of this study will be useful for both purely hydrologic and hydrologic-geothermal investigations. In the strict hydrologic sense, the results can be used to locate areas where recharge is occurring, the relative magnitudes of recharge events in a given study area, the geologic controls on shallow groundwater flow systems, and groundwater flow directions. Where hydrologic-geothermal information is important, information can be obtained on the relationships between thermal and non-thermal waters in a given area. Since shallow temperature surveys are starting to gain acceptance as a reconnaissance tool in geothermal exploration, it will be possible to use the temperature data to obtain important hydrologic data with little extra cost and effort.

Contract from Oct. 1979 to Sept. 1980. FY 1980 funding was \$13,060.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Thermal Springs List for the United States

Sponsoring Organization: DOC/National
Oceanic and Atmospheric Administration

Research Area(s):

Hydrology-Other (Unknown)

Contract/Grant Number:

Type of Research Activities:

Performing Organization:

Data Analysis/Documentation

DOC/National Oceanic and Atmospheric
Administration, National Geophysical
and Solar-Terrestrial Data Center

Principal Investigators:

George W. Berny
Paul J. Grim
Joy A. Ikelman

Objective:

Identify and document location and temperature of natural surface
hydrothermal features in the U.S.

Information/Status:

A list of 1,702 surface hydrothermal features has been published (see
below), including maps. This publication is one in a series of NOAA Key to
Geophysical Records Documentation publications and is available free of
charge.

Thermal Springs List for the United States, G.W. Berry, et. al.,
NOAA/NGSDC, Key to Geophysical Records Documentation No. 12, June 1980.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Geopressured-Geothermal Investigations
in Texas

Sponsoring Organization: Central Power
and Light Co.

Research Area(s):

Resource Evaluation/Identification

Contract/Grant Number:

Type of Research Activities:

Performing Organization:

Data Analysis/Documentation

University of Texas

Principal Investigators:

M.H. Dorfman

S. Caudle

B. Hainey

J. Swanson

Objective:

This research is a continuing comprehensive program on geopressured-geothermal resources in Texas. Topics include resource assessment, petroleum engineering research, legal, institutional and environmental studies, and resource utilization.

Information/Status:

Project begun in 1979.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Geothermal Plant Operation and Reservoir Interface Data Base

Sponsoring Organization: EPRI

Research Area(s):

Other/Unknown

Contract/Grant Number: RP1195

Type of Research Activities:

Performing Organization: Stanford Univ.;
Systems Science & Software; PFR
Engineering Systems Inc.

Data Analysis/Documentation

Principal Investigators:

Objective:

Establish a data base useful for predicting geothermal power plant design, operation, and interaction characteristics.

Information/Status:

Data will be gathered from:

- 1) Cerro Prieto
 - 2) Magma Power's binary cycle plant
 - 3) Experimental data on mineral and construction material solution in geothermal brines and their chemical kinetics
 - 4) Plant performance effects of acidization of geothermal brines.
-

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Geothermal Reservoir Assessment Techniques

Sponsoring Organization: EPRI

Research Area(s):

Resource Evaluation/Identification

Contract/Grant Number: RP929

Type of Research Activities:

Performing Organization:

Data Analysis/Documentation

Stanford University

Principal Investigators:

Objective:

Collect information on the generally accepted techniques for assessing geothermal reservoirs and compile these into a single reference document for use by utilities.

Information/Status:

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Solid Earth Geosciences

Sponsoring Organization: DOE/Office of
Basic Energy Sciences

Research Area(s):

Other/Unknown

Contract/Grant Number:W-7405-ENG-36

Type of Research Activities:**Performing Organization:**

Los Alamos Scientific Laboratory

Indeterminable From Project Description

Principal Investigators:R.R. Brownlee

Objective:

The geoscience program at LASL was conceived to promote basic applied science to support the experimental Hot Dry Rock (HDR) geothermal energy (GTE) project, although interests have expanded into nuclear and fossil fuels, waste management and weapons-related areas.

Information/Status:

Multidisciplinary activities encompass geology, geochemistry and geophysics. Specific research areas include: seismology; rock physics; experimental, theoretical and analytical geochemistry; thermodynamics; petrology; structural geology; sedimentology; field geology; and numerical modeling. Major experimental and analytical instruments used in the LASL geoscience research program include neutron activation, x-ray fluorescence, atomic absorption, x-ray diffraction, scanning electron microscopes, electron probe microanalyzer, and high pressure (P) -temperature (T) rock deformation equipment (including gas-, liquid-, and solid-pressure media apparatus). The LASL computer facility with an extensive library of hydrodynamic, geochemical and materials codes is also used. The LASL scientists in other research fields who have extensive experience in materials science which is applicable to geologic problems are available for consultation. Facilities, expertise and geographical location enable LASL geoscientists to respond well to DOE missions.

Contract began 1978.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Rock Deformation and Failure

Sponsoring Organization: DOE/Defense
Programs

Research Area(s):

Physical Properties Rocks/Liquids

Contract/Grant Number:

Type of Research Activities:

Performing Organization:

Laboratory Research-Experimental

Sandia National Lab.

Principal Investigators:

B.M. Butcher

Objective:

Information/Status:

Experimental studies are supporting model development for computer codes describing the static and dynamic deformation and failure of competent rock, deformation of joint systems and rock fragmentation.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Geothermal Resource Areas Database

Sponsoring Organization: DOE/Division
of Geothermal Energy

Research Area(s):

Other/Unknown

Contract/Grant Number: W-7405-ENG-48

Type of Research Activities:

Performing Organization:

Data Analysis/Documentation

Lawrence Berkeley Laboratory

Principal Investigators:

J. Dennis Lawrence
Susan R. Lepman
Keith Leung
Sidney L. Phillips

Objective:

Provide broad range of U.S. geothermal energy development information on a public-access search-and-retrieve computerized database system, to include database design, computerization, data collection and screening, and system maintenance and up-dating.

Information/Status:

The GRAD system is currently on-line and covers subjects such as leasing, well data, power plant operations, direct-use facilities, environmental issues, and regulatory aspects of development.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Cooperative Agreement Between U.S. ERDA (now DOE) and the Ente Nazionale per l'Energia Elettrica (ENEL), Italy

Sponsoring Organization: DOE/Division of Geothermal Energy

Research Area(s):

Resource Evaluation/Identification
Well Stimulation/Reservoir Engineering

Contract/Grant Number: W-7405-ENG-48

Type of Research Activities:

Performing Organization:

Data Analysis/Documentation

Hosted by Lawrence Berkeley Laboratory

Principal Investigators:

N/A

Objective:

Sponsor joint research activities, to be performed on an equivalent-effort basis, in various areas of geothermal energy to better understand geothermal resources and to develop advanced engineering methods for improving geothermal energy recovery.

Information/Status:

As laid out in the original agreement, research was performed in five broad projects:

Project 1 - Stimulation of hot dry rocks and hydrothermal reservoirs

Project 2 - Utilization of hot brine resources

Project 3 - Reservoir physics, engineering, and resource assessment

Project 4 - Deep drilling

Project 5 - Environmental control technologies

The results of these projects have been presented and discussed at two international conferences (1977 in Larderello, Italy and 1980 in Berkeley, California). The first conference was exclusively devoted to Project 3, which was the area in which cooperation was first initiated. Project 3 continued to occupy "center stage" in subsequent years, with most of the joint research activities focussed on geothermal reservoir engineering.

Proceedings of Second DOE-ENEL Workshop for Cooperative Research in Geothermal Energy, Oct. 20-22, 1980, Berkeley, California, LBL-11555, CONF-801098.

Proceedings of the Larderello Workshop on Geothermal Resource Assessment and Engineering, Sept. 12-16, 1977, Larderello, Italy.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Geothermal Exploration Technology

Sponsoring Organization: DOE/Division of
Geothermal Energy

Research Area(s):

Resource Evaluation/Identification

Contract/Grant Number: 005617

Type of Research Activities:

Performing Organization:

Hardware/Instrumentation Develop-
ment/Testing

Lawrence Berkeley Lab.

Data Analysis/Documentation

Type of Research Activities:

Principal Investigators:

N.E. Goldstein

Objective:

The objectives for FY 1982 are: (1) to extend the state-of-the-art in geothermal exploration and delineation of hydrothermal reservoirs by means of continued development of new and/or improved instruments, field survey techniques and methodologies, data processing and interpretation techniques, and exploration strategies; and (2) to test and demonstrate new technology by means of field surveys at geothermal areas and to distribute the technology by means of well-documented case studies, conferences and demonstrations for industry, and joint LBL-industry programs.

Information/Status:

The program was initiated in October 1977 and is on-going. Funding for FY 80 was \$600,000.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Borehole Measurements of In-Situ Velocity and Attenuation as Related to Rock Fracture Characteristics

Sponsoring Organization: DOE/Idaho Operations

Research Area(s):

Well logging

Contract/Grant Number: FC07-79ID12068

Type of Research Activities:

Performing Organization:
University of Southern California

Field Research
Data Analysis/Documentation

Principal Investigators:

T.L. Menyey

Objective:

Review and quantitatively assess an active seismic technique using a borehole seismic sensor to map fracture density, fracture orientation and other fracture parameters in the immediate vicinity of wells drilled into convective hydrothermal systems.

Information/Status:

Seismic compressional velocities and attenuation will be measured using a field procedure consisting of an azimuthally and radially distributed array of seismic surface sources and a moveable (uphole-downhole) borehole sensor. Velocity and attenuation data will be inverted based on the elastic and visco-elastic theories of cracked solids, to obtain a three-dimensional picture of fracture characteristics (density, aspect ratios, orientation, etc.). The viability of the scheme will be tested initially in a low-temperature 3000-foot borehole maintained as a geophysical observatory by the USC earthquake prediction program and later in a 6000-foot geothermal well in the Raft River field, Idaho. Hardware will be designed, assembled, and field-operated by USC personnel.

Contract from Sept. 1979 to Sept. 1980.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Assessment of the Geothermal/Geopressure Potential
of the Gulf Coastal Plains of Alabama

Sponsoring Organization: DOE/ORNL

Research Area(s):

Heat Flow Studies

Contract/Grant Number: AS05-79ET27015

Type of Research Activities:

Performing Organization:

Data Analysis/Documentation

University of Alabama

Principal Investigators:

G.V. Wilson

Objective:

The project objective is to provide a comprehensive data base for thermal and geopressure variations and anomalies in the subsurface of south Alabama and to correlate these features with geologic and geophysical data.

Information/Status:

Down-hole temperatures and pressure information provided by logs of oil and gas test wells were compiled and interpreted. Geophysical, geologic structure, and petrographic studies were made and correlated with geothermal and geopressure data. Specific areas and depths that have some potential for future development of low to moderate geothermal resources were defined.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Geothermal Reservoir Assessment Case Study

Sponsoring Organization: DOE/Nevada
Operations Office

Research Area(s):

Resource Evaluation/
Identification

Contract/Grant Number: 000101

Type of Research Activities:

Performing Organization:

Data Analysis/Documentation

Southland Royalty Co.

Principal Investigators:

J.M. Denton

Objective:

Information/Status:

The project involved geothermal exploration in Dixie Valley, NV, under DOE's Industry Coupled Geothermal Case Study for the northern basin and range area adjacent to the Battle Mountain heat flow high. Two deep wells were drilled, two shallow holes were drilled, and a seismic survey was run. The Mackay Minerals Research Institute did geochemical studies and structural interpretation. The Desert Research Institute did hydrology studies. The product will be a final report describing the project and providing data. Since the last annual report, two 1500 feet holes have been drilled and 18 miles of seismic have been done in the area. The Mackay Minerals Research Institute has done soil geochemistry in the area. The effort was funded at \$177,000 during FY 81.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Geothermal Resource Assessment, Low and Moderate Temperature Resources in California

Sponsoring Organization: DOE/SANOPS

Research Area(s):

Resource Evaluation/
Identification

Contract/Grant Number: 000106

Type of Research Activities:

Performing Organization:

Data Analysis/Documentation

California Division of Mines & Geology

Principal Investigators:

C.F. Bacon
R.C. Martin

Objective:

Information/Status:

For CDMG's geothermal studies the efforts for 1979-80 have been twofold: (1) Phase I studies including updating and USGS GEOTHERM file and compilation and submittal of data for the low and moderate temperature geothermal resources map of California; and (2) a concentrated Phase II study of the low and moderate temperature resources of the Calistoga area in Napa County, CA. The Calistoga study includes studies of the history of the resource, the geology of the area, geophysical studies, geochemical sampling and temperature testing for 206 wells in the area, and a map showing the seismicity of the region. Still to be completed are the drilling, sampling, and testing of up to six geothermal test holes ranging in depth from 400 to 990 feet. The final products are/will be an updated USGS GEOTHERM file, a statewide geothermal map, and a report and resource assessment for the Calistoga area.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Low to Moderate Temperature Geothermal Resource
Assessment for Nevada: Site Specific Studies

Sponsoring Organization: DOE/Nevada
Operations Office

Research Area(s):

Resource Evaluation/
Identification

Contract/Grant Number: 001167

Type of Research Activities:

Performing Organization:

Data Analysis/Documentation
Field Research

University of Nevada

Principal Investigators:

D.T. Trexler

Objective:

The project objectives are to: (1) conduct geothermal investigations at three Nevada locations (Carson-Eagle Valleys, Big Smoky Valley, Caliente) to determine if resource temperature may be applied for space conditioning purposes; (2) provide regional information to DOE about the nature and extent of geothermal resources; and (3) provide critical evaluation of assessment techniques.

Information/Status:

The approaches are geologic reconnaissance, gravity surveys, aerial photography, fluid sampling and analysis, shallow-depth temperature probe surveys, soil mercury surveys, shallow electrical resistivity measurements, and temperature gradient-hole drilling over a 12-month period for the first phase of project. The expected results are scientific studies delineating resource and reservoir characteristics in Nevada (i.e., chemistry, temperature, areal extent, etc.) and defining geologic parameters which appear to control resource - in order to provide a public service and stimulate geothermal use by public and private sectors. Work on the project was initiated in May of 1979 and completed in June of 1981.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Evaluation of Surface Microlayer Geochemistry for
Geothermal Exploration at Roosevelt Hot Springs

Sponsoring Organization: DOE

Research Area(s):

Geochemistry-Other/Unknown
Mineralogy/Alterations

Contract/Grant Number: FC07-79ID12062

Type of Research Activities:

Performing Organization:

Modeling/Simulation
Data Analysis/Documentation

Barringer Research, Inc.

Principal Investigators:

W.T. Meyer

Objective:

Establish detailed geochemical models for the hydrological and geothermal regimes in the Roosevelt Hot Springs area based on existing data and use these models as a basis for testing the practical application of soil microlayer geochemistry as a low-cost exploration method for detecting geothermal reservoirs.

Information/Status:

Soil microlayer samples will be collected over a 6 square-mile area. These samples will be analyzed by multi-element plasma emission and other chemical methods. Computer contour maps will be prepared for all elements.

Contract from October 1979 to June 1980.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Geothermal Assessment and Reservoir Definition
in Alaska

Sponsoring Organization: DOE

Research Area(s):

Resource Evaluation/
Identification

Contract/Grant Number: FC07-79ET27105

Type of Research Activities:

Performing Organization:

Data Analysis/Documentation

Alaska State Division of Geological and
Geophysical Surveys

Principal Investigators:

R.G. Schaff

Objective:

Assess geothermal resources in Alaska.

Information/Status:

The project activities include: (1) water quality analyses, (2) definition of geologic environments, (3) collection and interpretation of geophysical data, (4) thermal history of host rocks, (5) water flow rate measurements, and (6) publication of data and conclusions. Because of the general lack of detailed information about Alaska's geothermal energy, the programs have a strong field orientation. Equally important, however, are the laboratory analyses of rock and water samples as well as interpretation of geophysical information. To accomplish these tasks the expertise, field programs, and laboratory capabilities of the respective parties will be coordinated to maximize the impact on the geothermal energy program.

Contract from June 1979 to May 1980.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: Subsidence and Related Aspects of Geothermal Systems

Sponsoring Organization: USGS

Research Area(s):

Geology - Other/Unknown

Contract/Grant Number: NA

Type of Research Activities:

Performing Organization:

Data Analysis/Documentation

USGS

Principal Investigators:

Francis S. Riley

Objective:

To monitor vertical and horizontal displacements of the land surface, changes in subsurface pressure gradients, and changes in subsurface temperature and to attempt to explain if these are natural or induced by the extraction or injection of geothermal fluids. To analyze and interpret pertinent geodetic, geophysical and geologic data as a background for this investigation and to obtain the stress-strain parameters, and from these to appraise the behavior of geothermal reservoirs and accompanying groundwater systems.

Information/Status:

Measurements of horizontal and vertical control nets are continuing and/or are planned for geothermal areas in Imperial Valley, California; Raft River, Idaho; Roosevelt Hot Springs, Utah, and The Geysers, California. A reconnaissance of Dixie Valley, Nevada, was conducted, and a horizontal control net will be established there.

Geosciences R&D For Geothermal Energy Technology

Program/Project Title: General Geosciences

Sponsoring Organization: DOE

Research Area(s):

Mass Heat Transport
Mineralogy/Alterations

Contract/Grant Number: W-7405-ENG 48

Type of Research Activities:

Performing Organization:

Modeling/Simulation
Data Analysis/Documentation
Laboratory Research-
Experimental

Lawrence Livermore National Laboratory

Principal Investigators:

A.G. Duba

D.G. Miller

J.A. Rand

H.C. Heard

Objective:

Develop computer models that will aid in predicting and understanding the physical and chemical properties and responses of earth materials.

Information/Status:

- 1) Obtain experimental thermodynamic and transport data of geochemical systems especially those related to radioactive waste isolation problems.
- 2) Conduct laboratory studies of thermal and thermochemical properties of potential repository rock types and model the movement of a rock melt that is produced in the crust toward the surface.
- 3) Provide an enhanced diagnostic capability for characterizing the subsurface environment.
- 4) Measure the thermoelectric effect in mantle minerals olivine and pyroxene as a function of temperature, orientation, oxygen fugacity, and iron content.
- 5) Examine oxygen diffusion in grain boundary regions of forsterite Mg_2SiO_4 , between 1100 and 1370°C under atmospheric pressure.

TABLE 1-1
PROJECTS OF SPONSORING ORGANIZATIONS

<u>Sponsoring Organization</u>	<u>Total Number of Projects</u>	<u>Project Reference Number</u>
<u>DEPARTMENT OF ENERGY</u>		
• Regional Operations Office	14	264, 266, 267, 268, 269, 270, 271, 272, 273, 330, 331, 332, 333, 334
• Office of Defense Programs	2	259, 326
• Office of Basic Energy Sciences	17	275, 276, 277, 278, 279, 280, 281, 282, 283, 284, 285, 276, 287, 288, 289, 290, 325
• Division of Geothermal Energy/Geothermal and Hydropower Technology Division	55	158 through 213; 327, 328, 329
• Office of Energy Research	22	108, 109, 110, 111, 112, 113, 114, 115, 116, 117, 118, 119, 120, 122, 123, 124, 125, 126, 127, 295, 296, 297
• Office of Health and Environment	11	237, 304, 305, 306, 307, 308, 309, 310, 311, 312, 313
• Office of Nuclear Energy	11	219, 220, 221, 222, 223, 298, 299, 300, 301, 302, 303
• General	27	166, 186, 189, 190, 224, 225, 226, 227, 228, 229, 230, 231, 232, 233, 234, 235, 236, 249, 260, 261, 262, 263, 265, 274, 335, 336, 338

TABLE 1-1 (CONCLUDED)

DEPARTMENT OF INTERIOR

• Bureau of Mines	5	121, 214, 216, 217, 218
• Office of Water Research Technology	2	215, 320
• U.S.G.S.	111	1 through 106; 291, 292, 293, 294, 337

NATIONAL SCIENCE FOUNDATION

34	128 through 157; 314, 315, 316, 317
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DEPARTMENT OF DEFENSE

1	107
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DEPARTMENT OF COMMERCE

• NOAA	3	241, 243, 321
• NBS	1	242

ENVIRONMENTAL PROTECTION
AGENCY

5	238, 239, 240, 318, 319
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DEPARTMENT OF AGRICULTUREPRIVATE INDUSTRY

6	244, 245, 246, 322, 323, 324
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GENERAL (State Government,
Universities, Unidentified)

11	247, 248, 250, 251, 252, 253, 254, 255, 256, 257, 258
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TABLE 1-2
PROJECTS BY RESEARCH AREA

	<u>Research Area</u>	<u>Project Reference Numbers</u>
<u>GEOLOGY</u>	● Volcanology	1, 2, 3, 5, 6, 7, 11, 12, 14, 19, 20, 21, 22, 23, 27, 66, 75, 77, 79, 80, 111, 115, 132, 153, 234, 289
	● Geochronology/ Stratigraphy	2, 6, 7, 8, 9, 10, 14, 16, 31, 44, 46, 59, 75, 99, 145, 170, 266, 270, 301, 302, 315
	● Structural Geology	3, 10, 12, 15, 37, 38, 49, 66, 73, 74, 75, 92, 110, 126, 143, 147, 170, 179, 180, 213, 226, 231, 237, 260, 263, 264, 272, 300, 302, 315, 317
	● Petrology	3, 4, 5, 10, 22, 25, 38, 47, 80, 132, 144, 255, 276
	● Other/Unknown	247, 298, 314, 337
<u>GEOCHEMISTRY</u>	● Isotope Geochemistry	4, 10, 28, 29, 33, 40, 41, 43, 47, 148, 284, 285
	● Mineralogy/ Alterations	5, 7, 12, 14, 25, 45, 128, 131, 132, 148, 152, 228, 335, 338
	● Brine/Gas Chemistry	24, 27, 29, 30, 31, 33, 34, 36, 39, 42, 43, 44, 47, 48, 77, 78, 91, 93, 120, 121, 123, 125, 153, 155, 163, 172, 174, 175, 176, 179, 181, 183, 185, 189, 190, 191, 193, 194, 198, 200, 207, 211, 215, 216, 217, 218, 227, 228, 233, 238, 239, 242, 243, 245, 248, 256, 269, 278, 283, 287, 288, 310
	● Fluid Inclusions	44, 130, 221
	● Mass Heat Transport	18, 50, 52, 55, 56, 60, 62, 64, 120, 122, 137, 139, 141, 166, 167, 184, 191, 194, 225, 244, 250, 281, 295, 338

TABLE 1-2 (CONTINUED)

● Corrosion/Scaling 173, 177, 185, 190, 195, 196, 197, 201, 202, 203, 204, 205, 206, 208, 214, 216, 256, 277, 279

● Other/Unknown 192, 305, 314, 335

GEOFYSICS

● Physical Properties
Rocks/Liquids 1, 13, 17, 32, 35, 61, 63, 64, 108, 112, 113, 118, 120, 133, 136, 138, 140, 154, 156, 167, 184, 188, 199, 225, 226, 229, 230, 231, 235, 236, 246, 280, 282, 286, 290, 316, 326

● Electrical Studies 17, 23, 81, 83, 84, 87, 95, 96, 100, 102, 103, 105, 106, 111, 124, 134, 146, 169, 179, 212, 213, 220, 262, 265, 269, 289, 297

● Well Logging 88, 94, 104, 109, 133, 160, 169, 176, 181, 187, 209, 210, 219, 220, 222, 224, 259, 273, 330

● Gravity
Magnetic Studies 8, 9, 20, 51, 68, 71, 72, 82, 91, 98, 125, 213, 274

● Heat Flow Studies 1, 8, 13, 20, 57, 65, 67, 70, 86, 88, 89, 90, 91, 99, 107, 116, 119, 145, 151, 161, 162, 179, 187, 229, 241, 247, 251, 257, 258, 263, 264, 267, 271, 272, 291, 294, 320, 331

● Other/Unknown 11, 15, 26, 53, 54, 66, 69, 76, 85, 94, 101, 108, 109, 114, 115, 127, 129, 142, 143, 147, 150, 156, 157, 159, 168, 180, 186, 213, 228, 232, 237, 260, 270, 274, 275, 286, 290, 299, 301

HYDROLOGY

● Fluid Migration 50, 52, 58, 60, 117, 135, 137, 154, 178, 252, 295

● Fluid Tracer
Studies 97, 149, 163, 249, 253, 254, 261

● Well Stimulation/
Reservoir Engineering 48, 157, 158, 171, 182, 223, 240,

● Other/Unknown 164, 165, 171, 291, 292, 314, 319, 320, 321

TABLE 1-2 (CONCLUDED)

RESOURCE EVALUATION/IDENTIFICATION

293, 303, 332, 324, 328,
329, 332, 333, 334, 336

BIOLOGIC ENVIRONMENTAL STUDIES

304, 306, 307, 308, 309,
312, 313, 318

OTHER/UNKNOWN

189, 273, 296, 311, 323,
325, 327

PROJECT NO.	R&D AREA	GEOLOGY					GEOCHEMISTRY								GEOPHYSICS					HYDROLOGY					RESOURCE EVALUATION/ IDENTIFICATION	BIOLOGIC ENVIRONMENTAL STUDIES	OTHER/UNKNOWN
		VOLCANOLOGY	GEOCHRONOLOGY/ STRATIGRAPHY	STRUCTURAL GEOLOGY	PETROLOGY	OTHER/UNKNOWN	ISOTOPE GEOCHEMISTRY	MINERALOGY/ALTERATIONS	WATER/GAS CHEMISTRY	FLUID INCLUSIONS	MASS HEAT TRANSPORT	CORROSION/SCALING	OTHER/UNKNOWN	PHYSICAL PROPERTIES ROCKS/LIQUIDS	ELECTRICAL STUDIES	WELL LOGGING	GRAVITY/MAGNETIC STUDIES	HEAT FLOW STUDIES	OTHER/UNKNOWN	FLUID MIGRATION	FLUID TRACER STUDIES	WELL STIMULATION/ RESERVOIR ENGINEERING	OTHER/UNKNOWN				
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LEGEND: R&D TYPE

△ THEORETICAL RESEARCH

□ LABORATORY RESEARCH-ANALYTICAL

▽ LABORATORY RESEARCH-EXPERIMENTAL

○ FIELD RESEARCH

▲ MODELING/SIMULATION

■ DATA ANALYSIS/DOCUMENTATION

● HARDWARE/INSTRUMENTATION
DEVELOPMENT/TESTING

▽ INDETERMINABLE FROM PROJECT
DESCRIPTION

PROJECT NO. R&D AREA	GEOLOGY					GEOCHEMISTRY							GEOPHYSICS					HYDROLOGY					RESOURCE EVALUATION/ IDENTIFICATION	BIOLOGIC ENVIRONMENTAL STUDIES	OTHER/UNKNOWN
	VOLCANOLOGY	GEOCHRONOLOGY/ STRATIGRAPHY	STRUCTURAL GEOLOGY	PETROLOGY	OTHER/UNKNOWN	ISOTOPE GEOCHEMISTRY	MINERALOGY/ALTERATIONS	HEAVY/GAS CHEMISTRY	FLUID INCLUSIONS	MASS HEAT TRANSPORT	CORROSION/SCALING	OTHER/UNKNOWN	PHYSICAL PROPERTIES ROCKS/LIQUIDS	ELECTRICAL STUDIES	WELL LOGGING	GRAVITY/MAGNETIC STUDIES	HEAT FLOW STUDIES	OTHER/UNKNOWN	FLUID MIGRATION	FLUID TRACER STUDIES	WELL STIMULATION/ RESERVOIR ENGINEERING	OTHER/UNKNOWN			
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△ THEORETICAL RESEARCH

□ LABORATORY RESEARCH-ANALYTICAL

▽ LABORATORY RESEARCH-EXPERIMENTAL

○ FIELD RESEARCH

▲ MODELING/SIMULATION

■ DATA ANALYSIS/DOCUMENTATION

● HARDWARE/INSTRUMENTATION
DEVELOPMENT/TESTING

▽ INDETERMINABLE FROM PROJECT
DESCRIPTION

LEGEND: R&D TYPE

PROJECT NO. R&D AREA	GEOLOGY					GEOCHEMISTRY							GEOPHYSICS							HYDROLOGY					RESOURCE EVALUATION/ IDENTIFICATION	BIOLOGIC ENVIRONMENTAL STUDIES	OTHER/UNKNOWN
	VULCANOLOGY	GEOCHRONOLOGY/ STRATIGRAPHY	STRUCTURAL GEOLOGY	PETROLOGY	OTHER/UNKNOWN	ISOTOPE GEOCHEMISTRY	MINERALOGY/ALTERATIONS	WATER/GAS CHEMISTRY	FLUID INCLUSIONS	MASS HEAT TRANSFER	CORROSION/SCALING	OTHER/UNKNOWN	PHYSICAL PROPERTIES ROCKS/LIQUIDS	ELECTRICAL STUDIES	WELL LOGGING	GRAVITY/MAGNETIC STUDIES	HEAT FLOW STUDIES	OTHER/UNKNOWN	FLUID MIGRATION	FLUID TRACER STUDIES	WELL STABILIZATION/ RESERVOIR ENGINEERING	OTHER/UNKNOWN					
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△ THEORETICAL RESEARCH
 □ LABORATORY RESEARCH-ANALYTICAL
 ▽ LABORATORY RESEARCH-EXPERIMENTAL

LEGEND: R&D TYPE

○ FIELD RESEARCH
 ▲ MODELING/SIMULATION
 ■ DATA ANALYSIS/DOCUMENTATION

● HARDWARE/INSTRUMENTATION
DEVELOPMENT/TESTING
 ▽ INDETERMINABLE FROM PROJECT
DESCRIPTION

PROJECT NO. R&D AREA	GEOLOGY					GEOCHEMISTRY							GEOPHYSICS						HYDROLOGY					RESOURCE EVALUATION/ IDENTIFICATION	BIOLOGIC ENVIRONMENTAL STUDIES	OTHER/UNKNOWN
	VULCANOLOGY	GEOCHRONOLOGY/ STRATIGRAPHY	STRUCTURAL GEOLOGY	PETROLOGY	OTHER/UNKNOWN	ISOTOPE GEOCHEMISTRY	MINERALOGY/ALTERATIONS	BRINE/GAS CHEMISTRY	FLUID INCLUSIONS	MASS HEAT TRANSFER	CORROSION/SCALING	OTHER/UNKNOWN	PHYSICAL PROPERTIES ROCKS/LIQUIDS	ELECTRICAL STUDIES	WELL LOGGING	GRAVITY/MAGNETIC STUDIES	HEAT FLOW STUDIES	OTHER/UNKNOWN	FLUID MIGRATION	FLUID TRACER STUDIES	WELL STIMULATION/ RESERVOIR ENGINEERING	OTHER/UNKNOWN				
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LEGEND: R&D TYPE

- △ THEORETICAL RESEARCH
- LABORATORY RESEARCH-ANALYTICAL
- ▽ LABORATORY RESEARCH-EXPERIMENTAL

- FIELD RESEARCH
- ▲ MODELING/SIMULATION
- DATA ANALYSIS/DOCUMENTATION

- HARDWARE/INSTRUMENTATION
DEVELOPMENT/TESTING
- ▼ INDETERMINABLE FROM PROJECT
DESCRIPTION

PROJECT NO. RED AREA	GEOLOGY					GEOCHEMISTRY							GEOPHYSICS						HYDROLOGY				RESOURCE EVALUATION/ IDENTIFICATION	BIOLOGIC ENVIRONMENTAL STUDIES	OTHER/UNKNOWN
	VULCANOLOGY	GEOCHRONOLOGY/ STRATIGRAPHY	STRUCTURAL GEOLOGY	PETROLOGY	OTHER/UNKNOWN	ISOTOPE GEOCHEMISTRY	MINERALOGY/ALTERATIONS	WATER/GAS CHEMISTRY	FLUID INCLUSIONS	MASS HEAT TRANSPORT	CORROSION/SCALING	OTHER/UNKNOWN	PHYSICAL PROPERTIES ROCKS/LIQUIDS	ELECTRICAL STUDIES	WELL LOGGING	GRAVITY/MAGNETIC STUDIES	HEAT FLOW STUDIES	OTHER/UNKNOWN	FLUID MIGRATION	FLUID TRACER STUDIES	WELL STIMULATION/ RESERVOIR ENGINEERING	OTHER/UNKNOWN			
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LEGEND: RED TYPE					
△	THEORETICAL RESEARCH	○	FIELD RESEARCH	●	HARDWARE/INSTRUMENTATION DEVELOPMENT/TESTING
□	LABORATORY RESEARCH-ANALYTICAL	▲	MODELING/SIMULATION	▽	INDETERMINABLE FROM PROJECT DESCRIPTION
▽	LABORATORY RESEARCH-EXPERIMENTAL	■	DATA ANALYSIS/DOCUMENTATION		

PROJECT NO.	R&D AREA	GEOLOGY					GEOCHEMISTRY							GEOPHYSICS						HYDROLOGY				RESOURCE EVALUATION/ IDENTIFICATION	BIOLOGIC ENVIRONMENTAL STUDIES	OTHER/UNKNOWN
		VOLCANOLOGY	GEOCHRONOLOGY/ STRATIGRAPHY	STRUCTURAL GEOLOGY	PETROLOGY	OTHER/UNKNOWN	ISOTOPE GEOCHEMISTRY	MINERALOGY/ALTERATIONS	WATER/GAS CHEMISTRY	FLUID INCLUSIONS	MASS HEAT TRANSPORT	CORROSION/SCALING	OTHER/UNKNOWN	PHYSICAL PROPERTIES ROCKS/LIQUIDS	ELECTRICAL STUDIES	WELL LOGGING	GRAVITY/MAGNETIC STUDIES	HEAT FLOW STUDIES	OTHER/UNKNOWN	FLUID MIGRATION	FLUID TRACER STUDIES	WELL STIMULATION/ RESERVOIR ENGINEERING	OTHER/UNKNOWN			
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LEGEND: R&D TYPE

△ THEORETICAL RESEARCH
 □ LABORATORY RESEARCH-ANALYTICAL
 ▽ LABORATORY RESEARCH-EXPERIMENTAL

○ FIELD RESEARCH
 ▲ MODELING/SIMULATION
 ■ DATA ANALYSIS/DOCUMENTATION

● HARDWARE/INSTRUMENTATION
DEVELOPMENT/TESTING
 ▼ INDETERMINABLE FROM PROJECT
DESCRIPTION

PROJECT NO. R&D AREA		GEOLOGY					GEOCHEMISTRY						GEOPHYSICS					HYDROLOGY					RESOURCE EVALUATION/ IDENTIFICATION	BIOLOGIC ENVIRONMENTAL STUDIES	OTHER/UNKNOWN
		VOLCANOLOGY	GEOCHRONOLOGY/ STRATIGRAPHY	STRUCTURAL GEOLOGY	PETROLOGY	OTHER/UNKNOWN	ISOTOPE GEOCHEMISTRY	MINERALOGY/ALTERATIONS	MINERALS/GAS CHEMISTRY	FLUID INCLUSIONS	MASS HEAT TRANSPORT	CORROSION/SCALING	OTHER/UNKNOWN	PHYSICAL PROPERTIES ROCKS/LIQUIDS	ELECTRICAL STUDIES	WELL LOGGING	GRAVITY/MAGNETIC STUDIES	HEAT FLOW STUDIES	OTHER/UNKNOWN	FLUID MIGRATION	FLUID TRACER STUDIES	WELL STIMULATION/ RESERVOIR ENGINEERING			
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LEGEND: R&D TYPE

- △ THEORETICAL RESEARCH
- LABORATORY RESEARCH-ANALYTICAL
- ▽ LABORATORY RESEARCH-EXPERIMENTAL

- FIELD RESEARCH
- ▲ MODELING/SIMULATION
- DATA ANALYSIS/DOCUMENTATION

- HARDWARE/INSTRUMENTATION
DEVELOPMENT/TESTING
- ▼ INDETERMINABLE FROM PROJECT
DESCRIPTION

PROJECT NO.	R&D AREA	GEOLOGY					GEOCHEMISTRY							GEOPHYSICS						HYDROLOGY				RESOURCE EVALUATION/ IDENTIFICATION	BIOLOGIC ENVIRONMENTAL STUDIES	OTHER/UNKNOWN
		VOLCANOLOGY	GEOCHEMISTRY/ STRATIGRAPHY	STRUCTURAL GEOLOGY	PETROLOGY	OTHER/UNKNOWN	ISOTOPE GEOCHEMISTRY	MINERALOGY/ALTERATIONS	SEISMIC/GAS CHEMISTRY	FLUID INCLUSIONS	MASS HEAT TRANSPORT	CORROSION/SCALING	OTHER/UNKNOWN	PHYSICAL PROPERTIES ROCKS/LIQUIDS	ELECTRICAL STUDIES	WELL LOGGING	GRAVITY/MAGNETIC STUDIES	HEAT FLOW STUDIES	OTHER/UNKNOWN	FLUID MIGRATION	FLUID TRACER STUDIES	WELL STIMULATION/ RESERVOIR ENGINEERING	OTHER/UNKNOWN			
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LEGEND: R&D TYPE					
△	THEORETICAL RESEARCH	○	FIELD RESEARCH	●	HARDWARE/INSTRUMENTATION DEVELOPMENT/TESTING
□	LABORATORY RESEARCH-ANALYTICAL	▲	MODELING/SIMULATION	▼	INDETERMINABLE FROM PROJECT DESCRIPTION
▽	LABORATORY RESEARCH-EXPERIMENTAL	■	DATA ANALYSIS/DOCUMENTATION		

PROJECT NO. \ R&D AREA	GEOLOGY					GEOCHEMISTRY							GEOPHYSICS						HYDROLOGY					RESOURCE EVALUATION/IDENTIFICATION	BIOLOGIC ENVIRONMENTAL STUDIES	OTHER/UNKNOWN
	VOLCANOLOGY	GEOCHRONOLOGY/STRATIGRAPHY	STRUCTURAL GEOLOGY	PETROLOGY	OTHER/UNKNOWN	ISOTOPE GEOCHEMISTRY	MINERALOGY/ALTERATIONS	TRACE/GAS CHEMISTRY	FLUID INCLUSIONS	MASS HEAT TRANSPORT	CORROSION/SCALING	OTHER/UNKNOWN	PHYSICAL PROPERTIES ROCKS/LIQUIDS	ELECTRICAL STUDIES	WELL LOGGING	GRAVITY/MAGNETIC STUDIES	HEAT FLOW STUDIES	OTHER/UNKNOWN	FLUID MIGRATION	FLUID TRACER STUDIES	WELL STIMULATION/RESERVOIR ENGINEERING	OTHER/UNKNOWN				
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LEGEND: R&D TYPE

△ THEORETICAL RESEARCH

□ LABORATORY RESEARCH-ANALYTICAL

▽ LABORATORY RESEARCH-EXPERIMENTAL

○ FIELD RESEARCH

▲ MODELING/SIMULATION

■ DATA ANALYSIS/DOCUMENTATION

● HARDWARE/INSTRUMENTATION DEVELOPMENT/TESTING

▼ INDETERMINABLE FROM PROJECT DESCRIPTION

PROJECT NO. R&D AREA	GEOLOGY					GEOCHEMISTRY							GEOPHYSICS						HYDROLOGY									
	VOLCANOLOGY	GEOCHRONOLOGY/ STRATIGRAPHY	STRUCTURAL GEOLOGY	PETROLOGY	OTHER/UNKNOWN	ISOTOPE GEOCHEMISTRY	MINERALOGY/ALTERATIONS	TRACE/GAS CHEMISTRY	FLUID INCLUSIONS	MASS HEAT TRANSPORT	CORROSION/SCALING	OTHER/UNKNOWN	PHYSICAL PROPERTIES ROCKS/LIQUIDS	ELECTRICAL STUDIES	WELL LOGGING	GRAVITY/MAGNETIC STUDIES	HEAT FLOW STUDIES	OTHER/UNKNOWN	FLUID MIGRATION	FLUID TRACER STUDIES	WELL STIMULATION/ RESERVOIR ENGINEERING	OTHER/UNKNOWN	RESOURCE EVALUATION/ IDENTIFICATION	BIOLOGIC ENVIRONMENTAL STUDIES	OTHER/UNKNOWN			
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LEGEND: R&D TYPE

△ THEORETICAL RESEARCH	○ FIELD RESEARCH	● HARDWARE/INSTRUMENTATION DEVELOPMENT/TESTING
□ LABORATORY RESEARCH-ANALYTICAL	▲ MODELING/SIMULATION	▽ INDETERMINABLE FROM PROJECT DESCRIPTION
▽ LABORATORY RESEARCH-EXPERIMENTAL	■ DATA ANALYSIS/DOCUMENTATION	

PROJECT NO.	R&D AREA	GEOLOGY					GEOCHEMISTRY							GEOPHYSICS							HYDROLOGY					RESOURCE EVALUATION/ IDENTIFICATION	BIOLOGIC ENVIRONMENTAL STUDIES	OTHER/UNKNOWN
		VOLCANOLOGY	GEOCHRONOLOGY/ STRATIGRAPHY	STRUCTURAL GEOLOGY	PETROLOGY	OTHER/UNKNOWN	ISOTOPE GEOCHEMISTRY	MINERALOGY/ALTERATIONS	TRACE/GAS CHEMISTRY	FLUID INCLUSIONS	MASS HEAT TRANSPORT	CORROSION/SCALING	OTHER/UNKNOWN	PHYSICAL PROPERTIES ROCKS/LIQUIDS	ELECTRICAL STUDIES	WELL LOGGING	GRAVITY/MAGNETIC STUDIES	HEAT FLOW STUDIES	OTHER/UNKNOWN	FLUID MIGRATION	FLUID TRACER STUDIES	WELL STIMULATION/ RESERVOIR ENGINEERING	OTHER/UNKNOWN					
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LEGEND: R&D TYPE

- △ THEORETICAL RESEARCH
- LABORATORY RESEARCH-ANALYTICAL
- ▽ LABORATORY RESEARCH-EXPERIMENTAL

- FIELD RESEARCH
- ▲ MODELING/SIMULATION
- DATA ANALYSIS/DOCUMENTATION

- HARDWARE/INSTRUMENTATION
DEVELOPMENT/TESTING
- ▽ INDETERMINABLE FROM PROJECT
DESCRIPTION

PROJECT NO. R&D AREA	GEOLOGY					GEOCHEMISTRY							GEOPHYSICS						HYDROLOGY					RESOURCE EVALUATION/ IDENTIFICATION	BIOLOGIC ENVIRONMENTAL STUDIES	OTHER/UNKNOWN
	VOLCANOLOGY	GEOCHRONOLOGY/ STRATIGRAPHY	STRUCTURAL GEOLOGY	PETROLOGY	OTHER/UNKNOWN	ISOTOPE GEOCHEMISTRY	MINERALOGY/ALTERATIONS	BRINE/GAS CHEMISTRY	FLUID INCLUSIONS	MASS HEAT TRANSPORT	CORROSION/SCALING	OTHER/UNKNOWN	PHYSICAL PROPERTIES ROCKS/LIQUIDS	ELECTRICAL STUDIES	WELL LOGGING	GRAVITY/MAGNETIC STUDIES	HEAT FLOW STUDIES	OTHER/UNKNOWN	FLUID MIGRATION	FLUID TRACER STUDIES	WELL STIMULATION/ RESERVOIR ENGINEERING	OTHER/UNKNOWN				
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LEGEND: R&D TYPE

△ THEORETICAL RESEARCH
 □ LABORATORY RESEARCH-ANALYTICAL
 ▽ LABORATORY RESEARCH-EXPERIMENTAL

○ FIELD RESEARCH
 ▲ MODELING/SIMULATION
 ■ DATA ANALYSIS/DOCUMENTATION

● HARDWARE/INSTRUMENTATION
DEVELOPMENT/TESTING
 ▽ INDETERMINABLE FROM PROJECT
DESCRIPTION

PROJECT NO. R&D AREA	GEOLOGY					GEOCHEMISTRY							GEOPHYSICS						HYDROLOGY				RESOURCE EVALUATION/ IDENTIFICATION	BIOLOGIC ENVIRONMENTAL STUDIES	OTHER/UNKNOWN
	VOLCANOLOGY	GEOCHRONOLOGY/ STRATIGRAPHY	STRUCTURAL GEOLOGY	PETROLOGY	OTHER/UNKNOWN	ISOTOPE GEOCHEMISTRY	MINERALOGY/ALTERATIONS	HAZARDOUS WASTE CHEMISTRY	FLUID INCLUSIONS	MASS HEAT TRANSPORT	CORROSION/SCALING	OTHER/UNKNOWN	PHYSICAL PROPERTIES ROCKS/LIQUIDS	ELECTRICAL STUDIES	WELL LOGGING	GRAVITY/MAGNETIC STUDIES	HEAT FLOW STUDIES	OTHER/UNKNOWN	FLUID MIGRATION	FLUID TRACER STUDIES	WELL STIMULATION/ RESERVOIR ENGINEERING	OTHER/UNKNOWN			
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LEGEND: R&D TYPE					
△	THEORETICAL RESEARCH	○	FIELD RESEARCH	●	HARDWARE/INSTRUMENTATION DEVELOPMENT/TESTING
□	LABORATORY RESEARCH-ANALYTICAL	▲	MODELING/SIMULATION	▽	INDETERMINABLE FROM PROJECT DESCRIPTION
▽	LABORATORY RESEARCH-EXPERIMENTAL	■	DATA ANALYSIS/DOCUMENTATION		

PROJECT NO. R&D AREA	GEOLOGY					GEOCHEMISTRY							GEOPHYSICS							HYDROLOGY				RESOURCE EVALUATION/ IDENTIFICATION	BIOLOGIC ENVIRONMENTAL STUDIES	OTHER/UNKNOWN				
	VOLCANOLOGY	GEOCHRONOLOGY/ STRATIGRAPHY	STRUCTURAL GEOLOGY	PETROLOGY	OTHER/UNKNOWN	ISOTOPE GEOCHEMISTRY	MINERALOGY/ALTERATIONS	BRINE/GAS CHEMISTRY	FLUID INCLUSIONS	MASS HEAT TRANSPORT	CORROSION/SCALING	OTHER/UNKNOWN	PHYSICAL PROPERTIES ROCKS/LIQUIDS	ELECTRICAL STUDIES	WELL LOGGING	GRAVITY/MAGNETIC STUDIES	HEAT FLOW STUDIES	OTHER/UNKNOWN	FLUID MIGRATION	FLUID TRACER STUDIES	WELL STIMULATION/ RESERVOIR ENGINEERING	OTHER/UNKNOWN								
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LEGEND: R&D TYPE					
△	THEORETICAL RESEARCH	○	FIELD RESEARCH	●	HARDWARE/INSTRUMENTATION DEVELOPMENT/TESTING
□	LABORATORY RESEARCH-ANALYTICAL	▲	MODELING/SIMULATION	▼	INDETERMINABLE FROM PROJECT DESCRIPTION
▽	LABORATORY RESEARCH-EXPERIMENTAL	■	DATA ANALYSIS/DOCUMENTATION		

PROJECT NO. R&D AREA	GEOLOGY					GEOCHEMISTRY								GEOPHYSICS						HYDROLOGY						RESOURCE EVALUATION/ IDENTIFICATION	BIOLOGIC ENVIRONMENTAL STUDIES	OTHER/UNKNOWN
	VOLCANOLOGY	GEOCHEMISTRY/ STRATIGRAPHY	STRUCTURAL GEOLOGY	PETROLOGY	OTHER/UNKNOWN	ISOTOPE GEOCHEMISTRY	MINERALOGY/ALTERATIONS	SEDS/GAS CHEMISTRY	FLUID INCLUSIONS	MASS HEAT TRANSPORT	CORROSION/SCALING	OTHER/UNKNOWN	PHYSICAL PROPERTIES ROCKS/LIQUIDS	ELECTRICAL STUDIES	WELL LOGGING	GRAVITY/MAGNETIC STUDIES	HEAT FLOW STUDIES	OTHER/UNKNOWN	FLUID MIGRATION	FLUID TRACER STUDIES	WELL STIMULATION/ RESERVOIR ENGINEERING	OTHER/UNKNOWN						
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LEGEND: R&D TYPE

- △ THEORETICAL RESEARCH
- LABORATORY RESEARCH-ANALYTICAL
- ▽ LABORATORY RESEARCH-EXPERIMENTAL

- FIELD RESEARCH
- ▲ MODELING/SIMULATION
- DATA ANALYSIS/DOCUMENTATION

- HARDWARE/INSTRUMENTATION
DEVELOPMENT/TESTING
- ▽ INDETERMINABLE FROM PROJECT
DESCRIPTION

PROJECT NO. B&D AREA	GEOLOGY					GEOCHEMISTRY							GEOPHYSICS						HYDROLOGY				RESOURCE EVALUATION/ IDENTIFICATION	BIOLOGIC ENVIRONMENTAL STUDIES	OTHER/UNKNOWN
	VOLCANOLOGY	GEOCHRONOLOGY/ STRATIGRAPHY	STRUCTURAL GEOLOGY	PETROLOGY	OTHER/UNKNOWN	ISOTOPE GEOCHEMISTRY	MINERALOGY/ALTERATIONS	HEAVY/METAL CHEMISTRY	FLUID INCLUSIONS	MASS HEAT TRANSFER	CORROSION/SCALING	OTHER/UNKNOWN	PHYSICAL PROPERTIES ROCKS/LIQUIDS	ELECTRICAL STUDIES	WELL LOGGING	GRAVITY/MAGNETIC STUDIES	HEAT FLOW STUDIES	OTHER/UNKNOWN	FLUID MIGRATION	FLUID TRACER STUDIES	WELL STIMULATION/ RESERVOIR ENGINEERING	OTHER/UNKNOWN	RESOURCE EVALUATION/ IDENTIFICATION	BIOLOGIC ENVIRONMENTAL STUDIES	OTHER/UNKNOWN
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LEGEND: B&D TYPE

- △ THEORETICAL RESEARCH
- LABORATORY RESEARCH-ANALYTICAL
- ▽ LABORATORY RESEARCH-EXPERIMENTAL

- FIELD RESEARCH
- ▲ MODELING/SIMULATION
- DATA ANALYSIS/DOCUMENTATION

- HARDWARE/INSTRUMENTATION
DEVELOPMENT/TESTING
- ▼ INDETERMINABLE FROM PROJECT
DESCRIPTION

PROJECT NO. R&D AREA	GEOLOGY					GEOCHEMISTRY							GEOPHYSICS						HYDROLOGY				RESOURCE EVALUATION/ IDENTIFICATION	BIOLOGIC ENVIRONMENTAL STUDIES	OTHER/UNKNOWN
	VOLCANOLOGY	GEOCHRONOLOGY/ STRATIGRAPHY	STRUCTURAL GEOLOGY	PETROLOGY	OTHER/UNKNOWN	ISOTOPE GEOCHEMISTRY	MINERALOGY/ALTERATIONS	WATER/GAS COMPOSITION	FLUID INCLUSIONS	WATER HEAT TRANSPORT	CORROSION/SCALING	OTHER/UNKNOWN	PHYSICAL PROPERTIES ROCKS/LIQUIDS	ELECTRICAL STUDIES	WELL LOGGING	GRAVITY/MAGNETIC STUDIES	HEAT FLOW STUDIES	OTHER/UNKNOWN	FLUID MIGRATION	FLUID TRACER STUDIES	WELL STIMULATION/ RESERVOIR ENGINEERING	OTHER/UNKNOWN			
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LEGEND: R&D TYPE					
△	THEORETICAL RESEARCH	○	FIELD RESEARCH	●	HARDWARE/INSTRUMENTATION DEVELOPMENT/TESTING
□	LABORATORY RESEARCH-ANALYTICAL	▲	MODELING/SIMULATION	▽	INDETERMINABLE FROM PROJECT DESCRIPTION
▽	LABORATORY RESEARCH-EXPERIMENTAL	■	DATA ANALYSIS/DOCUMENTATION		

PROJECT NO. R&D AREA	GEOLOGY					GEOCHEMISTRY							GEOPHYSICS					HYDROLOGY					RESOURCE EVALUATION/ IDENTIFICATION	BIOLOGIC ENVIRONMENTAL STUDIES	OTHER/UNKNOWN
	VOLCANOLOGY	GEOCHRONOLOGY/ STRATIGRAPHY	STRUCTURAL GEOLOGY	PETROLOGY	OTHER/UNKNOWN	ISOTOPE GEOCHEMISTRY	MINERALOGY/ALTERATIONS	BRINE/GAS CHEMISTRY	FLUID INCLUSIONS	MASS HEAT TRANSPORT	CORROSION/SCALING	OTHER/UNKNOWN	PHYSICAL PROPERTIES ROCKS/LIQUIDS	ELECTRICAL STUDIES	WELL LOGGING	GRAVITY/MAGNETIC STUDIES	HEAT FLOW STUDIES	OTHER/UNKNOWN	FLUID MIGRATION	FLUID TRACER STUDIES	WELL STIMULATION/ RESERVOIR ENGINEERING	OTHER/UNKNOWN			
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LEGEND: R&D TYPE

△ THEORETICAL RESEARCH	○ FIELD RESEARCH	● HARDWARE/INSTRUMENTATION DEVELOPMENT/TESTING
□ LABORATORY RESEARCH-ANALYTICAL	▲ MODELING/SIMULATION	▼ INDETERMINABLE FROM PROJECT DESCRIPTION
▽ LABORATORY RESEARCH-EXPERIMENTAL	■ DATA ANALYSIS/DOCUMENTATION	

PROJECT NO. R&D AREA	GEOLOGY					GEOCHEMISTRY							GEOPHYSICS					HYDROLOGY					RESOURCE EVALUATION/ IDENTIFICATION	BIOLOGIC ENVIRONMENTAL STUDIES	OTHER/UNKNOWN
	VOLCANOLOGY	GEOCHRONOLOGY/ STRATIGRAPHY	STRUCTURAL GEOLOGY	PETROLOGY	OTHER/UNKNOWN	ISOTOPE GEOCHEMISTRY	MINERALOGY/ALTERATIONS	MINERAL/GAS CHEMISTRY	FLUID INCLUSIONS	MASS HEAT TRANSPORT	CORROSION/SCALING	OTHER/UNKNOWN	PHYSICAL PROPERTIES ROCKS/LIQUIDS	ELECTRICAL STUDIES	WELL LOGGING	GRAVITY/MAGNETIC STUDIES	HEAT FLOW STUDIES	OTHER/UNKNOWN	FLUID MIGRATION	FLUID TRACER STUDIES	WELL STIMULATION/ RESERVOIR ENGINEERING	OTHER/UNKNOWN			
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LEGEND: R&D TYPE

- △ THEORETICAL RESEARCH
- LABORATORY RESEARCH-ANALYTICAL
- ▽ LABORATORY RESEARCH-EXPERIMENTAL

- FIELD RESEARCH
- ▲ MODELING/SIMULATION
- DATA ANALYSIS/DOCUMENTATION

- HARDWARE/INSTRUMENTATION DEVELOPMENT/TESTING
- ▽ INDETERMINABLE FROM PROJECT DESCRIPTION

PROJECT NO. R&D AREA	GEOLOGY					GEOCHEMISTRY							GEOPHYSICS						HYDROLOGY					RESOURCE EVALUATION/ IDENTIFICATION	BIOLOGIC ENVIRONMENTAL STUDIES	OTHER/UNKNOWN
	VULCANOLOGY	GEOCHRONOLOGY/ STRATIGRAPHY	STRUCTURAL GEOLOGY	PETROLOGY	OTHER/UNKNOWN	ISOTOPE GEOCHEMISTRY	MINERALOGY/ALTERATIONS	WET/DRY CHEMISTRY	FLUID INCLUSIONS	MASS HEAT TRANSPORT	CORROSION/SCALING	OTHER/UNKNOWN	PHYSICAL PROPERTIES ROCKS/LIQUIDS	ELECTRICAL STUDIES	WELL LOGGING	GRAVITY/MAGNETIC STUDIES	HEAT FLOW STUDIES	OTHER/UNKNOWN	FLUID MIGRATION	FLUID TRACER STUDIES	WELL STIMULATION/ RESERVOIR ENGINEERING	OTHER/UNKNOWN				
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LEGEND: R&D TYPE

- △ THEORETICAL RESEARCH
- LABORATORY RESEARCH-ANALYTICAL
- ▽ LABORATORY RESEARCH-EXPERIMENTAL

- FIELD RESEARCH
- ▲ MODELING/SIMULATION
- DATA ANALYSIS/DOCUMENTATION

- HARDWARE/INSTRUMENTATION
DEVELOPMENT/TESTING
- ▽ INDETERMINABLE FROM PROJECT
DESCRIPTION

PROJECT NO.	R&D AREA	GEOLOGY					GEOCHEMISTRY								GEOPHYSICS						HYDROLOGY				RESOURCE EVALUATION/ IDENTIFICATION	BIOLOGIC ENVIRONMENTAL STUDIES	OTHER/UNKNOWN																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																													
		VOLCANOLOGY	GEOCHRONOLOGY/ STRATIGRAPHY	STRUCTURAL GEOLOGY	PETROLOGY	OTHER/UNKNOWN	ISOTOPE GEOCHEMISTRY	MINERALOGY/ALTERATIONS	WATER/GAS CHEMISTRY	FLUID INCLUSIONS	MASS HEAT TRANSPORT	CORROSION/SCALING	OTHER/UNKNOWN	PHYSICAL PROPERTIES ROCKS/LIQUIDS	ELECTRICAL STUDIES	WELL LOGGING	GRAVITY/MAGNETIC STUDIES	HEAT FLOW STUDIES	OTHER/UNKNOWN	FLUID MIGRATION	FLUID TRACER STUDIES	WELL STIMULATION/ RESERVOIR ENGINEERING	OTHER/UNKNOWN																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																	
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▲ THEORETICAL RESEARCH
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 ▼ LABORATORY RESEARCH-EXPERIMENTAL

LEGEND: R&D TYPE

○ FIELD RESEARCH
 ▲ MODELING/SIMULATION
 ■ DATA ANALYSIS/DOCUMENTATION

● HARDWARE/INSTRUMENTATION
DEVELOPMENT/TESTING
 ▼ INDETERMINABLE FROM PROJECT
DESCRIPTION

PROJECT NO. R&D AREA	GEOLOGY					GEOCHEMISTRY							GEOPHYSICS						HYDROLOGY				RESOURCE EVALUATION/ IDENTIFICATION	BIOLOGIC ENVIRONMENTAL STUDIES	OTHER/UNKNOWN
	VOLCANOLOGY	GEOCHRONOLOGY/ STRATIGRAPHY	STRUCTURAL GEOLOGY	PETROLOGY	OTHER/UNKNOWN	ISOTOPE GEOCHEMISTRY	MINERALOGY/ALTERATIONS	MINING/GAS CHEMISTRY	FLUID INCLUSIONS	MASS HEAT TRANSPORT	CORROSION/SCALING	OTHER/UNKNOWN	PHYSICAL PROPERTIES ROCKS/LIQUIDS	ELECTRICAL STUDIES	WELL LOGGING	GRAVITY/MAGNETIC STUDIES	HEAT FLOW STUDIES	OTHER/UNKNOWN	FLUID MIGRATION	FLUID TRACER STUDIES	WELL STIMULATION/ RESERVOIR ENGINEERING	OTHER/UNKNOWN			
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LEGEND: R&D TYPE

- △ THEORETICAL RESEARCH
- LABORATORY RESEARCH-ANALYTICAL
- ▽ LABORATORY RESEARCH-EXPERIMENTAL

- FIELD RESEARCH
- ▲ MODELING/SIMULATION
- DATA ANALYSIS/DOCUMENTATION

- HARDWARE/INSTRUMENTATION
DEVELOPMENT/TESTING
- ▼ INDETERMINABLE FROM PROJECT
DESCRIPTION

PROJECT NO. R&D AREA	GEOLOGY					GEOCHEMISTRY							GEOPHYSICS							HYDROLOGY					RESOURCE EVALUATION/ IDENTIFICATION	BIOLOGIC ENVIRONMENTAL STUDIES	OTHER/UNKNOWN
	VOLCANOLOGY	GEOBIOLOGY/ STRATIGRAPHY	STRUCTURAL GEOLOGY	PETROLOGY	OTHER/UNKNOWN	ISOTOPE GEOCHEMISTRY	MINERALOGY/ALTERATIONS	WATER/GAS CHEMISTRY	FLUID INCLUSIONS	MASS HEAT TRANSFER	CORROSION/SCALING	OTHER/UNKNOWN	PHYSICAL PROPERTIES ROCKS/LIQUIDS	ELECTRICAL STUDIES	WELL LOGGING	GRAVITY/MAGNETIC STUDIES	HEAT FLOW STUDIES	OTHER/UNKNOWN	FLUID MIGRATION	FLUID TRACER STUDIES	WELL STIMULATION/ RESERVOIR ENGINEERING	OTHER/UNKNOWN					
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LEGEND: R&D TYPE					
△	THEORETICAL RESEARCH	○	FIELD RESEARCH	●	HARDWARE/INSTRUMENTATION DEVELOPMENT/TESTING
□	LABORATORY RESEARCH-ANALYTICAL	▲	MODELING/SIMULATION	▼	INDETERMINABLE FROM PROJECT DESCRIPTION
▽	LABORATORY RESEARCH-EXPERIMENTAL	■	DATA ANALYSIS/DOCUMENTATION		

TABLE 2-2
GEOSCIENCES R&D CLASSIFICATION - SUMMARY MATRIX

R&D AREA	GEOLOGY					GEOCHEMISTRY								GEOPHYSICS						HYDROLOGY				RESOURCE EVALUATION/ IDENTIFICATION	BIOLOGIC ENVIRONMENTAL STUDIES	OTHER/UNKNOWN
	VOLCANOLOGY	GEOCHEMISTRY/ STRATIGRAPHY	STRUCTURAL GEOLOGY	PETROLOGY	OTHER/UNKNOWN	ISOTOPE GEOCHEMISTRY	MINERALOGY/ALTERATIONS	HEAVY/METAL CHEMISTRY	FLUID INCLUSIONS	MASS FLUX TRANSPORT	CORROSION/SCALING	OTHER/UNKNOWN	PHYSICAL PROPERTIES ROCKS/LIQUIDS	ELECTRICAL STUDIES	WELL LOGGING	GRAVITY/MAGNETIC STUDIES	HEAT FLOW STUDIES	OTHER/UNKNOWN	FLUID MIGRATION	FLUID TRACER STUDIES	WELL STIMULATION/ RESERVOIR ENGINEERING	OTHER/UNKNOWN				
Total # Projects by R&D Area (1)	26	21	32	13	4	12	14	62	3	24	19	4	37	27	19	13	38	39	11	7	9	9	10	8	7	
Projects by R&D Type: (2)																										
Theoretical Research	-	-	2	-	-	-	3	5	-	13	4	-	9	4	-	-	4	3	6	-	-	-	-	-	1	
Laboratory Research - Analytical	13	11	4	9	-	12	7	25	2	-	3	-	-	1	1	1	4	2	-	1	1	-	-	1	-	
Laboratory Research - Experimental	-	-	-	2	-	3	3	13	1	5	10	-	22	3	2	-	4	4	5	1	1	-	-	-	-	
Field Research	23	14	26	8	2	2	8	15	-	4	1	-	4	15	6	10	20	28	-	6	3	5	1	1	-	
Modeling/Simulation	7	1	3	2	1	2	4	11	-	9	4	1	6	9	-	3	12	5	4	1	2	1	-	2	-	
Data Analysis/ Documentation	3	6	10	-	2	-	3	13	-	5	3	3	3	6	9	4	13	18	1	2	5	5	10	3	5	
Hardware/Instr. Development/Testing	-	-	-	2	-	1	-	7	-	3	2	-	3	6	7	2	-	2	-	-	2	-	1	-	-	
Indeterminable From Project Description	-	-	-	-	-	-	-	2	-	-	1	1	1	-	-	-	-	-	-	-	-	-	-	1	1	

(1) The total number of projects by all R&D areas is greater than the total number of projects because many projects address multiple R&D areas.

(2) Within each R&D area/column, the cumulative number of R&D types will be equal to or greater than the total number of projects by R&D area, because many projects involve multiple research activities.