ERDA-76-44
UC 34 66

Summaries Of Physical Research In Geosciences

January 1976

U.S. Energy Research & Development Administration
Division of Physical Research

Washington, DC 20545

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FOREWORD

ERDA supports research in the geosciences in order to provide a sound underlay of fundamental knowledge in those areas of the earth, atmospheric and solar sciences which relate to ERDA's many missions. This research may be conducted in the major ERDA laboratories, industry, universities, and other government agencies. Such support provides for payment of salaries, purchase of equipment and other materials, an allowance for overhead costs, and is formalized by a contract between ERDA and the organization performing the work.

The summaries in this document describe the work performed during 1975 and include the scope of the work to be performed in 1976. The Division of Physical Research, through its Geosciences Program, supports research in geology, petrology, geophysics, geochemistry, hydrology, basic meteorology, solar-terrestrial relationships, aeronomy, physical oceanography, seismology, and natural resource analysis including the various subdivisions and interdisciplinary relationships, as well as their relationships, as well as their relationship to ERDA's technological needs.

PART I

GEOSCIENCES

ON-SITE

Contractor: ARGONNE NATIONAL LABORATORY
Argonne, Illinois 60439

Contract: 09 ENG 38

Title: Geosciences Program

Person in Charge: F. A. Cafasso

Scope of Work

A. Thermochemistry of Geothermal-related Materials (Cafasso/O'Hare)

The potential of fluorine bomb calorimetry for measuring standard enthalpies of formation (ΔH_f^o) of minerals of geochemical interest was demonstrated by our measurements of ΔH_f^o of α-quartz and of MoS_2. For α-quartz, the measurements resulted in an unequivocal value for the ΔH_f^o of this key datum in many geothermal cycles; for MoS_2 it is unlikely that any method other than Fluorine Bomb Calorimetry could have been used to obtain a reliable value of its ΔH_f^o. We plan to continue to use this method to study other sulfide-based minerals of geothermal interest, especially As_2S_3 and AsS.

B. Working Fluids for Bottoming Cycles (Cafasso/Blander)

Geothermal heat sources, especially those which are not steam-generating and those which are too corrosive for turbine use, tend to be relatively low temperature, large-scale heat sources. The direct use of these heat sources puts a premium on higher efficiencies of power generation in a temperature regime which would ordinarily be classified as "bottoming cycle". In this regime (below 300°C), water is not the ideal heat transfer fluid, nor is steam the ideal turbine gas.

This project involves research to find materials that will act as suitable heat transfer agents in bottoming cycles for low temperature heat sources. Materials are being selected from the broad category of perfluorinated alkyl amines and others based upon (a) known vapor pressure, density and heat of vaporization data, (b) known use as extremely stable, non-corrosive heat transfer fluids in electrical transformers, and (c) known trial results on small Rankine cycle turbines for automotive use. The materials selected are to be screened with regard to properties such as stability and corrosiveness, and P-V-T-H-S thermodynamic data will be obtained for the most promising candidates.

Contractor: BATTELLE MEMORIAL INSTITUTE
Pacific Northwest Laboratories
Richland, Washington 99352

Contract: AT(45-1)-1830

Title: Development and Operation of ERDA Insolation-Aeronomy Observatory

Person in Charge: R. A. Stokes

Scope of Work

The insolation and aeronomy programs at Battelle Observatory are designed to make high-resolution studies of the solar flux (insolation) and nighttime upper atmosphere optical (auroral) emissions. The orientation of the insolation studies is directed to the development of instrumentation capable of providing multispectral data on the temporal and spatial distributions of both direct and diffuse solar radiation. The data acquired in this program will have direct applicability to specific site studies as well as forming a basis set for incorporation into studies of aerosol and cloud cover modification of insolation.

Since both the insolation studies and the auroral emissions studies share a common instrument, and to a certain extent data handling techniques, much of the development has proceeded in parallel. The aeronomy program has concentrated upon studies of optical emission patterns in the mid-latitude region. The altitude, spectral energy content, and spatial and temporal distributions of the emissions are derived from the data and are used to determine the energies of the precipitating particles and bulk motion of magnetospheric plasma in the source region. The shape and motions of the emitting regions provide information on the dynamic behavior of the earth's magnetosphere and upper atmosphere during both disturbed and quiet geomagnetic conditions.

A. Insolation Studies (E. W. Kleckner, J. J. Michalsky)

1. Analysis (J. J. Michalsky, E. W. Kleckner)

Work is beginning on several theoretical aspects of aerosol scattering of the solar flux. A new addition to our staff (JJM), with a strong interest in planetary atmospheres, has enabled us to pursue this area in more depth. Of fundamental interest is the problem of more precisely defining the type, quantity, and size distribution of atmospheric aerosols given multispectral data on the intensity of the solar flux. Since aerosol particles possess a complex index of refraction, polarization measurements are needed in addition to the intensity in order to completely characterize the aerosol scattering properties. We intend to evaluate various existing models in order to provide a rational basis for obtaining the maximum utility from the data gathered by the experimental instruments described below.

2. Experiment (E. W. Kleckner)

The principal goal of the work in this area is the experimental measurement of a number of properties of the terrestrial solar radiation flux. To this end, we are developing a Mobile Automatic Scanning Photometer; it is a dual purpose instrument which makes both daytime and nighttime observations.

The instrument measures insolation in seven spectral bands from 427.8 nm to 940.0 nm. The field of view of the photometer is 3^{o} and the basic mode of operation is that of scanning the sky in a series of almucantars. In addition, the instrument measures the direct beam of the sun at 15-minute intervals. The basic data, therefore, consists of both direct and diffuse components of insolation which can be synthesized to yield the sum total falling on a surface of arbitrary orientation. The detection mode will allow a basic stability in the measurement of $\pm 2\%$ and the instrument module is portable and suitable for remote siting.

B. Aeronomy (L. L. Smith, E. W. Kleckner)

1. Analysis

The concept that the pattern and spectrum composition of the upper atmospheric optical emissions can be used to monitor the structural features and dynamic processes of the magnetosphere is extremely useful. The wealth of auroral phenomena which have optical emissions and occur in the mid-latitude region is notable. The prominent features are the Stable Auroral Red arcs (SAR-arc), the Hydrogen arcs (H-arc), and the Diffuse Aurora (DIF).

2. Observations

a. Battelle Observatory

Beginning in September 1967, all-sky photometric observations of the emissions [OI] 5577A, [OI] 6300A, N_2^+ 4278A, and Hβ 4861, and continuums 5350, 6080, and 7150A have been taken routinely on all cloudless, moonless nights from the Battelle Observatory (latitude 46.4^{o} N,

longitude 119.6°W), Richland, Washington. The observing technique consists of scanning the night sky in a series of almucantars at elevations 10°, 15°, 20°, 30°, and 50°. Since the photometric field of view is approximately 5°, these scans adequately cover the entire circle of view.

b. Global Program

Because most of the detailed investigations have been done at single stations, the understanding of the emission patterns tends to be regional. The synthesis that might be provided by simultaneous global observations is lacking.

What is needed is a set of simple, reliable, identical optical instruments dispersed over the globe. Battelle has developed such an instrument called the Mobile Automatic Scanning Photometer (MASP). The same all-sky scanning technique presently used at the Battelle Observatory is implemented on the MASP.

The first chain of MASP units will be installed across the United States between geographic latitudes 40-50° N. This resultant longitude chain will provide important "global" coverage of the plasmapause which is the boundary region between the "hot plasma" of the magnetosphere under direct influence of the solar wind and the "cold plasma" of the plasmasphere which is locked to and corotates with the earth. The first MASP unit of this chain has been installed on the McColly ranch near Hinsdale, Montana (geographic latitude 48.6° N and longitude 107.1° W). Observations from this installation coupled with the Battelle Observatory observations give continuous coverage for 400-km height emissions from longitudes 92° to 134° W.

3. Associations

a. ISIS-II Satellite

Simultaneous observations by a satellite and a ground-based observatory are advantageous for both observing platforms. The ground-based observatory has the problem of scattering and extinction due to the earth's atmosphere and a relative small circle of coverage for the 100-300 km height emissions. The satellite experimenters have the problems of calibration, and albedo and temporal coverage for any given geographic region. The major problems of one platform appear to be the least problems in the other.

b. AE-D Satellite

The AE-D satellite was put in orbit during the summer of 1975. One of the experiments is a photometer and we are working with the principal experimenter (Dr. Marsha Torr) in comparing our ground-based observations with the AE-D photometric observations in methods similar to our ISIS-II collaboration.

c. International Magnetospheric Study (IMS)

The IMS is an attempt to coordinate on an international basis all experiments that are important to magnetospheric research. We are members of this program which starts in July 1976 and runs through the next solar cycle maximum predicted to be over by the end of 1978. Data pools are being organized and satellite and ground-based experiments are being coordinated.

d. Joint Programs

Those which are now in progress but not included in the programs thus far described involve the University of Washington (Dr. K. C. Clark), Central Washington State College (Dr. R. Bennett), and the LaTrobe University in Australia (Dr. K. D. Cole). These collaborations include graduate students as well as faculty.

Contractor: LAWRENCE BERKELEY LABORATORY
University of California
Berkeley, California 94720

Contract: 05 ENG 48

Title: Geosciences Program

Person in Charge: Paul A. Witherspoon

Scope of Work

The Geoscience Program at the Lawrence Berkeley Laboratory consists of four projects, three of which support the ERDA effort in developing geothermal energy. They include two projects covering investigations in reservoir dynamics, rock fluid system properties, brine chemistry and the chemistry of magmatic materials, rock-water interactions, and hot springs, and a project devoted to the collection and dissemination of geothermal information. The fourth project aims at measuring variations in seismic wave velocity as a function of rock stress. Work done under this project could have application in earthquake prediction.

A. Geosciences Relating to Geothermal Energy (P. A. Witherspoon)

1. Reservoir Dynamics (P. A. Witherspoon, V. E. Schrock)

The purpose of this project is to provide theoretical support for investigations of geothermal systems. Objectives include the estimation of the useful life of a geothermal reservoir, the determination of the optimum rate of energy removal and the optimum distribution of production and reinjection points within the reservoir boundaries. The environmental effects of geothermal exploitation such as land subsidence due to fluid withdrawal will also receive attention.

These objectives are being met through the application of hydrodynamics, thermodynamics and other physical principles to the mathematical modeling of geothermal reservoirs. Computer codes are being developed which can simulate hypothetical or existing cases. The accuracy of the mathematical simulations will be tested experimentally through laboratory scale sand models.

Current efforts are directed towards the completion of a code for modeling two phase (steam/water) reservoirs, and the completion of a first generation code to predict the effects of reinjection in a geothermal system. The Cerro Prieto geothermal project in Mexico has been selected to be modeled by the single-phase, multidimensional computer code, named SCHAFF, developed at LBL for either liquid-dominated or vapor-dominated systems. Cerro Prieto is the only conveniently accessible liquid-dominated system that has been operating for a sufficient period of time to allow comparison between theoretical estimates and operating data. LBL is also assisting the staff of the Idaho National Engineering Laboratory in the selection of the location of producing and reinjection wells at the Raft River, Idaho, geothermal site.

2. Rock Fluid System Properties (W. H. Somerton)

The objectives of this project are to develop methods of, and equipment for, the measurement of the properties and behavior of rock-fluid systems at pressure, temperature and fluid saturation conditions which may be encountered in geothermal power development and thermal recovery methods applied in the extraction of fossil fuels. Such properties include porosity, permeability, formation resistivity factor, dilatational and shear velocities, bulk and matrix compressibilities, and thermal conductivity, diffusivity, expansion, and vaporization-condensation capillary parameters.

Data on these properties are needed in the interpretation of well logs in relation to zonal evaluation, in the study of fluid and heat flow in relation to subsurface reservoir management, and in the prediction of well bore stability and possible surface effects associated with fluid withdrawal from the reservoir. Methods of measuring the desired properties and equipment capable of making such measurements to temperatures as high as 200°C and pressures of 1000 bars were developed through earlier projects funded by the Water Resources Center, University of California, and the American Petroleum Institute. This equipment is being used for a continuing program of obtaining data on a widening variety of rock-fluid systems.

Design work has been completed on a new test facility capable of measuring all the desired properties concurrently on the same test specimen to temperatures as high as 500°C and pressures to 1250 bars. Design problems and materials limitations have necessitated modifications in measuring methods and the development of new methods in some cases. The existing test facilities are being used for these purposes. New work has also begun on the measurement of thermal contact resistivities and heat transfer coefficients for convective heat transfer in porous media.

During the remainder of FY 1976, it is hoped to construct the new test facility and perform initial test evaluations. Standard laboratory sandstones and samples from as many geothermal test well cores as may be available will be investigated.

3. Thermodynamics of High Temperature Brines (K. S. Pitzer, L. F. Silvester)

The objective of this project is a set of equations predicting the various thermodynamic properties of mixed aqueous electrolytes with particular attention to the temperatures, pressures, and components present in geothermal brines. The properties considered include both free energy and enthalpy, and will provide the basis for both solubility calculations and various heat transfer or heat balance calculations in geothermal power plants. The results are to be summarized in a form for convenient engineering use in geothermal plant design. Current efforts are directed towards the development of engineering equations and the tabulation of data on the thermodynamic properties of sodium chloride solutions to saturation and to 350°C. This information is of great value in the development of geothermal power plants using hypersaline brines.

It is expected that a rigorous set of equations predicting the thermodynamic properties of strong mixed electrolytes at elevated temperatures will be completed in FY 1977. The equations will be tested against available data in the literature and against the results of high temperature measurements of osmotic coefficients in mixed electrolytes. Construction of equipment to perform the latter measurements is scheduled for late FY 1976.

B. Studies of Magmatic Materials and Rock Water Interactions (F. Asaro, J. A. Apps, I. S. E. Carmichael)

1. Magmatic Materials (F. Asaro, I. S. E. Carmichael)

Magmatic materials are being studied in order to quantify the nature, mechanisms, and rates of convection in the upper mantle. This is being done to provide long range interpretive support for feasibility studies involving the recovery of energy from magmatic or volcanic sources.

Current efforts are directed towards basic geochemical, petrological, and mineralogical studies of lavas and intrusive rocks. Alkalic basalts from Baja, California, the Azores, and Antarctica, together with their associated xenoliths and megacrysts are being analyzed by NAA and XRF to determine major and trace elements concentrations. Partition coefficients of minor elements between the lava and the inclosed megacrysts, are being determined. Similar investigations are also being made of the Bishop Tuffs which erupted from the Long Valley caldera in southeastern California. Chemical analyses of xenoliths from alkalic lavas, and from the San Carlos and Flagstaff diatremes in Arizona will be made during the latter part of FY 1976.

As part of a cooperative effort with the United States Geological Survey in Menlo Park, volcanic ash deposits are being analyzed as a means of identifying their source, and iridium abundances in soils are being correlated with meteoritic falls of known age in an attempt to establish a dating system for the soils.

2. Rock Water Interactions (J. A. Apps, F. Asaro)

The objective of the project in rock water interactions is to determine what deleterious chemical effects, if any, will result from rapid withdrawal of hot water and reinjection of spent fluids in a convecting geothermal reservoir. The program will be addressed to questions regarding the rate and nature of formation sealing and other factors which have an adverse effect on geothermal plant operation. A longer term goal is to predict the transport and deposition behavior of major rock forming components and trace metals in convecting hydrothermal systems.

During FY 1976, a literature survey is being conducted to determine the kinetics of dissolution and precipitation of silica in water and salt solutions. The kinetics of silica dissolution and precipitation will be incorporated in a mathematical model of fluid flow in a geothermal reservoir, and specific cases modeled.

3. Geochemical and Radiometric Exploration (H. A. Wollenberg, F. Asaro, H. R. Bowman, A. J. Hebert)

This subproject supports the reservoir assessment project of the LBL DGE funded geothermal program. Its primary purpose is to develop techniques aimed at evaluating the geochemical and radiometric environment of geothermal systems. For example, the chemical composition of geothermal fluids is diagnostic of temperatures at depth in a geothermal system. Geochemical analysis of samples of surrounding regional rocks will furnish data for comparison of geothermal fluid chemistry and the chemistry of source area and reservoir materials. Radiometric studies are designed to determine if meaningful correlations exist between emanating radon and the structural setting of the geothermal area, and in evaluating the environmental effects of the development of a geothermal resource.

During FY 1976, it is planned to analyze 100 to 200 samples of water and rock from drillings made at the LBL geothermal test sites in Nevada. Samples will be analyzed for up to 50 elements by NAA, XRF, IZAA, etc. Measurements will be made periodically of radon emanations of hot springs and in adjacent soils. Operating techniques will be developed for the expedient analysis of radium in geothermal waters. Efforts will also be made to develop a model incorporating existing data on uranium contents of country rocks and spring waters, and of radon and radium contents in spring waters to estimate the uranium abundance at depth, and the age of the aquifer.

C. National Geothermal Information Resource (S. L. Phillips)

Geothermal energy exploration is a developing technology encompassing a wide range of disciplines. Available information is often fragmentary, difficult to obtain, and poorly organized. Nevertheless, such information must be made available rapidly to researchers, developers, equipment designers, policy planners and funding agencies so that geothermal energy in the United States can be developed rapidly to meet the Nation's expanding energy needs.

The National Geothermal Information Resource (GRID) has been set up to serve as a focal point for collection, organization and dissemination of information and numerical data pertaining to geothermal energy. Six major areas are covered. They are: exploration, physical chemistry, utilization, environmental, institutional, and reservoir characterization.

Present efforts are concentrated on summarizing data on the physical properties of NaCl solutions and on setting up GEODOC, a computer based file which contains descriptive cataloging and indexing information for all documents processed by the National Geothermal Information Resource Group. Also scheduled for FY 1976, is the compilation of geothermal exploration data, and a bibliography and data on hydrogen sulfide as it relates to geothermal energy development.

D. In-Situ Stress Measurements (T. V. McEvilly, C-Y Wang)

A number of techniques are being investigated for their potential value in predicting the occurrence of earthquakes. All rely to some degree on physical properties being functions of the state of stress in crustal rocks. One technique, variations in seismic wave velocity, has depended so far on the measurement of time delays of seismic waves whose paths have fortuitously passed through a zone of interest. The purpose of this project is to develop a method of observing stress-dependent changes in a specified region by monitoring the velocity of seismic waves generated by a controlled seismic source and propagating along known geometric (reflected/refracted) paths within the crust.

A capability for in-situ strain change monitoring would have implications for a wide range of geoscience problems. Apart from the merits for earthquake prediction, the technique is especially applicable for local monitoring of specific installations in earthquake zones such as nuclear reactors, geothermal facilities, and large dams.

During FY 1976, full scale field measurements will be made of stress dependent changes in the velocity of seismic waves generated by the VIBROSEIS* equipment donated by Continental Oil Company. Initial efforts will be directed towards evaluation of measurement precision and system stability. Concurrent with the field program, laboratory investigations of the behavior of rocks under stress will be underway with particular emphasis on fracture development processes and implications to earthquake prediction possibilities and the general stress/physical properties question.

*Trademark for Continental Oil Company.

Contractor: LAWRENCE LIVERMORE LABORATORY
University of California
Livermore, California 94550

Contract: 05 ENG 48

Title: Predictive Rock Mechanics

Person in Charge: J. F. Schatz

Scope of Work

The object of this research is to improve understanding of the response of geologic media to mechanical stimuli such as explosions or in situ stress. Rock behavior is being modeled on a microscopic scale, and the models are being verified by experimental work on well-characterized ceramic synthetic rocks. In the future, modeling will be extended to the larger scale of joints and faults, and experimental work will proceed to the field.

To date, a model for the isotropic response of spherical pores and flat cracks in dry rocks has been completed. Computer programs have been written, and the model has been verified for porous rocks such as tuff and sandstone. Non-isotropic response is handled by another model of the continuum plasticity type, and work is proceeding to relate the two models and include the effects of water and strain rate.

Synthetic rock fabrication is proceeding. Kaolinite has been chosen for simulation of weak, porous rock, and alumina for strong, less porous rock. Quantities of both kaolinite and alumina powder have been obtained. Dry kaolinite pellets of several porosities have been fabricated and characterized by optical and electron microscopy, x-ray, and other techniques. Hydrostatic, triaxial, and gas gun planar impact testing are under way. Alumina sample fabrication and procurement have begun.

Contractor: LOS ALAMOS SCIENTIFIC LABORATORY
University of California
Los Alamos, New Mexico 87545

Contract: W-7405-ENG-36

Title: Solid Earth Geosciences

Person in Charge: R. B. Duffield

Scope of Work

The thrust of the geosciences effort at LASL is to complement with geophysical/geological input ERDA programs at LASL and elsewhere that relate to geothermal energy needs, site and environment stability, and minerals prospecting and extraction. The LASL geoscience research program includes seismology, rock mechanics, experimental high pressure geophysics, experimental geochemistry, observational petrology and geochemistry, field geology, dynamic similitude modeling, and theoretical numerical simulation of dynamics within the earth, and geochronology.

Directly related to the support of geothermal energy programs are investigations to determine geochemical, petrological, physical, mechanical, heat flow and thermal properties of drill cores, as well as experimental and numerical investigations of the chemical interaction of granite and hot aqueous solutions, the latter research activity also contributing to possible mineral extraction procedures.

Because both ore/geothermal body location and geologic hazards (explosive volcanism, lava flows, lahars, earthquakes, etc.) are intimately related to regions that have seen or are presently seeing some form of tectonism, primary interests of the geoscience group are igneous geology, origin, emplacement and chemical evolution of plutons and volcanoes and the nature of heat and mass transfer and stress distribution within the earth.

Laboratory and theoretical work is being complemented by field studies in the Jemez Mountains--Rio Grande Rift Region and the Cascade Range.

Directly employed by the group in this research are the LASL Computer Facilities along with their extensive library of hydrodynamic and material codes, rock permeability testing apparatus, several large presses (maximum capacity 1400 mPa), a compression and tensile testing unit, a petrography laboratory and a CAMECA electron microanalyzer. The group also draws upon the expertise of other sections of LASL for specialized work such as neutron activation.

A. Geophysical Applications of High Temperature/Pressure Materials Science (T. J. Shankland, U. Nitsan, P. M. Halleck)

1. Measurement of Optical Absorption in Minerals and Rocks and the Calculation of Radiative Heat Transfer in the Earth (T. J. Shankland, U. Nitsan)

If the optical absorption spectrum of a material is known as a function of temperature, then it is possible to calculate an effective thermal conductivity due to radiation by integrating the absorption spectrum and the temperature deviation of the black-body distribution over the spectral range in which the material is transmitting. This calculation is being accomplished for several minerals for which absorption spectra are in hand, and apparatus is being constructed for continued absorption measurements in order to better evaluate the thermal conduction of rocks at very high temperatures.

2. Theory of Electrical Properties of Hetrogeneous Media and Interpretation of Electrical Conductivity Anomalies (T. J. Shankland)

Electrical conductivity measurements have revealed zones of anomalously high conductivity in many regions of the earth's mantle, particularly in the western U.S. By using theories of the electrical conductivity of composites, it is possible to evaluate the electrical conductivity in a rock which contains a highly conducting fluid such as water or a partial melt. These calculations are being used to investigate thermal conditions in zones of conductivity anomalies.

3. Elastic Properties of Rocks and Minerals (T. J. Shankland)

Work is continuing on the broad effect of chemical composition, crystal structure and state of aggregation on sound velocities of rocks and minerals. These calculations can be applied to the interpretation of seismic measurements in terms of composition and thermodynamic properties of crustal and mantle rocks.

4. Optical Studies of Electronic Properties of Minerals (U. Nitsan, T. J. Shankland)

Measurements of optical absorption and reflectivity spectra from the near infrared into the vacuum ultraviolet are interpreted in terms of various classes of electronic energy levels: crystal field transitions, charge-transfer transitions, and "fundamental" transitions involving the bonding and antibonding transitions. The silicates are compounds of mixed oxides and afford unique examples of systematic chemical variations of electronic structure.

5. High Pressure X-Ray Studies (P. M. Halleck)

Using primarily the technique recently described by Halleck and Olinger, compression and phase studies are being done on minerals of geophysical interest as well as on simple salts and solid solutions which may have a relation to the structure of matter in the deep mantle or inner core. The current range of these studies is ca. 12 GPa (120 kb); some technique development work is being done to improve the pressure range and add a high temperature capability. Lower-pressure phase studies are also contemplated using a small diamond-anvil cell designed by Merrill and Bassett for single-crystal work. These studies will continue to be done in conjunction with B. Olinger, LASL M-6.

6. Ultrasonics Experiments (P. M. Halleck)

Hardware is being assembled to give us the capability to perform ultrasonic sound velocity experiments, using a variety of techniques including simple pulse transmission, pulse-echo, buffer-rod, phase comparison and pulse superposition, as well as others designed specifically for dispersive media. Many of the applications will be to rock physics projects, but some high precision measurements on individual minerals are also contemplated.

7. Dynamic Rock Fracture Studies (P. M. Halleck)

Dynamic rock properties studies have relevance to the hot dry rock geothermal program and to general geophysical problems. One project is the modeling of fracture systems created by the simultaneous detonation of an explosive charge in two nearby boreholes.

A second project is the measurement of dynamic yield properties of the granodiorite from the Fenton Hill location as well as other rocks of interest to determine plastic yield criteria and will be performed using magnetic probes on a gas gun.

B. Observational and Analytical Petrology and Geochemistry (T. McGetchin, R. Gooley, G. Heiken, J. Balagna, R. Charles, R. Vidale, J. Reid, W. Laughlin, A. Eddy, F. Koch, C. Holley, L. Blatz, and subcontractors.)

1. Rock Permeability (J. Balagna, R. Charles, R. Vidale)

Rock permeability studies on GT-2 core granite from the Fenton Hill geothermal site will be extended to higher pressure (2 kbar) and higher temperatures (300°C). Several new techniques will be tried including: use of stable and radioactive tracers to mark transport paths; use of both aqueous and inert solutions to distinguish between chemical and thermal effects on permeability; and use of chemically active fluids such as Na_2CO_3 solution to enlarge fluid flow channels. Considerable effort will also be directed towards further characterization of alteration minerals in flow channels and determination of the solid state behavior of rock as a function of temperature and pressure.

2. Rock-Solution Equilibria in Agitated Systems (J. Balagna, R. Charles, R. Vidale)

Approach to equilibrium between aqueous solution and rock samples in a closed system will continue to be studied by rocking-bomb experiments. The data obtained shows the compositions that solution and alteration minerals will tend to approach in specific segments of an open circulating dry hot rock system.

3. Circulating Systems Simulating Dry Hot Rock Systems (J. Balagna, R. Charles, R. Vidale)

Further runs are planned in the two existing circulating systems. These permit control of "surface" heat exchanger temperature, "down-hole" heat exchange temperature, total pressure, flow rate, and initial rock and solution composition. One new circulating system will be built that permits control of temperature gradients (as opposed to uniform temperatures) in both "surface" and "down-hole" heat exchangers.

Work in 1976 will concentrate on long, steady-state runs using granite from the Fenton Hill site core. Data will be obtained on solution composition and on progressive alteration in the "down-hole" exchanger and scaling in the "surface" exchanger by atomic absorption spectroscopy, optical microscopy, scanning electron microscopy, non-dispersive x-ray analysis, electron microprobe analysis and tracer studies.

4. Standard Mineral Synthesis and Phase Equilibria Studies (C. C. Herrick, R. Charles, H. Sheinberg and A. Hakkilla)

A program is underway to provide a source of reasonable quantities of pure or at least well-characterized hydrous and anhydrous materials of geologic interest. Selected minerals are currently being prepared for geodynamic shock wave experiments, heat capacity and heat of solution measurements, and use as microprobe standards. These preparations require high pressure equipment, hydrothermal techniques, high-temperature sintering, or the plasma torch.

A $\frac{3}{4}$-inch Boyd-England die assembly has been made for investigations of high temperature, high pressure phase equilibria. Temperatures from 900 to 1500°C and pressures from 10 to 15 kbar will be employed.

5. Trace Elements as Whole Rock Reactor Tracers (J. Balagna, R. Charles, R. Vidale)

Quantitative mineral separations and chemical analyses of the trace elements unique to each mineral are being made by neutron activation of GT-2 core samples. The intergranular deposits of trace elements will also be described quantitatively.

Trace element analyses will be used for keeping an inventory on the solution of specific minerals both in the laboratory experiments and at the Fenton Hill dry hot rock site.

If funding permits, a study will be initiated using the isotopes of Hydrogen, Carbon and Oxygen to describe the solution progress of the dry hot rock reservoir. The chemical procedures, expertise, and mass spectrometer are already within LASL.

6. Single Mineral Alteration in a Static System (J. Balagna, R. Charles, R. Vidale)

Rock-fluid reactions in the "down-hole" heat exchanger of the dry hot rock geothermal project can be interpreted more simply by first examining single mineral-fluid systems before reacting the more complex polymineralic systems. Pure single mineral phases are being reacted with a well-defined solution in a static system. The objective is to react individually the major phases of the granite system (quartz, two feldspars, and two micas) found in our geothermal project. Since the reaction between solution and mineral involves the appearance of time dependent secondary phases, these must be identified and characterized with our scanning electron microscope (SEM) or more sensitive surface techniques such as AUGER and ESCA microscopy. Preliminary analyses have been made using these methods.

7. Transport Modeling in Dry Hot Rock Systems Based on Experimental Data (J. Balagna, R. Charles, R. Vidale)

Correlation of transport modeling with rock-solution processes (i.e., geothermal systems and solution mining) first requires agreement between model and experiment in simple monomineralic systems and then application to polymineralic systems such as a granite rock. Monomineralic studies will be continued and polymineralic studies begin in 1976. Two kinds of modeling approaches will be used: a "Pathcalc" solution-solid reaction program developed by Helgeson (University of California/Berkeley) and modified by Herrick (LASL); and a finite-difference material transport program being developed by Fletcher (Stanford University) and Vidale (LASL).

8. Solution Mining Feasibility Studies (J. Balagna, R. Charles, R. Vidale)

Our work in rock-water interactions, high temperatures permeability, and trace element analyses, leads to the study of solution recovery of low concentration constituents of economic interest. Dry hot rock systems will involve the intimate association of hot water with large volumes of rock over a period of years as the heat is mined from the reservoir. A study of other recoverable components and of techniques for recovery is imperative and will be begun in 1976.

9. Accessory Minerals Found in Coal (R. Gooley, T. R. McGetchin, G. Heiken)

Samples are being collected from selected Western coal deposits for an intensive analytical study of the inorganic minerals that occur in coal. Petrographic studies will be followed by electron probe microanalysis of all accessory mineral phases. Samples of the sedimentary coal-bearing country rock will be taken and studied in an attempt to correlate the inorganic phases within the coal seams to the mineralogy and chemistry of the host rocks. Trace element site and accessory phases will be identified and, hopefully, mineral source in order to relate coal seams to their sedimentary environment and to provide data useful for coal deposit evaluation, extraction methods, and treating slag formations and furnace erosion problems.

10. Petrologic and Geochemical Studies of Upper Mantle Xenoliths from the Basalts of Hawaii and the Southern Rio Grande Rift (J. B. Reid)

Electron microprobe data from suites of peridotite xenoliths from Hawaii and southcentral New Mexico are providing new information on the nature of the geothermal gradient beneath these areas and are elucidating the processes by which olivine tholeiitic basalts are derived by partial melting of the spinel peridotite upper mantle at depths of 35-60 km beneath Hawaii. A third group of xenoliths from the West Potrillo Mountains, southcentral New Mexico, represent early cumulates and eventual deep-seated totally-crystallized entrapped liquids very closely related to the basalts that brought them to the surface. These rocks are shedding valuable light on the evolution of basaltic magmas deep beneath the Rio Grande rift and will be subjected to oxygen-isotope studies on the hydrous phases in the entrapped melt fragments, to elucidate the nature of volatile phases in the earth's interior.

11. Petrologic Investigation of Lithic Fragments Within the Bandelier Tuff (J. C. Eichelberger, R. Gooley, F. Koch)

A petrographic and analytical study is being made of lithic fragments taken from seven measured sections of both the lower and upper members of the Bandelier tuff in the vicinity of the dry hot rock (DHR) well GT-2 were sampled. Representative samples of pre-Bandelier volcanic rocks and Precambrian granites are being compared with the lithic fragments and will provide basic information about conditions and processes at depth and the kinds and abundances of rock types in basement before deep drilling begins.

12. Partial Melt Products of Deep Crustal Rocks (T. R. McGetchin, R. Gooley)

Samples of a garnet-bearing granulite from southern Utah are being prepared in an attempt at laboratory duplication of partial melting processes occurring in the lower crust or upper mantle. The product obtained by selective partial melting will be studied petrographically and by electron microprobe to infer resemblance to natural magma compositions. This study may resolve questions concerning fractionation of deep-seated rocks and the formation of certain types of magma.

13. Stable-Isotope Geochemistry (G. Landis, University of New Mexico)

Oxygen and hydrogen isotopic studies have been started to determine the nature and amount of interacting between the rocks and ground water or water from the magma which produced the Bandelier tuff. These studies will also contribute geothermometric data useful in deriving a thermal history of the site.

14. Solid-Inclusion Studies (C. Barker, University of Oklahoma)

These studies have as an objective the determination of the gases present during crystallization of the rocks. A strong possibility exists that a geobarometer may be found (using the mineral quartz) that will allow pressures prevailing at various times to be determined.

15. Equation of State Determinations (R. G. McQueen)

The shock wave physics group at LASL is engaged in measuring the equation of state of geophysical materials at high temperatures and pressures: rocks, iron, minerals, and iron alloys. The effort is pursued on both theoretical and experimental fronts, and provides constraints for material models of the earth's interior. Two-stage gun, reflected shock, and release isentrope procedures are employed, complemented by high-precision static x-ray measurements, and high precision ultrasonic measurements; the latter obtained through phase comparison interferometer techniques.

16. Chemical Analyses of Core Samples from Geothermal Well Holes (W. Laughlin, LASL; J. Husler, University of New Mexico)

Whole rock analyses are being conducted to provide base information for rock-water interaction experiments. Thirty-five analyses have been completed for wells GT-2 and EE-1.

C. Geochronology (W. Laughlin and subcontractors)

1. K-Ar Studies to Determine Times of Metamorphism (R. Forbes and D. Turner, University of Alaska)

Argon loss has been demonstrated in the deeper portions of geothermal well GT-2. This loss occurred in response to the 1.1 to 1.4 Myr thermal perturbation that occurred in the surrounding region. This technique is useful in dating metamorphic events.

2. Rb-Sr Studies to Determine Thermal Histories and Mineralization Sources (D. Brookins, University of New Mexico; W. Laughlin, LASL)

These studies are being employed to determine age of crystallization, times of metamorphism and sources of vein minerals in the Precambrian of the DHR drilling site; a locally derived source for calcite in fractures has been demonstrated.

3. Fission-Track Studies (C. Naeser, USGS)

These studies are being employed to determine thermal histories and have markedly demonstrated the 1.1 to 1.4 Myr thermal perturbation that occurred in the region of the Fenton Hill Geothermal Drilling Site.

4. Zircon Crystal Metamorphic Indicators (R. A. Heimlich, Kent State University, W. Laughlin, LASL)

The extreme resistance of zircon crystals to metamorphic effects can be employed to infer pre-metamorphic conditions and souce material of metamorphic rock. This study is yielding information regarding the geologic history of the Fenton Hill Geothermal Site.

D. Resource Surveys (T. McGetchin, D. Janney, G. Wecksung, A. Rice)

Work is in progress for the purpose of assimilating available standard cartographic data and remote sensor data into a common geographic frame for the purpose of typifying geologic structures. This work is relevant to any large scale geologic survey, whether it be directed to geothermal resources, conventional metallic mineral resources, coal resources, uranium resources, etc.

1. Conventional Cartography

Much data of interest is currently available from federal and state agencies, often in the form of multicolored maps. We have a capability for color-separating and digitizing these maps for the purpose of computer analysis. Computer codes are now being written which will permit these maps to be superimposed with each other, with land-use maps, and with political maps. The superposition may require both scaling and modest deformation in order to overcome scale distortions in individual maps.

2. ERTS Imagery

Codes have been prepared for reading ERTS image tapes into the LASL library of image processing subroutines. With these codes, we have done principal component analyses of the multi-spectral ERTS images. First indications are that the resulting images may show geologic structures with greater clarity than did the original images. Verification will require field geological studies.

A code obtained from Colorado State University for land-use analysis of ERTS images is now being prepared for use on the LASL computers. This activity is relevant to geological studies, for land surface usage is important in determining the actual availability of mineral resources for commercial utilization.

3. Data Base Formatting

The abundance of data from these various sources will be formatted and placed in a data base at LASL for use by geoscientists, energy planners, land-use planners, etc.

E. Igneous, Tectonic, and Heat Transport Processes

1. Modeling of Volcanic Phenomena

a. Scale Model of Volcanic Area of Island of Hawaii (R. Widdicombe, J. Neudecker, T. McGetchin)

A scale model has been constructed of the volcanic terrain features of the Island of Hawaii. Experiments are being carried out to study the lava flow pattern of eruptions from active vent locations, particularly with regard to possible hazards to the city of Hilo, Hawaii and its environs. The effectiveness of lava barricades on the approaches to Hilo will be examined, and options as to barricade locations will be investigated.

b. Similitude Relationships in Lava Modeling Experiments (J. Neudecker, T. McGetchin)

The effectiveness of scale model studies of volcanic lava flows is dependent upon understanding and establishing valid similitude relationships between the lava flow and the laboratory models. Work has been initiated to examine the governing hydrodynamic, thermodynamic, and geological equations of lava flow and to develop valid similarity relationships between the lava flow and the laboratory model materials such as how melting point waxes and modeled terrain features.

2. Thermal History of Plutons (U. Nitsan, C. Kolstad, T. McGetchin)

A study is being initiated of the cooling history of shallow plutons. Calculation procedures are explored for realistically modeling the various igneous processes in and near the pluton, such as emplacement, convection, crystallization and interaction with the pluton's environment. This investigation will emphasize the changes with time of the thermal regime in the crustal layers overlying the pluton in an effort to determine the potential for geothermal energy production.

3. Thermal Stress as a Major Tectonic Force (A. Rice)

Due to dimensions and temperature differences inherent in earth dynamic models, thermal stresses well above yield strengths are available for the earth's crust. Since other possible stress mechanisms such as shear from mantle convection are considerably below yield strength, temperature variations in the crust may govern the tectonic upheavals which expose ore deposits, etc. Theoretical and experimental modeling of the response of crustal material to thermal stresses are being developed.

4. Nonlinear Instabilities in Geophysical Phenomena (A. Rice)

Explosive volcanism and diatreme development theoretically proceeds as a thermal runaway mechanism in geophysical transport processes. Instabilities of this nature are related phenomenologically to the transition from laminar flow, and may occur periodically in massive mantle convection. Information on conditions for these instabilities and their manifestations is being expanded.

5. Geologic Manifestations of Mantle Convection (A. Rice)

LASL's strength in computational hydrodynamics make natural the exploration of mantle convection as a potential driving force of tectonic mechanisms. To rationally guide such an effort, geologic constraints are being examined in order to relate field observations with theoretical and laboratory convection processes. Of particular interest is the possible rafting of the North American continent over the East Pacific Rise with potentially attendant development of Basin and Range features.

6. The Effect of Scattering on Radiative Heat Transfer in the Earth's Mantle (U. Nitsan)

Previous calculations of the effective thermal conductivity due to radiative heat transfer in Earth materials neglected scattering of radiation. Work is underway to examine if, and under what conditions, the effect of scattering is important. The study includes (a) a determination, by a combination of measurements and theoretical calculations, of the scattering coefficient and phase function of mantle rocks, and (b) calculations of the radiative heat transfer by solving the equation of transfer in the diffusion (Rosseland) approximation using the parameters obtained in (a).

Preliminary results indicate that the dominant scattering mechanism in mantle rocks is reflection and refraction of IR radiation by grain boundaries and that the intensity of the scattered radiation is strongly peaked in the forward direction.

7. Mechanics of Caldera and Ash Forming Eruptions (T. McGetchin)

Numerical computations of steam charged magma assuming isentropic shock tube flow in the vent are yielding shock propagation parameters, particule paths and velocities (for ash), gas temperatures, etc., over a wide range of given conditions.

F. Rock Mechanics

1. Fracture Studies (G. Simmons, MIT; A. Eddy, W. Laughlin, LASL)

Determinations are being made of the amount, type and timing of microfractures in Precambrian rocks taken from cores of geothermal wells GT-2 and EE-1 in order to assess the impermeability to fluid loss and mineral dissolution of the geothermal reservoir at these sites.

2. Paleomagnetic Studies (R. Dubois, University of Oklahoma; W. Laughlin, LASL)

Core orientation, hence orientation of planar features such as foliation, veins, and fractures (hydraulic or otherwise) is being attempted by paleomagnetic measurements.

3. Hydraulic Fracture Detection and Definition (R. Potter, L. Aamodt, J. Albright)

An important objective of the Los Alamos DHR project is the characterization of hydraulic fractures using near field monitoring of microseismic events associated with fracture initiation and extension. At present, a single station, three-component downhole geophone system is providing basic data on a hydraulic fracture created at 3 km depth in crystalline rock, for frequency and time domain studies concerning source location--thereby fracture dimension and orientation--and source mechanism.

G. Thermal Regime in Glaciers and Ice Sheets (U. Nitsan)

Successively more realistic models are being used to calculate the thermal and flow regime in glaciers and ice sheets. The models include conduction, convection and viscous heat generation within the ice body as well as the effects of surface temperature, accumulation rate and geothermal heat flux at the bed. An extension of this work is planned for temperate glaciers and for cases in which the bed temperature reaches the pressure melting point in an effort to determine more accurately the conditions for thermal instability and to model the development of an instability after it is initiated. The results of these calculations will be compared to observations of glaciers in an attempt to determine the relevance of thermal instability to surges in glaciers and to the rapid disintegration of continental ice sheets.

H. Field Investigations

1. Southern Cascades (J. Eichelberger, G. Heiken, T. McGetchin)

Geology, geophysics, geochemistry and petrology investigations of the Southern Cascades is being undertaken in a coordinated, 5-year program. This region has excellent geothermal potential and is a classic representative of plate tectonic dynamics, a manifestation of which is circum-Pacific andesite volcanism.

2. Mt. Baker Volcanic Activity (J. Eichelberger, G. Heiken, R. Widdicombe, LASL; D. Wright, J. Keady, D. Cobb, EG&G)

Recent increased fumarole activity on Mt. Baker provides the opportunity to expand considerably rather scanty information on volcanic processes in the Cascade Range. Photographic monitoring of activity in conjunction with IR overflights and gas- and rock-sampling are being carried out. This effort also serves to alert for geologic hazards such as intense eruption.

3. Hawaiian Volcanic Activity (T. McGetchin, J. Eichelberger, R. Gooley, G. Heiken)

Full scale observational efforts will be launched if there are significant basalt eruptions. Field data will be collected on the physical properties and gas compositions of the lavas and tephra and the eruption phenomena.

I. Seismology

1. Regional Network (K. Olsen, D. Cash, E. Homuth, J. Stewart, T. Handel, C. Newton, R. Bridwell, C. Edwards, W. Meadows)

An array of thirteen short period vertical component seismic stations in northern New Mexico is continuously recorded. Several stations have horizontal component instruments but not all can be telemetered to the recording station in Los Alamos. The film and paper seismograms are read daily for the purpose of identifying the seismic source. A catalog of local and near regional earthquakes is maintained and these data are used to calculate the seismicity around Los Alamos.

2. Portable Seismic Recording (K. Olsen, D. Cash, E. Homuth, J. Stewart, T. Handel, C. Newton)

Five smoked paper recorders and one analog 14-channel tape recorder are used as needed to record explosions, background noise levels, microearthquake activity, and earthquake aftershocks. Data from these $\leq$ 24-hour seismograms are used to determine seismic velocities, suitability of sites for locating network stations, seismicity, and earthquake fault zones.

3. Geothermal Experiment Monitoring Network (K. Olsen, E. Homuth, J. Stewart, T. Handel, C. Newton, R. Bridwell, C. Edwards, W. Meadows)

A special narrow aperture seismic array was operated during hydraulic fracturing phases of the Hot Dry Rock Geothermal Demonstration at LASL (Group Q-22). When that phase terminated temporarily two of the stations were made a part of the regional network.

4. Tiltmeter Instrumentation (E. Homuth, W. Johnson, J. Martin)

A low cost, mercury, long baseline (approximately 15 meters) tiltmeter with a sensitivity near 10^{-12} radians has been designed and built. After a suitable period of testing and adjusment (now in progress), others will be built and installed in areas of suspected tectonic creep (e.g., along the Rio Grande Rift and around the Valles Caldera).

5. Triggered Digital Seismic Tape Recorder (MPRC--Micro Powered Digital Recorder), (E. Homuth, F. Honey, J. Hollinrake)

A small, low power, digital tape recorder has been designed to record seismic ground motion when triggered by the first arrival of seismic energy. A prototype is nearly complete and field testing in microearthquake areas is expected to be done later this year. This unit, with a more sensitive transducer, was adapted from similar units being developed for recording strong ground motions within approximately 2 km of underground nuclear tests at the Nevada test site.

6. Velocity Modeling (D. Cash, R. Bridwell, C. Newton)

Travel time and amplitude data are being used to infer models of crust and upper mantle seismic velocities and densities around north central New Mexico. Analytical techniques include inversion of refraction profile and teleseismic arrival time data and synthesizing seismograms using generalized ray theory.

7. Earthquake Source Mechanisms (K. Olsen, D. Cash, E. Homuth, C. Newton)

Composite first motion data and aftershock locations will be used (when sufficient data are accumulated) to determine fault planes and slip vectors for earthquakes around northcentral New Mexico.

J. Potential Field Methods of Exploration

1. Magnetometer Surveys

Surface recorded magnetometer surveys in areas of tectonic faulting and Cenzoic volcanism will be initiated when the more urgent requirements of the seismology programs are satisfied.

2. Gravimeter Surveys (D. Cash, R. Bridwell)

A low level of effort is currently directed toward interpretation of gravity data. Data presently under investigation is largely from the Nevada Test Site, but future plans include the purchase of a gravimeter to assist in the interpretation of crustal structure in north central New Mexico.

3. Seismic Reflection Surveys (K. Olsen, D. Cash, C. Newton, C. Edwards, T. Weaver)

Specifications are being developed for several detailed shallow ($\leq$ 3 km) seismic reflection profiles to be carried out at the NTS using the most modern equipment and digital data processing techniques now provided by commercial geophysical exploration companies. In addition to the data acquired for test site applications, the experience will be used to assess the suitability and potential usefulness of such techniques for crustal exploration in the vicinity of Los Alamos.

K. Regional Tectonic Analysis of Rio Grande Rift (R. Bridwell)

A program is underway to integrate geological, geophysical, and geothermal data on the regional scale. To date, one review paper has delineated that the Rio Grande Rift has high heat flow, a moderate level of seismicity, high electrical conductivity, relatively young continental and, to a lesser degree, oceanic basaltic volcanism, and concomitant tectonism. These features are interpreted as representing a thinned crust and anomalous upper mantle intruded below the Rift as a mantle upwarp.

1. Mechanical Analysis of Stress (R. J. Bridwell)

Finite element models of the effects of mantle upwarps, deduced from regional data, have been evaluated to ascertain relative rates of uplift due to buoyancy.

2. Thermal Models of Rio Grande Rift (R. J. Bridwell)

A thermoelastic finite element code has been used to predict regional temperature depth distributions from measured surface heat flow. Structures for this model are deduced from regional structural geology and seismic refraction profiles, new local refraction data, and gravity interpretations of the shape of the local rift valleys. Preliminary results appear to be in accord with studies of others. Several abstracts have been prepared discussing the regional tectonic implications of thermal models.

L. Theoretical Source Mechanism Studies (R. Bridwell, G. Frazier)

Three dimensional wave propagation models, using a dynamic finite element code developed by Frazier, have been simulated to evaluate synthetic seismograms, displacement, and velocity fields produced during fault rupture and propagation with attendant stress drop.

M. Modeling of Geothermal Systems

1. Model Geothermal System (L. Blatz, C. Holley, G. Tester)

A dynamic system has been designed and is presently nearing completion to evaluate the rate of rock solution in superheated water and the rate of redeposition of dissolved rock components on the walls of a heat exchanger.

2. Static High Temperature, High Pressure Bomb Experiments (L. Blatz, C. Holley)

A series of static bomb measurements in the temperature range 200-300°C have been initiated to determine the solubility of pure SiO_2 in water and the effect of added oxidizing and reducing agents.

3. Thermodynamic Modeling of Geochemical Systems (C. C. Herrick)

Modeling is being applied to two types of rock-water interactions. The first type, which occurs on a relatively brief time scale, is concerned with the sequence of reactions at the rock-solution interface, e.g., in the Hot Dry Rock experiment. The second type, which occurs on a geologic time scale and within a rock, is typical of metasomatic processes such as ore deposition. Both models simulate time-dependent processes and are continually subject to improvement as new thermodynamic data for solid and aqueous phases appear, the equation of state for water is revised, and the numerical techniques are exploited for optimum program performance.

Testing of the model predictions for the first type of rock-water interaction has been done at LASL by single mineral alternation of albite in a static system. The objective is to test model predictions against experiments on simple systems, to provide the basis for computer calculations for complex polymineralic systems for which experiments are impractical.

Contractor: OAK RIDGE NATIONAL LABORATORY
Union Carbide Corporation
Nuclear Division
Oak Ridge, Tennessee 37830

Contract: 05ENG26

Title: Physical Chemistry of Geothermal Solutions

Person in Charge: R. E. Mesmer

Scope of Work

The objective of this program is to provide basic physical chemical information of several kinds on geothermal solutions in support of the governmental, industrial and academic efforts to harness geothermal energy from the various sources encountered in the Western U.S. Specifically we conduct potentiometric, isopiestic, conductance, calorimetric, light scattering and theoretical modeling studies as the level of funding permits on the properties of the brines and their interactions with minerals which occur most prominently. Among the homogeneous equilibria upon which this program focuses are the ionization of water in brines, the ionization of silicic acid and polysilicate equilibria, fluorosilicate equilibria, carbonate ionization equilibria as well as hydrolysis reactions, particularly of magnesium and calcium ions, and the association of chloride with metal ions. Heterogeneous systems of dominant importance will be investigated commencing with the pH dependence and salt effect on the solubility of quartz with later expansion to other silicate systems. The program would also include calorimetric studies on the heats of solutions of salts and heats of reactions in solution at high temperatures using a flowing-solution concept incorporating a Calvet heat-flow calorimeter. The simplified models developing in other ORNL programs for calculation of activity and osmotic coefficients in mixed salt solutions are being applied particularly to the concentrated brines found in the Imperial Valley.

Capacity for potentiometric measurement of pH at temperatures to 300°C is available as a result of previous AEC programs. This equipment, as well as the techniques, require some modification for heterogeneous equilibria. The conductance equipment capable of making measurements in neutral or acidic solutions at temperatures to 800°C and 4000 bars can be applied without appreciable modification. Isopiestic apparatus which was developed over the last 20 years at ORNL for measurements at temperatures to about 200°C have been reactivated. This isopiestic program requires precise measurements in solutions more dilute than previously studied thus more severely testing the uniformity of temperature control and the precision of weighing.

A. Ionization of Water in NaCl Solutions to 300°C (R. E. Mesmer, R. H. Busey)

Because the ionization of water was previously extensively determined only in KCl media at high temperatures, we initiated our geothermal program with a few experiments to determine the salt effect in NaCl media--that most relevant to geothermal waters. Measurements in 1 m and 3 m NaCl were made from 50°C to 300°C in the stirred hydrogen electrode concentration cell. The different (log Q_w)NaCl- (log Q_w) KCl varies from about 0.01 at 50° to about 0.09 (I=1 m) and about 0.16 (I=3 m) at 300°C. These data in NaCl can be fitted within twice the estimated standard error with an expression of the Bronsted-Guggenheim type where the interaction coefficient varies with temperature and ionic strength as a four parameter function. This important equilibrium reaction is now well determined under the conditions encountered in many geochemical and other practical systems at temperatures to 300°C and the effect of salt concentration can be extrapolated with useful accuracy to near saturation.

B. Ionization and Polymerization of Silicic Acid (R. E. Mesmer, R. H. Busey)

Equilibrium data on Si(IV) in solution is needed because of the relatively high concentrations sometimes encountered in natural brines and the prominence of silicate chemistry in geothermal and geochemical systems. Presently it appears that the behavior of dissolved silica is very complex at low temperatures and from our observations simpler at temperatures greater than 150°C. At low temperatures, large anionic polymers occur in solutions of moderate Si(V) concentrations but in relatively basic solutions smaller species occur, principally $SiO(OH)_3^-$ and probably $Si_4O_6(OH)_6^{2-}$. From potentiometric measurements covering broad variations of composition, equilibrium information on these species is being obtained. Titration experiments on solutions of 0.005 to 0.05m in Si(IV) have been carried out from 60°C to 200°C in 1 m NaCl in a hydrogen electrode concentration cell. Conditions where precipitation occurs were observed, and the data will ultimately be interpreted in terms of the species present. When completed, this study will provide data on the first and second ionization equilibria of $Si(OH)_4(Aq)$ as a function of salt concentration and temperature as well as information on the small polynuclear anionic silicates present in solution at high pH. Such information is needed in support of the project on geothermal scaling also being conducted at ORNL and other ERDA-related programs pervaded by the chemistry of silica.

C. Activity Coefficients in Geothermal Solutions (C. F. Baes, Jr., M. H. Leitzke, H. F. Holmes)

Measurements of activity coefficients of the components in concentrated geothermal brines are needed for the development of adequate models for the description of geothermal solutions in terms of the thermodynamic parameters of the components. For this purpose the high temperature isopiestic facility at ORNL is being reactivated and modified. We are using NaCl and $MgCl_2$ as isopiestic standards for initial studies on KCl and $CaCl_2$ as well as mixtures of NaCl, KCl and $CaCl_2$. The previously demonstrated precision of the weighing mechanism and the temperature control appear to be adequate for this purpose. Simplified models which have been developed in related programs will be tested with the results.

Contractor: SANDIA LABORATORIES
Albuquerque, New Mexico 87115

Contract: 2910789

Title: Magma Energy Research

Person in Charge: G. E. Brandvold

Scope of Work

Sandia Laboratories has in progress an engineering research program investigating the feasibility of extracting energy directly from buried circulating magma sources. Typically these magma deposits have temperatures on the order of 1000°C and represent great concentrations of high quality thermal energy. The amount of this high quality energy contained in the geothermal resource base of molten rock within the top 10 km of the surface of the United States is estimated by the U.S. Geological Survey to be $13,000 \times 10^{18}$ calories. This is equivalent to 2700 times the energy represented by the domestic U.S. petroleum production in 1974.

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 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.

The proposed concept has many speculative aspects, and therefore the research program is planned so that the "regret costs" will be low should the concept be proven infeasible or economically undesirable. Preliminary studies have shown that the concept may be both technically and economically feasible if (a) the magma exists in the form of a liquid pool, (b) the magma source is not more than, say, 5 or 10 miles below the surface, and (c) a heat exchanger can be designed to withstand the corrosive environment in the magma. However, the studies also indicate that the concept could be technically feasible if the magma exists in a network of intrusions in the rock, even at depths of more than 10 miles, but there are too many unknowns at this time (drilling techniques and costs, and in situ magma properties) to evaluate the economic viability.

A. Magma Energy

1. General (J. L. Colp)

A Magma Energy Research Advisory Panel with seven members (two from the U.S. Geological Survey and five from universities), each having recognized expertise in a field related to this project, was established early in the program. In addition to providing advice and direction to the overall project, each individual member provides consultation to one or more of the project principal investigators on a one-on-one basis. The entire panel meets only twice each year, but numerous one-on-one consultations are held. The establishment of this panel has resulted in improved performance of this project and in better, clearer directions for continuing work.

A Magma Workshop with participation limited to about 25 invited experts was held in March 1975. The objective was to assess the present state of knowledge of the occurrence of magma chambers, the chemical and physical properties of in situ magma, and the methods of exploration for magma and to recommend the most critically needed research and development in these areas. The results of this Workshop have been published by Sandia.

2. Source Location and Identification (J. L. Colp)

Cooperation with the U.S. Geological Survey, other government groups, and universities is being emphasized in this phase. Implementation of Magma Workshop recommendations include ongoing programs of seismic surveys of possible magma chamber existence at Augustine volcano, demonstrations, of seismic, electrical, and electromagnetic sensing capabilities over a known molten rock deposit in Hawaii, and the planned physical delineation by drilling of the Hawaiian deposit.

3. Source Tapping (J. L. Colp)

Cooperation with other groups interested in deep drilling, such as the Continental Drilling Program, LASL Subterrene program and others, is conducted in this phase. Sandia has an ongoing ERDA-funded program on drilling improvement and downhole hot-well logging. A high pressure/high temperature rock properties experimental study is being funded at Texas A&M University.

4. Magma/Materials Interactions (M. J. David, E. J. Graeber, P. Modreski, T. Gerlach)

Laboratory testing to determine the interactions between three selected magma simulants with a variety of engineering materials under conditions of high temperatures and moderate pressures have been performed. In accordance with the recommendations of the Magma Workshop, new facilities to continue this experiment series at conditions of 1600°C temperature, 4 kilobars pressure and with selected additive gases are being procured and installed.

Field experiments to observe material interactions with molten lava and volcanic gases at Kilauea volcano in cooperation with the University of Hawaii have been and are continuing to be performed as opportunities become available.

5. Energy Extraction (H. C. Hardee)

Analytical models of the extraction of thermal energy from molten rock have been developed and are being refined. A laboratory experiment to measure heat extraction rates from molten lava has been successfully performed. A laboratory experiment to study the thermodynamics of long, concentric single tube boilers has been designed and the necessary equipment has been procured.

Field experiments to measure heat flux values in naturally-occurring molten rock at Kilauea volcano have been performed. The initial test was not completely successful and modified equipment now awaits another opportunity to enter the molten material. A field lava lake research experiment to study heat extraction from molten rock on a larger scale and to obtain measurements to verify analytical model studies is being planned for performance in FY 1978.

The Magma Energy Project has been structured to interrelate with several organizations outside of Sandia Laboratories. A good working relationship exists between this project and the USGS Geothermal Program. Cooperation with the USGS, Menlo Park, on magma exploration methods has existed from the very start of this project. Cooperative efforts with the USGS Hawaii Volcano Observatory personnel on making measurements on Kilauea volcano have occurred in the past and are planned for the future. Personnel from the USGS Denver office are being funded by this project to make measurements on Kilauea Iki lava lake.

The project is either currently funding or plans to fund several university research contracts. These include: University of Hawaii work on materials compatibility in fresh lava and volcanic gases; University of Alaska work on magma sensing on Augustine volcano; the aforementioned Texas A&M University study on rock properties; Massachusetts Institute of Technology study on seismic sensing of molten rock in Kilauea Iki; and Lamont-Doherty Geological Observatory study on magnetoelectric sensing of molten rock in Kilauea Iki.

In addition, cooperative liaison is being maintained with several other universities having magma-related geothermal programs. These include: the University of Hawaii Puna District Geothermal project; the Colorado School of Mines study at Kilauea volcano; the University of Texas program; the University of Oregon magma studies; and the University of Washington Mt. Baker studies.

Our Laboratories' close physical location to and past working relationship with Los Alamos Scientific Laboratory enables us to cooperate closely with their Geosciences Group, Geothermal Energy Project, and Subterrene Project.

PART II

GEOSCIENCES

OFF-SITE

Contractor: UNIVERSITY OF ALASKA
Geophysical Institute
Fairbanks, Alaska 99701

Contract: 4512229 #5

Title: A Study of Magnetospheric Substorms in Conjunction with the IMP-1 and Vela Satellite Data

Person in Charge: Syn-Ichi Akasofu

Scope of Work

The objectives of the proposed contract are to work jointly with scientists in the Los Alamos Scientific Laboratory and the Lawrence Livermore Laboratory on a variety of geophysical phenomena which might give us some insight into problems associated with thermonuclear energy production. Specifically, we are interested in basic processes associated with the solar wind (plasma)-magnetosphere dynamo and also in the emission of the auroral green line (5577A). It is proposed to study the distribution of plasmas in the magnetosphere on the basis of the IMP-I,J, Vela and ATS-5 satellites and also photo-chemical processes which lead to the excitation of oxygen atoms.

Contractor: UNIVERSITY OF ALASKA
Geophysical Institute
Fairbanks, Alaska 99701

Contract: 4512229 #6

Title: Alaska Peninsula Telemetered Seismic Network: Phase III

Person in Charge: H. Pulpan

Scope of Work

The addition of three remote short period seismic stations to the eastern Aleutian-Alaska Peninsula network is proposed. Signals of these stations are VHF-telemetered into existing stations of the network and eventually to a central recording site in Homer, Alaska.

Contractor: UNIVERSITY OF ALASKA
Geophysical Institute
Fairbanks, Alaska 99701

Contract: 4512229 #8

Title: Search for Shallow Magma Accumulations at Augustine Volcano

Person in Charge: J. Kienle

Scope of Work

Three large plug domes were extruded from the volcano the last 39 years, and the theoretical constraints concerning their cooling history, along with strong attenuation of body waves from local microearthquakes, suggest that a shallow andesitic magma accumulation may exist below the volcano. If proven, such a reservoir would be extremely useful to test new concepts in geothermal energy, such as hot-rock heat extraction techniques and direct magma tap. The primary objectives of the proposed research are: 1) to study the feasibility of using thermal methods and seismic fan shooting techniques as geophysical prospecting tools for magma detection; 2) to investigate the presence of magma at a very shallow depth below Augustine and to try to delineate the shape and size of the suspected magma body; 3) to estimate the viscosity of this body; 4) to thus gain insight into the internal plumbing and modes of magma transport and storage in a typical andesitic composite volcanic cone; and 5) to assess the potential of Augustine Volcano as a natural geothermal laboratory to test novel techniques of geothermal power generation such as hot-rock techniques and direct magma tap. Two geophysical techniques will be used to investigate the suspected shallow magma body at Augustine. Seismic fan shooting: partially or fully molten rock will strongly attenuate high frequency P- and S-waves. Fan shooting in different quadrants and at different elevations of the volcano will permit the detection of central molten zones. Heat flow: preliminary heat flow studies on the summit of the volcano suggest a minimum flow of 1600 to 7000 HFU's and advective and convective heat transfer below a depth of 12 cm. In order to improve these estimates, it is planned to conduct detailed shallow pit temperature surveys over the entire summit area and to study thermal stability in order to test the permanence of anomalies detected in a preliminary survey.

Contractor: UNIVERSITY OF CALIFORNIA
Berkeley, California 94720

Contract: 0430034 #32

Title: Isotopic Studies in Rare Gases in Terrestrial Samples and in Natural Nucleosynthesis

Person in Charge: J.H. Reynolds

Scope of Work

This laboratory conducts 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. Working with terrestrial samples it is observed that in subterraneous gases the 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 that 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 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 with particular interest in assaying the proportions of recycled atmospheric gas and radiogenic gas which originated in the rocks will also be examined. This group maintains a continuing interest in geochronology, particularly in problems where physicists--as opposed to geologists--can make contributions. For example one current interest is how explosive shock and controlled heating can affect the apparent age patterns in the ^{40}Ar-^{39}Ar method of K-Ar dating, which originated some years ago in this laboratory. Studies in natural nucleosynthesis make use of the meteorites and the clues they contain to the chronology of nucleosynthesis by virtue of the presence of traces of rare gases which are daughter products of extinct and extant radioactivities. An interest is also maintained in isotopic inhomogeneities, such as have here been observed in the carbonaceous chondrites, and the possibility that they may originate because of incomplete isotopic mixing of fractions with different histories of nucleosynthesis.

Contractor: UNIVERSITY OF CALIFORNIA
Institute of Geophysics and Planetary Physics
Los Angeles, California 90024

Contract: 0430034 #224

Title: Relationship of Rock Physics and Petrology to Geothermal Energy

Person in Charge: O. L. Anderson

Scope of Work

The research done under this grant was conceived as a supplement to the active research program underway at Los Alamos Scientific Laboratory within the geothermal energy program. Effort is concentrated on hydrothermal alteration and surface properties of rocks, and their relation to sound velocity. Studies are proceeding on the propagation of sound waves in samples in which hydrothermal alteration of the rock grains and pore structures can be controlled. Surface wave measurements are being carried out on altered rocks from J. Balagna's Laboratory at LASL and it is hoped to provide new information on the effects of rock structure on, and of geothermal solution interaction with, the seismic properties of rocks in possible geothermal regions.

Contractor: UNIVERSITY OF CALIFORNIA
Institute of Geophysics and Planetary Physics
Los Angeles, California 90024

Contract: 0430034 #171

Title: Compressibility Measurements

Person in Charge: G. C. Kennedy

Scope of Work

Efforts are under way to determine Gruneissen's gamma by the method of release adiabats. Experimentally, a solid is taken to high pressures and high temperatures and then decompress the solid over a few bars or tens of bars. Decompression takes place in a few seconds time. The temperature drop is then observed owing to adiabatic expansion. From this measured temperature drop, the value of Gruneissen's gamma can then be computed. Results, to date, on lead suggest that Gruneissen's gamma is essentially as estimated from thermodynamic data at room temperature and pressure. However, work is progressing with lead only to calibrate this method. The behavior of the alkali metals will soon be examined by these techniques.

Contractor: COLUMBIA UNIVERSITY
New York, New York 10027

Contract: 1112441

Title: Maps of North American Crustal Stability and Geothermal Potential

Person in Charge: R. W. Fairbridge

Scope of Work

The objective of this program is a quantitative study and cartographic presentation of crustal stability and geothermal potential of North America on a 1:6 million scale (i.e. a single map sheet).

The effort is intended to provide source material for first approximation assessment of geothermal feasibility and long term site stability (for installations relating to atomic energy as well as other major structures) on a geographic basis. Both practical needs and important academic needs will be served as no such large scale mapping exists. A data base for map construction is being obtained from various government agencies (e.g. NOAA, USGS, etc.) in digitized form and will be processed by computer techniques. Useful information from the open literature is also being drawn upon and digitized. Cross correlation analyses are to provide statistical integration of geophysical variables, i.e., tide gauge, geodetic relevelling, seismic, residual stress, gravity, structural, heat flow, and other data in order to weight tendencies for crustal motion. Liaison has also been opened with the Defense Mapping Agency and other governmental offices engaged in cartographic activities. The assessment of in-house mapping techniques of several federal agencies to determine compatibility for maps of this nature is being made. Certain exchange agreement policies may allow an agency to construct maps from our finalized results in some standard form. This project as planned, will extend for a period of over three years, the first part of which is being directed to a contemporary (last 100 years) neotectonic map of Eastern North America. Longer period maps extending over the rest of the North American continent will be developed in the second or third phases of the project.

Contractor: COLUMBIA UNIVERSITY
Lamont-Doherty Geological Observatory
Palisades, New York 10964

Contract: 1113134

Title: A Comprehensive Study of the Seismotectonics of the Eastern Aleutian Arc

Person in Charge: L. Sykes

Scope of Work

Seismological, geodetic and geological data are analyzed to derive a coherent theory for the present tectonic processes and history of the eastern Aleutian arc in the framework of recent advances in plate tectonics. The seismic and tsunami risk is evaluated to lay the basis for an earthquake prediction program. Seismic studies of Pavlof Volcano are made to delineate its magma chamber. A large aperture seismic network has been installed to obtain a broad, long term data base for the seismotectonic study of the arc. A more concentrated network has been installed in the Shumagin Islands, a region identified as a seismic gap, to detect premonitory seismic changes which may allow the prediction of the expected earthquake. A very dense network around Pavlof Volcano is proposed. Geodetic measurements of dry tilt figures and 1 km level lines are made to monitor strain accumulation.

Contractor: MASSACHUSETTS INSTITUTE OF TECHNOLOGY

Contract: 1112534

Title: Seismological Investigation of Crack Formation in Hydraulic Rock Fracturing Experiments and in Natural Geothermal Environments

Person in Charge: K. Aki

Scope of Work

An active seismic method for defining cracks in hydrofracturing experiments will be developed by a computational study of seismic waves diffracted by cracks. Self-contained, event-recording digital seismographs will be constructed and deployed in the field to determine the source mechanism of seismic events and the earth's structure in geothermal areas.

TOPICAL INDEX