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Summaries of Physical Research in the Geosciences

September 1978

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FORWARD

The Department of Energy supports research in the geosciences in order to provide a sound underlay of fundamental knowledge in those areas of the earth, atmospheric, and solar/terrestrial sciences which relate to DOE's many missions. This research may be conducted in the major DOE 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 the Department and the organization performing the work.

The summaries in this document, prepared by the investigators, describe the work performed during 1977, include the scope of the work to be performed in 1978 and provide information regarding some of the research planned for 1979. The Division of Engineering, Mathematics, and Geosciences, which is a part of the Office of Energy Research, supports, under its Geoscience Program, research in geology, petrology, geophysics, geochemistry, hydrology, solar-terrestrial relationships, aeronomy, seismology and natural resource analysis, including the various subdivisions and interdisciplinary relationships, as well as their relationship to the Department's technological needs.

PART I

GEOSCIENCES

ON-SITE

Contractor: Argonne National Laboratory
Argonne, Illinois 60439

Contract: 109 ENG 38

Title: I. Geosciences Program

Person in Charge: F. A. Cafasso, M. Steindler

Scope of Work

A. Thermochemistry of Geothermal Materials (F. A. Cafasso/C. E. Johnson)

This program involves measurement of thermochemical properties of minerals of geochemical interest. Enthalpy of formation ($\Delta H^\circ_{f,298}$) and enthalpy increments ($H^\circ - H^\circ_{298}$) of sulfide minerals are determined by fluorine bomb and drop calorimetry respectively. Solution calorimetry is being used to determine hydration enthalpies of selected zeolites (e.g. Mordenite and Phillipsite) and an attempt is being made to develop a correlative scheme for predicting hydration enthalpies of other unmeasured zeolites. Research is planned on enthalpies and heat capacities at elevated pressures of brine systems having compositions characteristic of geothermal systems.

B. Trace Element Transport in Geologic Media (M. Seitz)

Transport of trace elements by flowing aqueous fluids through geologic media at high temperatures is examined principally by hydrothermal experiments in which liquid is pumped through packed columns of rock or minerals. Infiltration experiments are used because migration depends on flow rate, solution composition, and on solid-solution impurities in minerals. In addition, migration is difficult to model with thermodynamic data derived from static experiments. Hydrothermal experiments in the temperature range 50 to 600°C and at pressures to 500 bars are used to provide data on migration in geologic formations at elevated temperatures. In addition, high temperatures accelerate reactions, and with consideration of temperature coefficients, chemical mechanisms and phase stability, extrapolation to geologic time scales at lower temperatures is possible.

Studies are conducted or planned with cations (e.g., strontium, cesium, and actinides) and anions (e.g., iodide) as trace elements with hydrous silicates, feldspars, and quartz as the geologic media. Migration is studied as functions of pH and composition including dissolved gases in aqueous solutions, and as functions of temperatures and fluid flow.

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

Contract: EY-76-C-06-1830

Title: I. Remote Sensing/Geoscience Data Analysis Methodology

Person in Charge: J. R. Eliason

Scope of Work

The objective of this program is to conduct research in remote sensing and to develop data analysis methodology and instrumentation required to meet DOE's needs for data relating to geoscience and the environment.

A. Remote Sensing and Geophysical Data Set Correlation (H. P. Foote, T. N. Bishop)

Geological remote sensing is generally most effective when it can be combined with other kinds of geological and geophysical data. Data correlation methodologies are being developed to effectively acquire, process, and utilize combinations of remote sensing and geophysical data sets. These techniques will be based on conversion of remote sensing and geophysical data into compatible digital data sets which can be analyzed on high-speed digital computer systems and displayed on computer graphics devices.

B. Image Enhancement and Classification (H. P. Foote)

Computer and analog processing techniques are being developed for enhancing and analyzing multispectral satellite and aerial remote sensing data. These techniques include spectral analysis, image enhancement, noise filtering, pattern recognition, texture analysis and geographic transformations.

C. Instrumentation Development (H. P. Foote, G. A. Sandness)

PNL develops aerial imaging systems for specific remote sensing applications. These systems include both optical, mechanical and photographic systems which can be configured with various sensors or film. Also, an interactive digital system is being developed to conduct data analysis required to produce final remote sensing data products.

D. Simulation of Solid Earth Processes (H. P. Foote)

Advanced data analysis methodologies are used by PNL geoscientists to better understand large-scale geologic processes in the Pacific Northwest Region. These studies will provide data needed to develop an initial simulation model of tectonic processes in this region.

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

Contract: EY-76-C-06-1830

Title: II. Development and Operation of DOE Insolation-Aeronomy Observatory

Person in Charge: R. A. Stokes

Scope of Work

The insolation and aeronomy programs at Battelle Observatory are concerned with measurement and characterization of ground-based solar flux (insolation) and nighttime, upper-atmospheric, optical emissions (auroras). The insolation program is directed toward spectral resolution studies of direct and diffuse solar radiation and high spatial resolution measurements of the diffuse component of solar radiation. Data acquired in the program will have direct applicability to solar power site evaluations, photovoltaic and photo-biological programs, and it will provide the basis for a quantification of insolation modification by clouds and aerosols.

Since insolation studies and 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 focused on use of nighttime optical emissions as a diagnostic tool for investigation of the state of the upper atmosphere and the plasmasphere-magnetosphere interaction region. It is important to obtain a good understanding of the earth's magnetosphere because it influences not only radiation belts but helps protect the ozone layer, significantly affects radio communications, and it has been recently suggested that there exists a close but subtle relationship between the state of the magnetosphere and terrestrial weather.

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

1. Analysis

Analysis of insolation data proceeds at several levels. The fundamental objective is to provide carefully calibrated spectral data in the 300-1100 nm range to potential users. Data is to be archived at the National Climatic Center in Asheville, North Carolina. Direct solar measurements through seven filters are taken at five-minute intervals throughout each day, and all-sky scans are made every half hour. Routine data collection also includes higher spatial resolution solar-zenith and solar almucantar scans at half-hour intervals. On clear days, data provided by these latter measurements as well as direct measurements will be used to derive aerosol properties including average size, size distribution, index of refraction and, of course, quantity. A good deal of interest has been indicated by several investigators in the diffuse measurements as they will be of value in quantifying radiative transfer properties of clouds.

2. Experiment

The principal goal in this area is to measure and calibrate solar radiation both direct and diffuse at seven specific wavelengths. To this end, a Mobile Automatic Scanning Photometer has been developed. It is a dual-purpose instrument which makes nighttime observations as well.

The instrument measures insolation in spectral bands centered at 395.0 nm, 470.0 nm, 570.0 nm, 680.0 nm, 785.0 nm, 900.0 nm and 1010.0 nm. The field of view of the solar photometer is 1.5° . The basic scanning sequence was outlined above. Basic data yield both direct and diffuse measurements of radiation. We are in a developmental process on programs to synthesize these data to yield total radiation amounts for any orientation of a collector. The detection mode allows a basic stability in the measurement of ±2 % and the instrument module is portable and suitable for remote siting.

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

1. Analysis

The wealth of auroral phenomena which have optical emissions and occur in the mid-latitude region is notable. The prominent features are Stable Auroral Red arcs (SAR arc), Hydrogen arcs (H arc) and Diffuse Aurora (DIF).

The concept that pattern and spectrum composition of upper atmospheric optical emissions can be used to monitor structural features and dynamic processes of the magnetosphere is extremely useful. A recently completed analysis program included correlating nights when observations of plasma densities, temperatures and spectral energies were obtained by the ISIS-II, AEC, AED and ESRO-4 satellites simultaneously when ground observations of auroral optical emissions were obtained by the MASP units at Battelle Observatory, Richland, Washington, and at Hinsdale, Montana. A high spatial coincidence was found between the ground-based observed equatorward boundary of the diffuse 6300A auroral emission with the equatorward boundary of satellite observed soft particle precipitation and the F region electron density trough poleward cliff. If diffuse aurora is indeed the ionospheric counterpart of the plasmasheet earthward boundary, the 6300A diffuse boundary may afford a means of monitoring convection characteristics of the spectrally soft, near-earth, plasmasheet boundary over large spans of time and activity.

2. Observations

a. Battelle Observatory

Beginning in September 1967, all-sky photometric observations of the emissions [OI] 5577A, N_2 + 4278A and HB 4861, and continuums 5350, 6080, and 7150A have been taken routinely on all cloudless, moonless nights from Battelle

Observatory (latitude 46.4° 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 detailed investigations have been done at single stations, understanding the emission patterns tends to be regional. 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 Battelle Observatory is implemented on the MASP. The main thrust of the aeronomy observational program is siting, calibrating and operating MASP units as a part of the "Global Patterns" program. Three MASP units are now in operation, one at Battelle Observatory (latitude 46.4 N, longitude 119.6 °W), one at Hinsdale, Montana (latitude 48.6 ° N, longitude 107.1 °W), and one at Boulder, Colorado (latitude 40.1 °N, longitude 105.2 °W). Data are now being received from these stations and analysis programs have been initiated.

Battelle Observatory is a member of the International Magnetospheric Study (IMS). One MASP unit has been constructed and installed, and it is now providing data from Iron Mountain, (latitude 45.8 ° N, longitude 88.1 ° W), through this collaboration. Funds have been received to build two additional units for this program. This collaboration has proven to be a great asset to aeronomy research goals. The IMS program has organized a data center in Boulder, Colorado, at which each member reports his observations and can also retrieve whatever observations other members report that is pertinent to his research.

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

Contract: W-7405-ENG-48

Title: I. Geosciences Program

Person in Charge: Paul A. Witherspoon

Scope of Work

The Geosciences Program at Lawrence Berkeley Laboratory consists of four projects, three of which support the DOE effort in developing geothermal energy. These three projects cover investigations in reservoir dynamics, rock-fluid system properties, brine chemistry, geochemistry and mass transfer, thermodynamics of magmas, and collection and dissemination of geothermal information. The fourth project addresses problems relating to chemical transport in material systems, and has several applications including problems relating to leaching and transport of radioactive waste.

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

Background. The purpose of this project which was started in FY 1975 is to apply the principles of thermodynamics, hydrodynamics and geochemistry to geothermal and related systems. The investigations are a necessary part of the LBL program to develop geothermal energy from low-salinity, high-temperature brines. However, results of investigations will have broader impact in geothermal energy development from other sources and in subsurface energy storge.

Four areas are being investigated:

1. Reservoir Dynamics
2. Rock-Fluid System Properties at High Temperatures and Pressures
3. Thermodynamics of High Temperature Brines
4. Geochemistry and Mass Transfer in Geothermal Systems

The proposed work in these areas for FY 1979 is discussed below.

1. Reservoir Dynamics (P. A. Witherspoon and C. F. Tsang)

The purpose of this project is to investigate geothermal and hydrogeological systems with the following objectives:

1. To understand the physics and chemistry of mass and energy transport in geological systems.
2. To isolate and focus on critical physical and chemical phenomena in these systems.
3. To simulate and study their behavior under natural conditions.
4. To predict their response when disturbed by man.
5. To determine optimal exploitation methods.

These objectives are accomplished by developing mathematical techniques, computer codes and physical models, incorporating thermodynamic, hydrodynamic, and other physical and chemical principles. Beginning FY 1979, the efforts in this element of our research program may be divided into two subareas: (1) Isothermal and (2) Non-isothermal. The former includes studies of flow in complex ground water basins, simulation of transient flow in three-dimensional saturated-unsaturated deformable systems, and calculation of the flow to wells in systems with or without fractures. The latter includes various studies in geothermal reservoirs and the problems of hot water storage in aquifers.

a. Isothermal. Mathematical models have been developed to simulate transient flow of water in saturated-unsaturated deformable systems in three dimensions. These models are formulations including the integrated finite difference method as well as a new approach involving a blend of the integrated finite difference concept with the well-known finite element method, combining the special advantages of these techniques.

   During FY 1979, it is proposed to initiate work in two new areas, in addition to updating, improving and modifying existing computer programs. The two new areas include: (1) study of relations between pore fluid pressure and rock stresses in multiphase systems, and (2) study of the problem of parameter estimation of models by means of history matching.

b. Non-isothermal. Studies will be made to incorporate gas solution chemistry into a three-dimensional two-phase numerical model. Work will also be done on double diffusion, which is a process that results when two components such as heat and salt (or another dissolved component) have different diffusivities. Instabilities in the flow can result when the two components make opposing contributions to a vertical density gradient. This instability could have an effect on the flow of injected brine in a geothermal reservoir. The double diffusion phenomenon could cause mixing of injected fluid with in situ fluid resulting in precipitation of salt or it could affect the path of the injected fluid. The limits of stability for a fluid in a non-porous medium are known but what is of interest is stability of fluid in a porous medium where porosity and permeability of the rock will have an effect. Two-dimensional flow in a porous medium will be considered that incorporates both mass and heat transfer in order to determine stability limits, extent of mixing, and the general importance of double diffusion in porous media.

2. Rock-Fluid System Properties at High Temperatures and Pressures (W. H. Somerton)

Objectives of the present research are to develop methods and equipment to measure required rock properties at high temperatures (to 400° C) and high pressures (1000 bars). Properties to be measured include porosity, permeability, formation resistivity

factor, dilatational and shear velocities, bulk and matrix compressibilities and thermal properties including conductivity, diffusivity, thermal expansion and the evaporization-condensation-capillary (heat pipe) parameter. Efforts will be made to combine all or as many as possible of the above measurements in one test so that correlation of results will be facilitated. Thermal properties and behavior of rock-fluid systems will also be measured with use of existing equipment. Since all of these measurements require complex equipment and test procedures, efforts will be made to develop models so that high-temperature, high-pressure behavior may be predicted from more readily available data on the rock-fluid system.

Principal emphasis during FY 1978 was on thermal properties and behavior of a large range of rock types. These included volcanics, basalts, limestones and a wide range of sandstones, siltstones and shales. These data are being catalogued and tested against previously developed models and correlations. Work is continued on an improved three-dimensional model of heat flow through multi-fluid saturated porous media to aid in correlation work. A computer program for specific heat calculations from oxide analyses was revised and updated so that thermal diffusivity data can be provided for the above rock-fluids system.

Permeability and fluid storage capacity measurements at high temperatures and pressures will be made with redesigned equipment. Tests will be run on a wide range of rock types saturated with different fluids. Data will be correlated with models so that flow and storage capacity behavior may be predicted from more easily measured physical properties.

3. Thermodynamics of High Temperature Brines (K. S. Pitzer)

Theoretical and experimental studies of solution thermodynamics of strong aqueous electrolytes over a wide temperature range provides essential information for technical utilization of many geothermal resources. Theoretical work has successfully dealt with complex mixtures at room temperature, simple systems over wide temperatures, moderately weak electrolytes involving a dissociation equilibria, and moderately soluble electrolytes. Future work will continue using existing volumetric and thermodynamic data for modeling. The experimental progam includes construction and use of a flow calorimeter and of a densimeter measuring heat capacities and densities up to about 300° C and 1 kbar on systems previously unreported plus extending existing data to higher temperatures and pressures. Results will be integrated with theoretical work to develop equations allowing prediction of properties at temperatures and compositions other than those measured.

After tests with NaCl, measurements will proceed to other pure components important in geothermal fluids, KCl, $CaCl_2$, $MgCl_2$, Na_2SO_4, $MgSO_4$ etc., and then to mixtures. The aim is to determine important parameters over the range to 300° C and 1 kbar and to verify the accuracy of our equations for mixed electrolytes.

With experimental data becoming available it will be possible to extend modeling calculations, of the type so successful for NaCl at high temperatures, to other salts and to mixtures.

4. Geochemistry and Mass Transfer in Geothermal Systems (J. A. Apps)

Fluid convection in a geothermal reservoir leads to dissolution, transport and precipitation of rock forming minerals. These phenomena occur naturally and cause sealing of strata and development of confining beds in geothermal systems. During exploitation of a geothermal reservoir, dissolution, transport and reprecipitation processes will be accelerated, with potentially significant declines in reservoir production and injection capacity. The objective of this project is to determine and quantify deleterious effects, if any, which will result from rapid withdrawal of hot water and reinjection of spent fluids in a convecting geothermal reservoir. A longer term objective will be to predict transport and deposition behavior of major rock forming component and minor metal components in convecting geothermal systems. Emphasis will be placed on experiments to study mineral dissolution kinetics. These experiments will provide data on dissolution, transport and precipitation of major rock forming components in a geothermal reservoir. Fluid flow models incorporating these processes and hypothetical cases simulating a producing geothermal reservoir are being evaluated.

During FY 1979, we will collect data on dissolution rates of tremolite, chlorite and zoisite in aqueous solutions at temperatures ranging from 25°C to 400°C. Solution samples will be taken from a stirred one liter rechargeable autoclave at periodic intervals and analyzed by atomic absorption and soft XRF techniques. Resulting data will be evaluated and models formulated to help identify dissolution mechanisms and equilibrium thermodynamic relations between solid and aqueous phases.

B. Thermodynamic Properties of Silicate Materials (I. S. E. Carmichael)

Magmas are generated at depths of between 15 and 250 kms in the earth, and their ascent towards the surface is governed largely by their thermodynamic and transport properties. Some magmas reach the surface to form volcanoes, whereas others rise to within only a few kilometers of the surface where they congeal as igneous intrusions.

This project is a continuing investigation into the properties of silicate liquids, with the intention of measuring their thermodynamic properties as functions of composition, temperature, and pressure. As natural silicate liquids cover a wide range of composition, experiments have been designed so that partial molar properties can be derived. Information is currently being obtained on densities, volumes, and thermal expansivities of melts containing the components SiO_2, TiO_2, Al_2O_3, FeO, MgO, CaO, Na_2O and K_2O in the temperature range from 1000 to 1500°C. An apparatus has been designed and built to measure the ultrasonic velocity in silicate magmas in order to determine the adiabatic compressibility. From these measurements, the isothermal

compressibility and its temperature dependence will be obtained on silicate melts of similar compositions to those used for density and thermal expansion studies.

The above experiments take no account of coordination in silicate liquids as a function of pressure, and the density changes that could ensue; experiments presently underway show that Al may change from four-fold to six-fold coordination in some liquids. There is no information on the compositional dependence of this change. Preliminary results obtained in FY 1978 will be extended in FY 1979 to investigate this dependence.

One of the major problems in understanding natural silicate liquids is the paucity of data on the heats of fusion of the common rock-forming minerals. This is mainly due to the high temperatures involved, and it is planned to design a drop calorimeter to operate up to 2000°C in order to determine the heats of fusion of the dozen or so common minerals that crystallize from magmas.

From the study of natural silicate liquids, it appears that certain elements may migrate preferentially to a hot source (e.g., Sr) whereas others may migrate preferentially to colder regions (e.g., Zr, REE). It is proposed to measure the migration of a number of elements in a silicate liquid with an imposed thermal gradient. From these measurements will come both sign and magnitude of the Soret coefficient.

During FY 1979 sufficient measurements of adiabatic compressibility should have been made to allow the partial molar quantities to be derived. With the completion of these measurements, the density of any anhydrous silicate liquid, or magma, will be described as a function of pressure, temperature, and composition. Studies of migration of a wide variety of elements in a strong thermal gradient will be complete, and if the results are significant, in terms of a geological time-scale; experiments will be extended into the following year to complete the preliminary investigation.

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

The principal objective of the GRID program is to critically evaluate and disseminate basic properties data on aqueous electrolyte solutions (e.g. NaCl, KCl, $CaCl_2$) to 350° C, 50 MPa, and saturation concentrations. The basic properties currently covered include the following: (1) viscosity (completed in 1977, for NaCl): (2) density (completed in 1977, for $CaCl_2$); (3) thermal conductivity (completion expected 1978, for NaCl; (4) enthalpy (completion expected 1978, for NaCl); (5) electrical conductivity; (6) free energy; (7) entropy; (8) solubility; (9) activity coefficient; (10) osmotic coefficient.

During FY 1979 thermal conductivity data for aqueous sodium chloride solutions will be compiled and a report issued on results of the work. Enthalpy data on sodium chloride solutions is expected to be critically evaluated, a correlation expression developed, and a report issued on results of the evaluation.

D. Chemical Transport in Natural Systems (L. V. Benson and C. Carnahan)

In natural systems, chemical reactions occur primarily at solid/liquid interfaces. We can group these reactions into three categories; precipitation, dissolution, and sorption (sorption is taken to include ion exchange processes). Little work has been done to characterize sorptive properties of minerals common to natural systems and effects of dissolution and/or precipitation processes on the sorption process. For the most part, previous experiments provide information only on a macroscopic level (i.e. distribution of solute between solid and aqueous phases at various solution concentrations). Since variables which affect the sorption process have not been identified or thoroughly studied, distribution data is often not applicable. We intend to study variables which influence the sorption process and determine whether it is theoretically possible to predict distribution of solute between solid substrate and the aqueous phase. We also intend to study the feasibility of performing experiments which are necessary inputs to a predictive theoretical model. During the first year, our research will be directed toward a study of sorption of radioactively "labeled" solute species on simple oxide and aluminosilicate surfaces. Surface characterization by transmission electron microscopy and scanning electron microscopy will be done. The possibility of surface characterization by photoelectron, Raman infrared and Auger electron spectroscopies will also be investigated. From a study of sorption isotherms we hope to begin to understand the effect, if any, of crystalline structure on sorptive behavior. We will also attempt to determine the form of potential energy distribution associated with the solid surface and the importance of lateral attraction/repulsion on sorption isotherms and derived heats of sorption.

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

Contract: W-7405-ENG-48

Title: I. Geosciences Program

Person in Charge: Robert N. Schock

Scope of Work

The geosciences program at LLL is organized to study physical and chemical properties and responses of rocks that are important to DOE programs. Current effort concentrates on basic rock mechanics (fracturing with explosives, micro-structural analysis, and computer modeling of fracture) and properties of rock-fluid systems. In the immediate future, work will include studies of seismic Q, kinetics and transport in aqueous solutions, and activities as part of a continental drilling program. All of these efforts make use of experimental work, novel diagnostic techniques, and computer modeling. Their common objective, from a scientific viewpoint, is to develop models that may be used to predict and understand behavior of the rock mass.

A. Basic Rock Mechanics (J. F. Schatz)

1. Rock Fracturing with Explosives

Explosively-induced fracturing of rock in the absence of a free surface with purposes of fragmentation and permeability enhancement has had little prior scientific attention. The objectives of this study are to understand effects of emplacement geometry, multiple charge timing, confining pressure, and explosive design parameters on fracturing.

Currently, several phases of this study have been completed or are underway. A special explosive charge has been designed that allows small, but repeatable and safe laboratory detonations. Detonation delay between two charges has no significant ability to increase total fracture damage, but has a dramatic effect on fracture orientation. Confining pressure, in a porous sandstone, inhibits fracturing out of proportion to the effect expected from simple strength considerations, and is apparently the result of absorption of energy by pore collapse. A special water tank test facility is being constructed that will allow measurement of explosive expansion adiabats to unusually low pressures and large volumes. These parameters are thought to be of crucial importance to fracturing.

New small-scale experiments are being prepared in the laboratory to study the effect of a rate of loading of a borehole wall which is lower than conventional explosives would provide, with hopes of producing and lengthening fractures, even in porous media.

2. Micro-Structural Rock Analysis

In order to study effects of explosively-induced fracturing, intermediate-rate tests, and quasi-static tests, with the objective of developing mechanistic models of behavior, a structural analysis facility is being developed. This facility will include capability for statistical analysis of fracture patterns, since models cannot be expected to produce exact one-to-one fracture mapping, but only a general statistical correspondence. Techniques for which equipment or expertise are available include: petrography, metallography, scanning-electron microscopy, x-ray structural analysis, acoustic analysis, tomography, and computer-assisted pattern recognition. Currently, these facilities are in use to study fracturing related to detonation timing effects and confining pressure effects.

3. Computer Modeling of Rock Fracture and Deformation

The ultimate objective of rock mechanics studies under this program is to develop predictive models of rock behavior that can be used as design tools for field development of energy and resource recovery techniques. Two types of advanced modeling are currently receiving attention. One involves generation of discrete fractures in a continuum finite-difference computer code framework, and the other involves motion of a discontinuous, blocky rock-mass, as might be encountered after fragmentation has occurred. The discrete fracture propagation model is in its initial stages. Particular attention is given to formulation of a model that has a small number of measurable physical parameters. This model will be applied to results of explosive-fracturing experiments now underway. The discontinuous block model is applied to the problem of creation of a rubble column for in situ retorting of oil shale.

B. Rock-Fluid Systems (A. G. Duba)

Seismic velocity measurements and electrical resistivity measurements are important field tools which can delineate structure and extent of natural rock-fluid systems. This study will experimentally relate seismic velocity, electrical resistivity, and permeability to pressure, temperature, pore pressure, fluid content, and fluid composition. Then, field measurements may be interpreted in terms of system models. Initial application will be to a geothermal fluid system in the Salton Sea Geothermal Field. Apparatus is developed with a capability of 600 °K and 200 MPa, with variable saturations, concentrations of fluids, and dissolved solids. Initial measurements have encountered difficulties of material compatibility with the experimental environment. Particular problems have occurred with jacketing material and electrical leads.

The data interpretation portion of the program produced the capability to model the forward problem of an insulator inside a good conductor. In addition, we designed a system which allows determination of electrical conductivity parallel to a core axis without electrodes on the ends of the core. This design, coupled with data analysis techniques

similar to those used in x-ray tomography, allows mapping of conductive anomalies to a degree of precision not possible before.

C. Seismic Q in the Earth (F. E. Followill)

A unique suite of seismic and geologic data gathered through the LLL seismic net will be used to calculate interval velocity and seismic Q between reflectors in the Earth's mantle for the Basin and Range Province. This will allow detailed knowledge of a particularly interesting part of the upper mantle, from the viewpoint of plate tectonics as applied to North America. There is strong application to treaty verification of foreign nuclear testing.

D. Kinetics and Transport of Aqueous Solutions (D. Miller)

Computer models of processes in complex aqueous systems are being developed. Included will be precipitation, diffusion, nucleation, heat transfer, fluid flow, corrosion, and chemical reaction. Potential applications are in scale control and other reactions in geothermal brine, leaching, weathering, precipitation of metal resources, and leaching of radionuclides from radioactive wastes. The basic development work now underway has incorporated simple models of silica and sulfide precipitation.

E. Continental Drilling: Subsurface Processes (R. N. Schock)

Planning has begun on a continental drilling program within DOE-Basic Energy Sciences. LLL will contribute to several facets of that program: planning, data base management, geophysical modeling, physical-chemical measurements on recovered core and studies of a hydrothermal system as part of the goal of drilling into a complete magma-hydrothermal system. A listing of planned new drill holes of possible use in the drilling program is being compiled for publication.

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

Contract: W-7405-ENG-36

Title: I. Solid Earth Geosciences

Person in Charge: R. R. Brownlee

Scope of Work

The geoscience program at LASL was conceived to provide a basic reserch capability in support of the applied experimental Hot Dry Rock (HDR) geothermal energy (GTE) project. Although GTE remains a major focal point of research projects, interests have expanded into nuclear and fossil fuels, waste management, and weapons-related areas. Experimental and analytical facilities primarily committed to this program include electron probe microanalyzer/scanning electron microscope, automated single-crystal and powder x-ray diffraction, high-temperature and -pressure rock deformation equipment, and a high-temperature/pressure experimental petrology laboratory. In addition, neutron activation, x-ray fluorescence, atomic absorption, and mass spectrometry facilities are regularly utilized under this program. The LASL computer facility with its library of hydrodynamic, geochemical, and material codes is used extensively, and LASL scientists in related fields are consulted regularly. It is the strong basic research capability in geosciences which has enabled LASL to successfully seek coordinated and complementary applied research programs in the areas of geothermal energy exploration, radioactive waste management, and weapons-related geosciences.

A. Field, Analytical and Theoretical Petrology

1. Silicic Volcanic Fields - Sources of Geothermal Energy, Western United States (B. Crowe, J. C. Eichelberger, F. Goff, G. Heiken, A. W. Laughlin, J. Smyth)

The origin, magmatic evolution, and cooling history of igneous bodies associated with young volcanic fields are important factors that determine energy reserves of geothermal fields. On-going research provides information concerning the evolution of several major volcanic fields. Petrological and tephrochronological (the study of the age and spatial distribution of explosively ejected volcanic debris) studies of the Medicine Lake volcanic center suggest the field is underlain by a relatively small and shallow magma body. Field studies of the internal structures of dissected volcanoes in the central High Cascade Range provide an understanding of mechanisms of growth and shallow level plumbing systems of andesite volcanoes (composite cones).

A goal of petrologic work is to predict presence of large magma reservoirs within the crust from petrology of surface lavas. Useful criteria are: (1) evidence of crustal melting, (2) evidence of convective stirring of large batches of magma, (3) similarity of certain volcanic rocks to pluton-forming crystalline rocks. In

addition, evolution of magma reservoirs within the crust is investigated through analysis of frozen reservoirs exposed by erosion, and studies of large-volume tuff sheets. Results apply to the problem of crustal evolution.

Volcanic hazard analysis of future volcanic activity in the western United States is studied for the terminal radioactive waste storage program. This work consists of three parts: (1) a worst case scenario predicting disruptive events and potential biosphere pathways due to breaching of a vault by volcanic activity; (2) prediction of high risk zones or provinces of future volcanic activity in the western United States; (3) development and evaluation of calculation procedures to determine risk probabilities of volcanic activity.

2. Rio Grande Rift (J. Bridwell, W. S. Baldridge, J. C. Eichelberger, J. Smyth, R. Riecker)

Integrated research of field relations, petrology, chemistry, age dating, rare earth data, deformation mechanisms, and numerical models are directed toward understanding structure, tectonics, and magmatic evolution of the Rio Grande Rift (RGR).

Basalt samples collected from the length of the RGR provide approximately 100 whole rock analyses, 30 rare earth analyses, and interpretations on composition of the upper mantle and magma genesis. These parameters provide constraints on comprehensive models of major geothermal anomalies. Ultramafic xenoliths collected along the RGR are analyzed to provide P, T conditions from pyroxene geothermometry techniques. Direct estimates of stress from deformation fabrics of olivine xenocrysts provide a qualitative picture of stress in the lithosphere along the length of a major continental rift.

3. Mantle Petrology (J. Smyth)

A computer program casts chemical analyses of rocks, either real or hypothetical, into a suite of "normative" minerals, similar to CIPW-norm minerals, but more appropriate to assemblages at 30 kbar. Results apply to observational petrology and planetary science. Mineralogy and petrology of natural high pressure assemblages from basalt and kimberlite nodules will enhance modeling capability.

4. Waste Management (B. Crowe, J. Smyth)

The Bandelier Tuff consists of a thick sequence of ash-flow and air-fall tuff that encircles the Jemez Mountains. Detailed volcanic stratigraphy of tuff and variations in geochemistry and physical properties related to eruptive and post-emplacement processes were determined. These data are used to characterize the geological environment of waste disposal sites within the Bandelier Tuff on LASL property.

B. Seismology (K. Olsen, D. Cash, F. Homuth, C. Newton)

The objectives of this program are: (1) to determine regional background seismicity in order to assess possible effects of LASL programs on seismic activity; (2) to determine probability of earthquake damage to LASL facilities; and (3) to evaluate regional crustal and mantle structure.

Northern New Mexico crustal and mantle structure is investigated seismically for: (1) location of major discontinuities in the crust and upper mantle to facilitate understanding of regional tectonics; and (2) determination of seismic velocities for accurate location of earthquake hypocenters. We initiated a program to correlate seismic data on earthquake locations in northern New Mexico with information on fault scarps and long-term vertical crustal displacements obtained by classical geologic and geodetic techniques.

Measurements of the Earth's gravity and magnetic fields are helpful supplements to seismic studies of crustal and mantle structure. Potential fields are measured and interpreted in geographical areas of specific interest.

We currently maintain a network of 15 telemetered continuously recording short-period seismic stations. Three are located in the immediate vicinity of the Fenton Hill HDR project. The number of stations in this short-period network will be doubled in the next few years in order to provide more complete coverage of critical areas. In addition, 15 portable seismographs can be fielded to record aftershocks of larger earthquakes and earthquake swarms.

A network of four to six special, telemetered, long-period/broadband seismographs will be installed in northern New Mexico which will provide surface wave disperison data.

Our mobile recording/telemetry trailer and other portable recording units are used for seismic refraction line experiments that utilize various mining and other explosions as energy sources. Data from these experiments are used to derive crustal structure sections at local and near-regional distances.

C. Theoretical and Experimental Geochemistry

1. Experimental Geochemistry (R. Vidale, R. Charles, C. Duffy, T. Beddoe)

   a. Geothermal systems: Experimental and analytical studies are conducted on reactions between rock and aqueous solutions at high T and P in closed reaction vessels and in circulating loops. These reactions cause changes in geothermal solution composition, and in geothermal rock reservoir permeability, size, and geometry, all of which critically affect efficienty of energy extraction.

b. Element migration: The intent of this project is to develop better techniques for observing minor and trace elements in rocks and pore solutions over a wide range of temperature, pressure, and oxygen fugacity and to study the source, migration, and fixation of elements of particular interest. What is the geochemistry of these elements? More specifically, in what rock types are they most abundant, which mineral phases incorporate them, and under what circumstances are they concentrated in the intergranular regions? What processes will free them from the source rocks, how do they migrate, and how are they fixed at a new location? What thermodynamic data can be derived from solution-solid equilibria and what are the kinetic controls on release and fixation?

c. Continental drilling: The intent of this project is to compare geothermal alteration observed in drill cores with that produced in our laboratory experiments, to evaluate the chemical buffering capacity of a wide range of potential terminal geologic storage environments for radioactive wastes, and to observe the behavior of U and Th in crustal sections in conjunction with element migration.

2. Synthetic Mineral Standards (C. Herrick)

We fabricate large diameter olivine discs for equation-of-state studies. Gram quantities of fluoramphiboles are synthesized and macropreparations are underway for measurements of thermodynamic properties necessary for modeling geothermal systems.

Organic chemistry techniques are used to prepare zeolitic minerals. The catalytic potential of zeolites in synthetic fuel reformation processes and refined methods of synthesizing fluor-amphiboles and iron-bearing minerals will be investigated. These minerals are used for analytical standards and for geophysical experiments.

3. Thermochemistry of Minerals (C. Holley)

We measure enthalpies and entropies of formation of minerals for use in modeling calculations related to Synthetic Mineral Standards.

Measurements are made by using heat of solution of minerals and their component oxides in a molten oxide solvent. These data, plus published data on heats of formation of component oxides, are used to calculate the heats of formation of the minerals. A molten oxide calorimeter is under construction and thermodynamic measurements will begin upon its completion.

4. Geochemical Computer Modeling (C.Herrick)

Comparison of laboratory results of mineral alteration experiments simulating geothermal systems with computer mass-transfer experiments reveal the need for thermodynamic data on

hydrated minerals such as zeolites, amphiboles, and clays. The purpose of this project is to expand capabilities of an existing geochemical computer code which predicts mass transport due to chemical reactions at rock-water interfaces. We modified the code to study open-ended systems, evaporation phenomena, and time-dependent processes. Additional features such as order-disorder transitions, multicomponent solution theory, heats of reaction, revised equation-of-state for water, optimized numerical methods, and improved computer processing techniques will be included as the need arises.

The ultimate goal of this project is a series of subroutines, each describing a specific physicochemical process. Each subroutine can be included, omitted or ordered to suit the particular geochemical process under analysis.

D. Rock and Mineral Physics

1. Mechanical Properties (P. Halleck, R. Riecker, J. Bridwell, T. Shankland, J. Blacic)

The purposes of rock physics research at LASL are: (a) to support HDR-GTE; (b) to evaluate long term stability and integrity of nuclear waste repositories; (c) to define structure and tectonics of the RGR; (d) to apply geophysical techniques to site selection, in situ properties, and samples from the Continental Drilling Program.

We study deformation mechanisms in silicates. This work, within a range of T, P and strain rate conditions, determines regions in which fracture, dislocation motion, kink banding and recrystallization are active. Numerical models of non-Newtonian thermal creep are used to scale experimental observations to real geophysical problems.

We perform experiments to determine the extent of rock cracking due to thermal stress. These data are needed in calculations of the efficiency and lifetime of the HDR-GTE system at LASL since the increase in available surface area for heat transfer is affected by it.

Mechanical response of rock behavior under pressures of 1 to 2 kbar and temperatures of 300 to 500° C is becoming increasingly important as mines and drill holes reach deeper into the earth. We are building a large testing machine for work on 2-inch diameter samples under brittle, ductile and "transition" conditions.

Ultimately, a geothermal resource depends on conduction of heat into near-surface rocks. Current work confirmed that radiative heat transport accounts for about half of the total thermal conductivity in the mantle mineral olivine, but radiative contributions to the other less transparent mantle minerals, or the more transparent crustal minerals, remains to be established.

2. Nuclear Waste

A thermo-mechanical creep code is being developed which will allow calculation of the thermal and stress states in emplacement media as a function of time. We are building a prototype experiment of creep apparatus units.

We assembled apparatus for simultaneous measurements of sound velocities and electrical conductivity of rocks at moderate pressures. Results apply to problems involving fluid-filled rocks such as waste disposal or geothermal exploration.

3. Transport Properties (T. Shankland)

Transport properties of rocks and minerals are examined to assist in understanding emplcement of crust and upper mantle geothermal heat sources, high-temperature thermal conductivity, and hot zone exploration in the mantle.

E. Coal Research (R. Raymond, Jr., R. Gooley)

Immediate goals of our coal research are: (1) develop a fast, reliable method of organic sulfur determination in coal; (2) determine abundances and distribution of this environmentally troublesome element; (3) correlate our organic sulfur data with published data for total sulfur and pyrite (iron sulfide) contents in coal. Longer range objectives are: (1) define mineralogic sites of trace elements in coal which are of environmental concern or economic interest; (2) correlate characteristic trace elements and inorganic minerals in coal with depositional environments; (3) determine chemical and mineralogical effects (e.g., trace element concentrations, mineral alterations) in laboratory simultations of in situ coal gasification (and possible liquefaction) processes.

Electron probe microanalysis and scanning electron microscopy are used to determine occurrences and distributions of minor and trace elements in coal. Current efforts are concentrated on organic sulfur, its origin in various coals, and what its distribution may reveal on molecular structure variations between different maceral types. A new organic sulfur standard for electron microanalysis is developed, and we are currently working to improve its quality.

F. Continental Drilling (G. Heiken, R. Gooley, J. Bridwell, A. W. Laughlin)

A multifaceted effort is being planned which will provide service and science to the proposed Continental Drilling Program. We will manage a core sample repository to provide a center for preparation, care and distribution of drilling samples along with basic lithologic and historical data for each sample. Laboratory and field activities will include analytical and experimental studies of the mineralogy, petrology and transport properties of core samples, geophysical modeling, and field geophysics and geology. LASL hosted a Program workshop held in July, 1978.

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

Contract: W-7405-ENG-26

Title: I. Physical Chemistry of Geothermal Solutions and Materials

Person in Charge: R. E. Mesmer

Scope of Work

The objectives of this program are (1) to provide physical, chemical and thermodynamic data on brines encountered in hydrothermal resources of the U.S. and (2) to characterize primary phase assemblages and crystallization processes in magmas during formation of igneous materials and their reaction products. This program is concerned with chemical changes resulting from extraction of heat from hydrothermal and magmatic resources and specific problems encountered with reinjection of spent brines. The results will also apply to disposal of environmentally hazardous waste products of nuclear and fossil fuel electrical power production.

We conduct potentiometric, isopiestic, calorimetric, conductance, and theoretical modeling studies on properties of brines and their interactions with host materials. Among the homogeneous equilibria upon which the program focuses are: ionization of water in concentrated brines, ionization and polymerization of silicic acid, fluorosilicate equilibria, carbonate equilibria, and hydrolysis behavior of metal ions. Processes involved in silica transport have a primary focus. Thermodynamics of the major components of the brines are being determined and modeled.

We plan to model common igneous rock types (e.g., gabbros, basalts, granites, and rhyolites) using chemically simplified bulk compositions in the system SiO_2-Al_2O_3-FeO-MgO-CaO-Na_2O-K_2O-O_2-H_2O. After phase equilibria and kinetic data are obtained for the simplifed systems, concentrations of chemical components of special interest (e.g., H_2O, O_2 FeO, MgO) can be varied and new components (e.g., CO_2, F, Cl, S, U, Th, Cs, Sr, W, Sn, Cu, Ni, etc.) can be added to the system to observe their specific effects. We will concentrate our efforts on low to moderate pressure (1 atm to 5 kbar) experiments. Geologic evidence suggests that natural magma systems are undersaturated with respect to a vapor phase during much of their crystallization history. Experimental data on vapor undersaturated silicate systems which closely model natural magmas is not extensive and cannot be predicted from more abundant vapor saturated data.

A. Fluorosilicate Equilibria (R. H. Busey and R. E. Mesmer)

There are small amounts of fluoride in geothermal brines and there is indication that processes involving silica are often catalyzed by the presence of fluoride. We used a potentiometric method employing quinhydrone, hydrogen, and solid state fluoride electrodes to observe free hydrogen ion and free fluoride ion concentrations in equilibrium

with fluorosilicates in aqueous solutions at 0° to 60° C. In all titration experiments the initial silicon concentration was 0.001 m, but the total initial fluoride concentrations was 0.001, 0.003, 0.009, or 0.02 m. The supporting electrolyte was 1 m NaCl and the titrant was 0.15 m HCl in 1 m NaCl. In dilute silicic acid solutions the predominant equilibrium reaction can be expressed as

$$Si(OH)_4(aq) + 4H^+ + 6F^- \rightleftarrows SiF_6^{2-} + 4H_2O.$$

From low temperature data it is possible to estimate stability of the SiF_6^{2-} complex at 200-300° C and show that the position of occurrence of the fluoride complex shifts toward more acidic media as temperature increases, i.e., the stability of SiF_6^{2-} with respect to $Si(OH)_4$ decreases as temperature is increased. These results demonstrate that at any temperature in this range there is no significant complexing by fluoride ion at free fluoride concentrations less than 0.01 m at pH values greater than 6, which encompasses most natural waters.

B. Solubility of Amorphous Silica in Aqueous Electrolytes (W. L. Marshall)

Additional solubilities of amorphous silica were obtained in aqueous sodium nitrate solutions at 25-300° C. These measurements provide a consistent description of decreasing solubility with increasing sodium nitrate concentration. Throughout the range, 25-300°C, the solubility at a constant temperature decreases approximately one-half as the molarity of sodium nitrate is increased to 5.4.

C. Thermodynamic Properties of Brines (H. F. Holmes, C. F. Baes, Jr., and R. E. Mesmer)

Data previously obtained for the osmotic coefficients of aqueous solutions of KCl, $CaCl_2$, and $MgCl_2$ over the temperature range of 109° to 201°C were fitted to a model developed by Pitzer. The resulting standard deviation of fit (in the osmotic coefficient) ranged from 0.0009 to 0.0029. Parameters obtained from the mathematical fit to experimental data were then used to calculate activity coefficients for these electrolytes. The activity coefficients showed a monotonic decrease with increasing temperature and became much less dependent on concentration at higher concentrations as temperature increased. Data acquisition during the fiscal year has concentrated on electrolyte mixtures NaCl-KCl-H_2O and NaCl-$CaCl_2$-H_2O. The experimental study of these two mixtures should be completed during this period and the NaCl-KCl-H_2O data put into publishable form. These results will make possible calculation of thermodynamic properties for the Salton Sea brines for the first time.

D. Phase Equilibria and Crystallization in Magmatic Systems (M. T. Naney)

Laboratory apparatus will be constructed to perform 1 atm high temperature experiments at 1400°C. Initial experiments will be made with air as the furnace atmosphere. Subsequent experiments with gas mixtures at 1 atm total pressure will be performed after modifications to the existing furnace are made. Mixed gas atmospheres make it possible to control and lower the oxygen fugacity of an experiment to other

geologially appropriate values for investigating reactions in which multivalent elements (e.g., Fe, U) participate.

Study of modal basalt and rhyolite compositions at 1 atm will provide phase equilibria and crystallization kinetic data on solidification of magmas at surface conditions for the "simplified" seven-oxide component compositions and guide further experiments with additional components.

Contractor: SANDIA LABORATORIES
Albuquerque, New Mexico 87115

Contract: 2910789

Title: I. Magma Energy Research

Person in Charge: H. M. Stoller

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 current concept involves locating a suitable magma source, drilling into liquid magma, and installing a heat exchanger to continually transfer 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 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.

A. Magma Source Location and Definition (J. L. Colp)

A high priority recommendation of the Sandia/USGS Magma Workshop (SAND 75-0306) was a demonstration of abilities of geophysical sensing systems to detect and delineate a known body of molten rock. The lava lake in Kilauea Iki crater on the island of Hawaii, still molten since the 1959 eruption, was chosen as a site for this demonstration experiment performed in FY 1976. The results are being compiled with the assistance of Professor John Hermance, Brown University, and will be published as a Sandia report in FY 1978.

Assessment of abilities of the various sensing systems used in the Lava Lake Sensing Experiment to correctly detect and delineate the buried body of molten rock requires drilling a series of holes into and through the molten lense of Kilauea Iki. Two holes were drilled through 150 feet of the upper crust into molten rock in FY 1976. An unexpected solid layer of hot rock was encountered after penetrating only 30 inches of molten rock. Results of the two holes drilled clearly showed two things: (1) that the molten lense as it presently exists in Kilauea Iki is not a simple, relatively homogeneous liquid, and (2) that previously postulated methods for penetrating that molten lense would not work. Immediately following that drilling sequence, a Lava Lake Drilling Program to develop and build an advanced drilling system that would reliably drill through hot (∿1050°C), solid rock while the drill string is rotating immersed in molten (∿1075°C) rock was started. A number of

thermal and heat transfer calculations, several studies of appropriate materials and bit fabrication methods that would be required were conducted.

The design finally selected utilized an uncooled three-wing drag bit made of Mar-M 509, a super alloy having appreciable strength at 1070° C, on the end of a double pipe insulated drill string made of high-temperature resistant stainless steel. The outer pipe will be allowed to reach the molten rock temperature to minimize rock chilling onto it. The inner pipe will be cooled to 200°C by air flowing through it so that it can transmit the driving torque to the bit. An instrumented experiment section will be installed between the bit and the insulated drill string. Parts have been designed and procured. A number of development and proof tests on various parts of the design have been performed in the laboratory. Additional holes extending at least 20 feet into molten rock will be drilled into Kilauea Iki lava lake late in FY 1978.

B. Magma Source Tapping (J. L. Colp)

Another high priority recommendation of the previously mentioned Magma Workshop was determination of the strength and ductility of representative igneous rocks at conditions to 1000° C and to 4 kbars pressure. A Sandia-sponsored research study to accomplish this objective was started at the Center for Tectonophysics at Texas A&M University in FY 1975 and is continuing. Results to date are that considerations of instantaneous failure strengths and stresses likely at the walls of open and water-filled boreholes show that a hole as deep as 10 km in either dry Mt. Hood andesite and Charcoal granodiorite is not likely to fail under short-time loading even at 1000°C, unless the in situ horizontal stress is $\geq$ vertical stress and the hole is open. Effects of water weakening and duration of loading are now being investigated.

C. Magma Characterization and Material Compatibility (T. M. Gerlach, E. J. Graeber, P. J. Modreski, M. J. Davis)

High temperature gas collectors have been fabricated and field tested during the September 1977 east rift eruption of Kilauea Volcano. Computer studies of volcanic gases are being used to restore the analytical data to original compositions for use as a data base as part of materials-compatibility and magma-properties simulation experiments.

Field experiments conducted during the eruptive events of Kilauea consisted of (1) temperature measurements of gas vents and lava flows, (2) collection of gas samples, (3) testing of material compatibility alloys, (4) thermal measurements from a heat transfer probe and (5) collection of ejecta. Motion picture and audio coverage were acquired for documentation of experiments.

A comprehensive thermodynamic study of volcanic gas collection data is nearly completed. This study provides a data base of approximately 80 high quality volcanic gas analyses corrected for contamination by the atmosphere and from reactions with sampling equipment during collection. All samples in the data base were collected in close association with

active lava at temperatures in excess of 600° C. The data base documents the range of gas compositions to be expected in low-pressure erupted gases, fugacities of critical constituents from a materials compatibility standpoint, and the nature of short-term and long-term chemical variations in erupted gases from Mount Etna, Erta' Ale, Surtsey and Kilauea volcanoes. The results of these investigations were applied in simulating magmatic environments for materials development research. They have also been useful in evaluating and improving volcanic gas collection and analysis techniques.

Thermodynamic modeling studies are now under way for C-O-H-S-Cl-N magmatic gases at pressures and temperatures up to 5 kbar and 1400° C. These studies will be used to simulate magmatic gases in the magma-properties and materials-compatibility experimental facility now under development. They are also used to characterize degassing of magma. These techniques, coupled with recent data on volatile contents of matrix glasses and glass inclusions in submarine basalts, hold considerable promise for improved understanding of the evolution of magmatic gases from upward-moving bodies of magma.

A Magma Simulation Facility, an internally heated 4-kbar pressure system, is being constructed that will be capable of maintaining large volume samples ($\sim$1 liter) at uniform temperature to 1500° C in a controlled atmosphere with a variety of electrical sensors present. The system will be used to measure chemical and physical properties (including viscosity, electrical and thermal conductivity, seismic transmission properties, etc.) of molten rock containing dissolved volatiles, and to study compatibility of metals with simulated volatile-containing magma. The first experiments in the pressure system should be conducted in the early part of FY 1979.

Experiments are being conducted to examine types and mechanisms of reaction of metals with molten rock and simulated magmatic gases. Pure elemental metals, binary alloys, and high-temperature engineering alloys have been examined. Gas atmospheres ranging from low-f_{O_2} inert gas (argon) to H_2-O-CO_2-CO-SO_2-H_2S mixtures with controlled oxygen and sulfur fugacity have been used at 1100-1200° C at atmospheric pressure. Experiments in FY 1978 will concentrate on detailed study of reaction mechanisms in atmospheric pressure experiments and on experiments at moderate pressure in 1 kbar "cold-seal" pressure vessels. These experiments will be extended to higher pressures in FY 1979 when the Magma Simulation Facility is operational.

Alloy specimens were exposed to hot gases (600-1000° C) at lava flows and volcanic vents during the September 1977 eruption of Kilauea Volcano, supplementing our earlier field exposures to lower temperature fumarole gas environments (100-200° C). Such field exposures are valuable to confirm or supplement laboratory simulations of magmatic/volcanic corrosion environments.

D. Energy Extraction (H. C. Hardee, D. W. Larson, D. O. Lee, P. C. Montoya)

1. Molten Rock Drilling Studies

A series of magma drilling simulation experiments were run in molten paraffin using a model drill bit which was cooled with Freon 11. This type of drill develops a chilled porous matrix ahead of the bit as the coolant chills the medium. Experiments were run to study problems associated with drilling through a molten lense. Another experiment was performed to check calculated flow rates through a full size experimental magma drill bit.

Calculations were made to determine the torque required to rotate the drill bit and drill pipe in a molten magma body with temperature dependent viscosity. Calculations were also made to determine the effects of thermally insulating the drill pipe as well as the required flow rate of water or air to maintain the insulated drill pipe at or below 200°C. The required orifice sizes necessary to maintain the specified flow rates for various pressure drops have been determined.

The expected heat transfer data that could be obtained from a one-foot thermal test section behind the drill bit has been investigated. If the test section is made from RA-330 or a material with a similar thermal conductivity and a wall thickness of 1.0625", the measurable temperature difference across test-section wall varies from 43°F at 100 seconds to 7°F in 6 hours (assuming the air coolant flow is maintained).

An analysis was conducted to determine pressures and flow rates necessary for a water jet to penetrate into liquid rock and chill it into a foam ahead of a drill bit. Results indicate that this is a feasible method of drilling into and through liquid rock. A nozzle with a radius of 0.1 inch and a 50 psi pressure drop will deliver 8.4 gallons/mixture with an exit velocity of 86 ft/sec. This water jet will penetrate approximately 1.2 inches into molten magma and has sufficient cooling capacity to chill a plug that is 12.0 inches in diameter (approximately 4 drill-bit diameters) at a drill rate exceeding 50 ft/hr.

2. Magma Thermal Characterization Studies

An analytical study of heat transfer mechanisms in magma bodies was undertaken in order to improve our estimates of potential heat extraction rate. Only one of four possible heat transfer regimes was found which would support a process of convective upmelting. The length to diameter ratio of an upmelting magma body was theoretically found to be limited to a maximum value of 5. An analytical heat transfer model of forced intrusion magma flow coupled with available experimental evidence suggests that magma chambers likely have low superheat. Further calculations indicate that magma heat extraction rates for conventional heat exchangers will be on the order of 10 kW/m^2 or less. A rough economic study

was performed which showed that at heat extraction rates of 5 kW/m^2, magma electric power should become competitive with coal and nuclear electric power.

Analytical solutions have been found for predicting the surface heat flux distribution above rectangular (dikes) and spherical magma sources. The solution for dike geometry predicts the steady-state heat flux distribution at the surface of the earth for a conduction dominant region above magma source. The solution for a spherical magma source includes transient effects. These solutions have application in locating magma bodies. The surface heat flux distributions can be used to estimate characteristics of a magma body such as its extent and depth. The dike solution was compared to some recent measurements made on the Yellowstone Caldera (Morgan, Blackwell, and Spafford, J. Geophysical Research, September 10, 1977, pp. 3719-3732). If the underlying constant temperature source is assumed to be at a depth of 1.0 km, then agreement between measured and predicted surface heat flux distribution is excellent.

3. 20-Meter Long Tube Heat Exchanger

The assembly of the Long Tube Heat Exchanger (LTHE) facility was completed in October 1977. Initial checkout of the fluid loop indicates that constant flow rates could be obtained although fluctuations are very sensitive to certain valve settings. The electrical system was turned on and checked out in the latter part of October 1977, and a preliminary set of experiments was performed. There are seven heaters in this facility. The test conditions were brought to steady state before data were taken. Boiling first occurred at about the 25-foot depth.

4. Heat Transfer Measurements in Lava

The 1977 Kilauea eruption (September-October 1977) which occurred on the east rift of Kilauea Volcano in Hawaii produced a river of basaltic lava which flowed for several days. The lava river which formed at the Puu Kia'si vent was flowing at about 3-5 km/hr and was at a temperature of 1065-1095° C. An experiment was performed in which a heat transfer probe was placed in the lava river. The purpose of the experiment was to make measurements of heat transfer rates in fresh lava which could be compared with theoretical calculations of heat flux and thereby verify assumptions about thermal conditions in fresh molten lava. A secondary purpose of this experiment was to obtain engineering information which would affect design of future heat transfer probes and heat exchangers. To the best of our knowledge, this is the first time that precise heat flux measurements have ever been made in fresh flowing lava.

A heat flux gauge has been designed for use in future surface lava flows. The instrument has been designed to determine both conduction and convection (if any) heat flow. In addition, the thermal diffusivity of the magma can be determined from the thermal response of one section of the probe.

E. Future Plans

Analytical studies of heat transfer mechanisms in magma bodies will continue. We plan to include effects of porous natural convection in overlying hydrothermal systems. We are investigating numerical techniques used by others as well as developing our own porous natural convection codes. We also have plans to compare existing surface heat flux data with our calculations.

We plan to modify the inner tube of the long tube heat exchanger to allow distributed fluid injection during boiling. This is one of the prime techniques that needs investigation in order to enable design of very long tube boilers. We also plan to fabricate some of the new design heat flux gauges, designed for surface lava flows.

PART II

GEOSCIENCES

OFF-SITE

Contractor: UNIVERSITY OF ALASKA
Geophysical Institute
Fairbanks, Alaska 99701

Contract: EY-76-S-06-2229

Title: I. Alaska Peninsula Telemetered Seismic Network

Person in Charge: Hans Pulpan

Scope of Work

A large aperture network of ten short-period, vertical component seismometers is installed and is being operated on the eastern portion of the Alaska Peninsula. The network is an integral part of our seismic monitoring system extending over an approximate 1000-km portion of the Aleutian-Alaskan arc system. Data being collected from the system are valuable for developing a comprehensive understanding of the seismotectonics of this structure. Such an understanding is important in assessing the potential of volcanism associated with the arc structure for geothermal energy use and in assessing the seismic risk of an area of high energy potential.

Contractor: UNIVERSITY OF ALASKA
Geophysical Institute
Fairbanks, Alaska 99701

Contract: EY-76-S-06-2229 005

Title: II. A Study of the Magnetic Field Annihilation Process in the Magnetosphere and Some Applications (Electric Currents in the Trans-Alaska Pipeline Induced by Auroral Activity)

Person in Charge: Syun-Ichi Akasofu

Scope of Work

The magnetic field annihilation process is believed to be one of the basic processes in cosmic electrodynamics, releasing a considerable amount of energy in a relatively short time and converting magnetic energy to kinetic energy of high energy plasma particles. This process is believed to take place in the magnetosphere in some planets and comets. Among the above regions where the annihilation process has been suspected to take place, the magnetotail is commonly the only region where satellite-borne instruments can make detailed measurements of plasma conditions.

Thus, the purpose of our study is to identify basic plasma processes which are responsible for the annihilation process. Our finding indicates, so far, that acceleration of plasma particles takes place along magnetic field lines as a result of diversion of electric currents which generate the magnetic field. This result differs from what one expects from the widely accepted reconnection process.

We are interested in energy related geophysical problems in the Arctic region. We are helping corrosion engineers of the Alyeska Pipeline Co. in monitoring the Aurora-induced electric current in the trans-Alaska pipeline. We have found that electric currents on the order of 200 amperes are induced in the pipe during medium auroral activity and are monitoring the amount of electric currents which leak from short segments of an underground section of the pipe. We are studying effects of the Aurora-induced electric currents on powerline systems in the northern U.S., Canada, and Fairbanks, Alaska. We also are interested in applying the audio-frequency (10 Hz-10 KHz) magnetotelluric method and RF radio-wave methods in sounding permafrost regions in Fairbanks.

Contractor: ASPEN INSTITUTE FOR HUMANISTIC STUDIES
Food, Climate and the World's Institute
1919 Fourteenth Street, Suite 811
Boulder, Colorado 80302

Contract: ER-78-S-02-4634.A000

Title: I. Mechanisms for the Effect of Variable Solar Activity on the Weather

Person in Charge: Walter Orr Roberts and Roger H. Olson

Scope of Work

In the past five years or so, the amount of evidence for effects of variations in the solar energy output on tropospheric weather has become highly convincing. The principal problem facing us now is not to prove that such relationships exist, but to discover what the most important correlations are and what physical mechanisms are responsible. We are interested primarily in short-term relationships, i.e., of duration of days to a few weeks.

In the past we have used such parameters as the vorticity area index, which is a measure of strength of cyclonic activity, to evaluate solar effects both on individual pressure troughs and on the entire northern hemisphere circulation pattern. In the future we hope to analyze the atmospheric energy budget in order to get a more meaningful insight into physical processes involved.

The goals of our future work may be summed up as follows: (1) to specify principal empirical relationships between variations in the solar energy output and tropospheric weather; (2) to find the most plausible physical mechanisms to explain these relationships; (3) to verify these possible mechanisms using independent data.

We work in conjunction with other atmospheric and solar scientists in Boulder and at such institutions as the National Center for Atmospheric Research (NCAR), the National Oceanic and Atmospheric Administration (NOAA), and the University of Colorado.

Contractor: UNIVERSITY OF CALIFORNIA
Berkeley, California 94720

Contract: EY-76-S-03-0034 032

Title: I. Isotopic Studies on Rare Gases in Terrestrial Samples and in Natural Nucleosysthesis

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. In terrestrial samples subterraneous 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 as a primordial component more ancient than the earth itself. Rocks similarly contain atmospheric gases, radiogenic gases, and sometimes primordial gas. A new program 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 gas versus radiogenic gas. While instrumentation for 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.

This group maintains a continuing interest in geochronology, particularly in problems where physicists -- as opposed to geologists -- can make contributions. Our work in establishing the ^{39}Ar-^{40}Ar method of K-Ar dating is an example of this kind of research.

Studies in natural nucleosynthesis make use of meteorites and clues they contain to the chronology of nucleosynthesis. Rare gases are in part daughter products of extinct and extant radioactivities. We also study isotopic inhomogeneities, such as we observe in the carbonaceous chondrites. It is likely that they originate because of incomplete isotopic mixing of fractions with different histories of nucleosynthesis.

There is currently emphasis in our work on the carbonaceous, acid-resistant residues in chondritic meteorites which, although they represent less than one percent by weight of the stones, have been found to carry virtually all of the planetary gases trapped in these objects. Very markedly anomalous isotopic patterns for xenon are observable in these residues after the bulk of the gases have been released by selective chemical treatments.

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

Contract: EY-76-S-03-0034 171

Title: I. Compressibility Measurements

Person in Charge: G. C. Kennedy

Scope of Work

The Grüneisen parameter of KBr and Bi through their high pressure phase transitions was determined. At high pressure, temperature changes ΔT associated with adiabatic pressure changes were measured and γ has been calculated using the relation $\gamma = K_S/T\,(\partial T/\partial P)_S$. A discontinuous increase in $(\Delta T/\Delta P)$ is observed which results in an increase in when the sample undergoes a phase transition.

Measurements of the pressure dependence of γ for pyroxene and quartz also were made. In all the cases, $\Delta T/\Delta P = (\Delta T/\Delta P)_0 \times (V/V_0)^q$ where q is ~ 5 or 6. This is very similar to our earlier observation on NaCl and on some fluids such as methanol, ethanol, pentane, isopentane and the metals iron, lead, aluminum, indium and copper. Measurements on other minerals are in progress.

The first and second pressure derivatives of the elastic moduli of fused quartz were determined by ultrasonic measurements of the sound velocity as a function of pressure. The second derivaties are positive in sign and are larger in magnitude than those in crystalline materials. The data are used to calculate the adiabatic compressibility, equation-of-state, and the volume dependence of the Grüneisen constant.

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

Contract: EY-76-S-03-0034 P.A. 224

Title: II. The Relationship of Rock Physics to Geothermal Energy Technology

Persons in Charge: Orson L. Anderson and Nick Warren

Scope of Work

Properties of the Earth's crust at low overburden pressure are controlled to a great extent by the rock fracture and microstructure. This grant continues our work on characterizing the effect of pores and cracks on rock bulk properties. There are two areas of research: (1) that of characterizing rock microstructure using acoustic and petrographic methods; (2) application to characterizing permeability and its pressure derivative in terms of microstructure. The results of our investigations should be to give us more detailed understanding of fracture and crack properties under geological conditions and of the effects of detailed crack spectra on bulk physical properties as well as new methods of measuring or estimating averaged microstructure distributions in rock.

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

Contract: EY-76-S-02-3134

Title: I. A Comprehensive Study of the Seismotectonics of the Eastern Aleutian Arc and Associated Volcanic Systems

Persons in charge: J. Davies, K. Jacob, and L. Sykes

Scope of Work

The seismotectonics of the eastern Aleutian arc and associated volcanic systems are studied in a comprehensive program to develop a coherent understanding of tectonic processes at this convergent plate margin. An important objective is to study emplacement of magma in magma chambers beneath a volcano and in the "plumbing system" (central vents, radial dykes) of the volcano through which magma reaches the surface during eruptions. Understanding these processes is needed for evaluating feasibility of geothermal energy extraction from island-arc type volcanoes. For this purpose we operate a dense seismic network on an active volcano (Pavlof) and monitor other volcanoes (Akutan, Makushin) with single seismic stations. We attempt to locate seismic events within and beneath the volcano and monitor wave propagation, attenuation, and time delays indicative of presence of migration of substantial bodies of magma in or beneath the volcano. A regional seismic network in the Shumagin Islands segment of the eastern Aleutian arc provides information on stress and strain release in the arc-trench gap adjacent to the volcanic arc. It is augmented by a crustal deformation monitoring system using geodetic leveling lines and mean-sea-level meters, some of which are satellite data transmission. These highly damped tide gauges are installed on islands in the arc-trench gap. The purpose of the combined monitoring of crustal deformation, seismic activity, and volcanism is to study the interrelationship of crustal loading from plate subduction, cyclic strain relief by large earthquakes, and periodicities in volcanic eruptive activity. There are indications that island-arc volcanism may be controlled by tectonic stresses transmitted from the subduction zone into the volcanic arc. To determine the orientation of tectonic stress systems we use fault-plane solutions of earthquakes in the seismically active portions of the arc-trench system, and distribution of flank eruptions and dykes in the volcanically active portions. This comprehensive study provides, as a byproduct, important data for seismic and volcanic hazards evaluation in the outer continental shelf and coastal zones of the Alaska Peninsula which are presently under consideration for leasing for oil and gas resource development.

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

Contract: EY-76-S-02-4054

Title: II. Fluid Transport Properties of Rock Fractures at High Pressure and Temperature

Persons in Charge: C. Scholz, T. Engelder

Scope of Work

Emphasis of this study is on mechanical-hydraulic interactions, in an attempt to understand the process of fracture closure and its influence on fracture permeability. To determine fluid transport properties of a fracture, we investigated the effect of surface roughness, geometry and filling on fracture permeability. We measured the permeability of whole and jointed Barre granite up to pressures of about 2 kbars. Jointed samples were actually split cylinders joined by surfaces with controlled surface roughness. Samples with induced tension fractures were also measured. The permeability of the whole rock, which ranged from about 10^{-6} to 10^{-8} darcies, was 3 to 4 orders of magnitude less than the jointed rock at all pressures.

Permeability was not a simple function of the difference between internal fluid pressure and confining pressure. Changes in permeability were found to be proportional to $(bP_f - aP_c)$ where P_c is confining pressure, P_f is fluid pressure and the ratio b/a is related to both whole rock and joint compressibility. The value of b/a was close to one for the whole rock and most highly polished surfaces, but decreased slightly with increasing surface roughness. Not only did confining pressure have a slightly greater effect than fluid pressure on permeability, but the order in which the rock was subjected to changes in P_c or P_f also affected the permeability. Increasing P_c first resulted in lower permeabilities at the same value of $(P_c - P_f)$ than when P_c and P_f were increased simultaneously.

Both permeability and joint aperture decreased smoothly with normal stress to an arbitrarily small fraction of their zero pressure values. The effective pressure $(P_c - P_f)$ at which this fraction was reached was greatest in the whole rock and decreased with joint surface roughness.

Contractor: MASSACHUSETTS INSTITUTE OF TECHNOLOGY
Department of Earth and Planetary Sciences
Cambridge, Massachusetts 02139

Contract: EY-76-S-02-2534

Title: I. Seismology of Crack Formation and Natural Geothermal Systems

Person in Charge: Keiiti Aki

Scope of Work

We are developing several seismic methods for determining the structure of geothermal energy source regions, such as magma reservoirs and conduits in a volcano or a hydrofractured crack of a hot dry rock geothermal system. We are taking a dual approach based on active and passive experiments.

In the active experiment, we use an artificial source such as a buried explosion and study scattered waves in the near-field and far-field of a structure upon which primary waves are incident. Theoretical work is conducted on diffraction of P waves incident upon dry and fluid-filled finite cracks. We also study reflection and transmission of elastic waves by a sheet of viscous liquid sandwiched in an elastic body. These results have been used in interpreting seismic data obtained at the Kilauea Iki Volcano, Hawaii, and at the Fenton Hill Hot Dry Rock Geothermal Site, Los Alamos, New Mexico, for defining location, shape, and size of fluid-filled cracks.

In the passive experiment, we use seismic signals generated from the geothermal energy source region to determine physical parameters of the geothermal system. Theoretical work is being done on the seismic motion of a fluid-filled crack due to jerky extensions. The results are being applied to volcanic tremors observed in Hawaii for determining the mechanism of magma transport under Hawaii. Seismic data from the USGS Kilauea network were digitized and are currently being analyzed. Detailed seismic studies of thermal cracks in Kilauea Iki determine their source parameters such as focal depths and seismic moments. A similar study is underway on microseismic events which are generated when the fracture of Fenton Hill Hot Dry Rock Geothermal system is pressurized.

A network of digital event recorders is being constructed and tested for collection of high quality seismic data.

Contractor: MASSACHUSETTS INSTITUTE OF TECHNOLOGY
Department of Earth and Planetary Sciences
Cambridge, Massachusetts 02139

Contract: ER-78-S-02-4972.A000

Title: II. Microcrack Technology

Person in Charge: Gene Simmons

Scope of Work

The object of this project is to develop methods of using data obtainable from microcracks in rocks. We are initially examining a suite of rocks from two geothermal sites, Coso and Raft River. The scanning electron microscope and petrographic microscope are used to determine morphology, spatial and temporal relationships, and degree of sealing of microcracks. Energy dispersive x-ray systems and the electron microprobe are used to determine the elemental composition of host grains, crack sealing minerals, and small (less than 1000 Å) grains that are dispersed along many sealed cracks. Differential strain analysis, a new high precision strain measuring technique, yields information about open microcracks: the orientation of sets of cracks, the distribution of volumetric and linear crack porosity with respect to the closure pressure of individual cracks.

Contractor: NATIONAL ACADEMY OF SCIENCES
Washington, D. C. 20418

Contract: E(49-1)-3772

Title: I. Studies in Geophysics

Person in Charge: Pembroke J. Hart

Scope of Work

The Geophysics Research Board (GRB) of the National Academy-National Research Council is conducting a series of studies in geophysics dealing with timely scientific and societal aspects of geophysics and the corresponding demand on geophysical knowledge.

The series of studies is guided by the Geophysics Study Committee consisting primarily of members of the GRB or their designated alternates. Each study is conducted by a panel selected for the purpose. The studies include: (1) problem-oriented studies, e.g., demands on geophysical knowledge in connection with climatic variations, fresh water resources, mineral resources, geothermal and other energy sources, geophysical predictions, air quality, and food; and (2) science-oriented studies such as international programs in geophysics, status of developments and opportunities in geophysics, impact of technology on geophysics, and criteria for assessment of priorities. Two or three studies are expected to be completed each year. The series of studies is supported in part by the Department of Energy.

The panel for each study consists of a chairman and authors of papers for the study. These papers are presented at a suitable symposium, after which, the authors prepare their final papers. Each study contains an introductory section providing a synthesis of the volume, findings, and recommendations, and discussing its relation to other studies. Identification of societal issues and assessment of adequacy of geophysical knowledge is the basic element of these studies. The complex but important question of priorities is considered by each panel.

The proposed modular pattern for the Studies in Geophysics was designed to permit selection of the most timely topics and rapid completion of individual studies to meet the following objectives:

(1) to set forth the current and prospective contributions that the geophysical sciences can make to such concerns of mankind as energy, nonrenewable resources, and the environment;

(2) to provide government officials with technological and scientific evaluations that can serve as a rational basis for decision making in matters involving geophysical research and knowledge, both in policies and programs;

(3) to provide to the scientific community itself a basis for rational judgments with respect to the development of the basic science of geophysics in the broad sense and with respect to the relative

importance to society of the developments within various branches of geophysics.

A. Studies Completed

Some of the principal results and recommendations of the studies that have been completed are outlined below:

1. Energy and Climate (Roger R. Revelle, Panel Chairman. Published 1977; 158 pages, $9.50)

A principal conclusion of the report Energy and Climate is that the climatic effects of carbon dioxide release may be the primary limiting factor on utilization of fossil fuels over the next few centuries. On the basis of a scenario for growth of energy use for the next century, an increase in carbon dioxide concentration in the atmosphere by a factor of 4 to 8 is foreseen for the latter part of the twenty-second century. The report anticipates that the threat of a corresponding increase in world temperatures of over 6° C would lead to a curtailment in the growth of fossil fuel use long before this scenario could fully unfold. Specific recommendations are made for research to reduce uncertainties and fill gaps in our knowledge regarding the physical and biological processes involved.

The principal conclusions of the study were announced to the scientific community and to the public at a news conference held on July 22, 1977 at the Academy.

2. Climate, Climatic Change, and Water Supply (James R. Wallis, Panel Chairman. Published 1977; 132 pages $7.75)

Lack of water hampers population and economic growth in some areas of the world, but even in such areas it is common to think of water as a resource that is renewable within the bounds imposed by a stationary regional climate. Unexpected, prolonged, and widespread shortages of water resulting from climatic change could have an unsettling, and depressing effect on regional, and possibly even the national economy. However, for a number of reasons, including institutional factors associated with water resource design considered in the context of climatic change, the rate at which it can be expected to occur, and our ability to predict it, it does not seem apropos to call for a radical revision of current water resource design practices.

Nonetheless, a dramatic change in climate that would cause us to question this reasoning is by no means impossible, and there is a great deal that could be done now that would allow for mitigation of the effects of possible climatic changes on future water supplies. In particular, the study examines the relationship between hydrology, water supply, climate, and climatic change and points out areas where deficiencies in knowledge and information make rational water resource decision making more difficult than it need be.

3. Estuaries, Geophysics, and the Environment (Charles B. Officer, Panel Chairman. Published 1977; 127 pages, $8.50)

Compared with the science of rivers and lakes on the one hand, and that of deep oceans on the other, the science of estuaries is extraordinarily complex. If we consider strictly the geophysics of water bodies, there is a recognizable group of scientists -- hydrologists -- studying the oceans. There is not an analogous, identifiable group working in a traditional discipline studying estuaries and their associated coastal waters per se. This study includes recommendations for dealing with this recurrent theme: division of responsibility among many agencies and scattering of research effort among many disciplines.

4. The Upper Atmosphere and Magnetosphere (Francis S. Johnson, Panel Chairman. Published 1977; 168 pages, $10.00)

Rockets and satellites have probed the upper atmosphere and magnetosphere for the last two to three decades. It is natural to wonder whether, after such extensive study, most of the interesting and important problems in this area have been solved. The understanding of phenomena in the upper atmosphere and space documented in the papers of this study is indeed impressive, but in fact, new and important physical processes taking place in the upper atmosphere continue to be discovered. A principal conclusion of this study is that many significant problems remain.

5. Geophysical Predictions (Helmut E. Landsberg, Panel Chairman. Published May 1978)

This study emphasizes those geophysical predictions intended to reduce loss of life and to protect property. The prediction of earthquakes is an example. Other hazards, related not only to the solid earth, but also to the atmosphere and hydrosphere, are discussed. Included are such phenomena as volcanic eruptions, hurricanes, tornadoes, and tsunamis. In most instances, timely warnings can reduce the loss of life, but property damage may be unavoidable.

B. Studies Planned or in Progress

Brief descriptions of studies in progress or whose planning is well advanced are given below.

1. The Impact of Technology on Geophysics (Homer E. Newell, Panel Chairman)

Technology has a profound impact on geophysical research, primarily through the instrumentation and research techniques it makes possible. In turn, geoscience contributes extensively to technology and practical applications. Examples include meteorology, water resources, mineral resources, ocean resources, and cartography. Future possibilities include weather modification,

climate prediction, and earthquake prediction. This study focuses on the importance of technology to geophysical research and illustrates that importance rather than attempting to create an exhaustive catalogue. The study was presented at the American Geophysical Union meeting in December 1977 and a first draft of the report is complete and under review. Publication is expected in 1978.

2. Continental Tectonics (B. Clark Burchfiel, Panel Chairman)

Continental areas of the world are man's natural habitat; thus, it seems only reasonable that a significant research effort should be directed toward obtaining greater knowledge of our land areas and their interface at continental margins with the marine environment. Focus in the next decade on continental geology, in its broadest sense, and all processes that affect the continents, both within and below the lithosphere, should be a major goal of earth science. The majority of our material resources accessible over the next decade is on continents, and the formation of both metallic and non-metallic ore deposits in relation to continental evolution should be of principal interest to all earth scientists. The panel members have been selected and their papers were presented at the meeting of the American Geophysical Union in April 1978.

3. Mineral Resources (Paul B. Barton, Panel Chairman)

Because of the increasing scarcity of a growing number of essential elements, an improved understanding of the fundamental processes that determine the location of ore bodies is needed. This study will be a joint undertaking of the GSC and the U.S. National Committee on Geochemistry. Among the topics and issues in this study are: sites and level of effort of present research and their effect on basic understanding of mineral resources; gaps in data and research both current and projected; implications of level of research to supplies of critical minerals; and evaluation of understanding of processes of mineral concentration. Panel members have been selected and their papers are scheduled to be presented at the Geological Society of America meeting in October 1978.

4. Sun, Weather, and Climate

The question to be addressed by this study is: Do changes in the sun influence weather or climate, and if so, how? Past studies of this question have been confused by erroneous statistical analyses and the lack of identifiable physical mechanisms relating solar parameters to weather and climate. Because of recent results, it is timely to reexamine the question. A chairman has been selected and proposed topics for the study include solar variability, empirical evidence for meteorological effects, and a survey of possible physical mechanisms.

5. Paleoclimatology

This subject has been a recurrent theme in the studies carried out so far. Topics in the study may include a recapitulation of the role that paleoclimatology plays in determining the relationship between climate and water and in providing evidence for models of climatic change related to projected energy use as developed in the studies "Climate, Climatic Change, and Water Supply," and "Energy and Climate." Additional topics might include the relevance of paleoclimatic studies to understanding the physical mechanisms of climate dynamics. A special ad hoc meeting was convened in 1977 to review the need for studies in this area. A detailed internal report recommending several different kinds of studies resulted from that meeting.

C. Geophysics Study Committee

The Geophysics Study Committee was established to serve as a steering committee to implement the plan for the Studies in Geophysics. Members of the Committee are:

Charles L. Drake, Chairman
Louis J. Battan, Vice-Chairman
Philip H. Abelson
Richard M. Goody
Francis S. Johnson
Walter B. Langbein
Thomas F. Malone
Hugh Odishaw

Contractor: NATIONAL ACADEMY OF SCIENCES/NATIONAL RESEARCH COUNCIL
Committee on Seismology

Contract: EY-76-C-02-2708-003

Title: II. Partial Support for the Committee on Seismology

Person in Charge: Joseph W. Berg, Jr.

Scope of Work

The Committee on Seismology meets twice a year to discuss current topics of major importance relevant to seismology, to review with government agency personnel, in particular, the actions that have resulted from recommendations of the Committee and its panels, and to take actions to assure a healthy science which is in a position to provide maximum benefits to the nation and to society. The two most recent reports were published in 1977. These are: (1) Trends and Opportunities in Seismology, which deals with major areas of concern to the U.S. citizens--geological hazards, exploration for energy and for other resources, understanding the earth and planets--and discusses roles of government agencies, universities, and industry in helping to realize benefits that seismology can provide; and (2) Global Earthquake Monitoring: Its Uses, Potentials, and Support Requirements, which recommends actions to stabilize funding for networks, to improve the Worldwide Standardized Seismograph Network, and to provide a digital data base for research purposes in addition to the existing analog data base.

The new panels have been established as follows: (1) The Panel on Earthquake Problems Related to the Siting of Critical Facilities, which is currently writing a report that will recommend geological and seismological research to help in the siting of critical facilities (such as dams, reactors, etc.); and (2) The Panel on National, Regional, and Local Seismograph Networks, which has been charged to review current practice but to emphasize recommendations for future developments of such networks relevant to the needs of the nation and of the science. The reports from both panels probably will be available during 1979.

The Committee on Seismology will continue to take actions which result in recommendations either by letter or by the more formal published report. Topics that could result in additional panels of the Committee are: (1) new information and insights about the continental United States to be gained from deep-refraction and reflection-seismic studies; (2) actions that can be taken with real time monitoring of earthquakes; and (3) planning for regional data centers for using digital data. As necessary, the Committee will establish ad hoc groups to attack important problems such as these, including in the studies scientific and technical evaluations and consideration of implications for society.

Contractor: NOAA ENVIRONMENTAL RESEARCH LABORATORIES
Space Environment Laboratory
Boulder, Colorado 80303

Contract: EI-78-I-01-3093

Title: I. Solar-Terrestrial Predictions Program

Person in Charge: Richard F. Donnelly

Scope of Work

The program includes working groups, a proceedings and workshop on Solar-Terrestrial Predictions. The proceedings will include reviews by groups that routinely make some type of predictions, reviews of future needs for predictions by users, literature reviews, contributed papers on particular prediction techniques and working group reports. The workshop is scheduled for April 23-27, 1979, at the College Inn in Boulder. The plans call for an exchange of papers before the workshop is held. Those attending the workshop are expected to have completed extensive reading before April 1979.

The working groups include the following topics:

A. Solar Activity Predictions (prediction techniques, theoretical and empirical background from the sun out to 1 AU).

1. Long-term solar variations (years, solar cycles and longer)
2. Short-term solar variations (minutes, hours, days, months: flares, proton events, active region evolution, coronal holes and interplanetary phenomena, such as shocks, streams, and sector boundaries)

B. Geomagnetic and Magnetosphere-Particle Disturbance Predictions

1. Interplanetary-magnetosphere interactions
2. 27-day recurrent storms
3. Substorms
4. Flare-related magnetic storms
5. Particle fluctuations

C. Ionospheric Predictions (prediction techniques, theoretical and empirical background).

1. Magnetosphere-Ionosphere coupling
2. F- and E-regions
   a. Equatorial
   b. Midlatitudes
   c. High altitude
3. D-Region

D. Solar-Weather Predictions

E. Communications Predictions

1. Transionosphere: VHF, UHF....Optical
2. Ionosphere-reflected propagation: MF, HF
3. Ionosphere waveguide: ELF, ULF, VLF, LF

F. Geomagnetic Applications

1. Geomagnetic surveys
2. High-latitude long-line power systems
3. Pipelines
4. Seismology

G. Space-Craft Environment and Manned Space Flight Applications

Contractor: STANFORD UNIVERSITY
Stanford, California 94305

Contract: EY-76-S-03-0326 045

Title: I. Porosity with Fluids: Origin and Effects on Physical Properties of Crustal Rocks

Person in Charge: A. Nur

Scope of Work

A. Poisson's Ratio in Geothermal Areas

We measured in the laboratory both compressional and shear velocities in sandstones and cracked granites, containing hot water and steam, under various conditions of confining pressure, pore pressure and temperature. We find, as expected, that shear velocity is higher in rock with steam than in rock with hot water, whereas compressional velocity shows the reverse relationship. Consequently the ratio V_p/V_s, and Poisson's ratio are low in rock with steam and high in rock with hot water. An unexpected result is low V_p/V_s velocities, and Q, in the neighborhood of the phase transition.

The results are very encouraging in using Poisson's ratio to detect the presence of steam in geothermal reservoirs from seismic data. Abnormal reflections are expected from boundaries between steam and hot water.

B. Attenuation of Seismic Waves in Rocks

Attenuation of seismic waves in porous rock was found in the laboratory to be related to several parameters: confining pressure, nature of pore fluid, pore pressure, temperature, strain amplitude, and the density of internal surface area in rock. At present we are measuring Q to 1 % and the Associated wave dispersion to .1 %. Results show that the presence of gas and liquid phases in porous rocks lowers both Q and velocities relative to fully saturated end cases. Theoretical results further show that the most likely mechanism for attenuation in hot crustal condition is thermal relaxation.

The results thus provide the physical basis for the nature of wave propagation in hot reservoirs in the crust.

Contractor: U.S. GEOLOGICAL SURVEY
National Center, Stop 959
Reston, VA 22092

Contract: EG-77-A-01-6150

Title: I. National Center for the Thermodynamic Data of Minerals (Partial Support)

Person in Charge: John L. Haas, Jr.

Scope of Work

The National Center for the Thermodynamic Data of Minerals (Data Center) searches world literature on a continuing basis, retrieves and indexes papers pertaining to minerals and their synthetic analogs, extracts numerical data, and carries out critical evaluation leading to publication of tables and reviews. Primary emphasis is placed on coverage of numerical data needed to understand the geological environment and to utilize its resources. Specifically, the Data Center will develop critically evaluated thermodynamic constants for all naturally occurring solid phases or chemical end-members, as appropriate, and will cooperate with other data centers of the National Standard Reference Data System on properties of gases and aqueous ions. The goal of the Data Center is to make available the following information: (1) For each mineral at nominal intervals of 50 K from 0 to 200 K tabulated heat capacities at constant pressure C_p°, entropy S°, relative heat content $H^\circ(T)-H^\circ(298.15K)$, Gibbs energy functions $[G^\circ(T)-H^\circ(298.15K)]/T$, enthalpy of formation ΔH_f°, free energy of formation ΔG_f°, equilibrium constant for formation $\log_{10} K_f^\circ$, molar volume V°, molar compressibility β, and molar expansivity α. (2) Mathematical functions which closely describe energy and volumetric properties of geologic materials. (3) Estimates of precision and accuracy of the tabulated data. (4) A synopsis of the data and assumptions that were considered in critical review. (5) References to the source of all data used.

Richard A. Robie, Bruce S. Hemingway, and James R. Fisher have completed a summary of available calorimetric data for minerals (USGS Bulletin 1452).

Critical evaluations on minerals in the system K_2O-Al_2O_3-SiO_2-H_2O and CaO-Al_2O_3-SiO_2-H_2O are in progress. In addition to expanding these critical reviews to other silicate systems, critical reviews of sulfide systems are started.

Contractor: WOODS HOLE OCEANOGRAPHIC INSTITUTION
Woods Hole, Massachusetts 02543

Contract: EG-77-S-02-4392

Title: I. Organic Geochemistry of Outer Continental Margin and Deep Ocean Sediments

Person in Charge: J. M. Hunt

Scope of Work

A gas chromatograph-thermal distillation unit has been set up and is being tested for evaluating the petreoleum potential of deep sea sediments. The study will determine free hydrocarbons and those available from cracking of organic matter in fine-grained sediments from the outer continental margins, slope, and rise of the United States. It also will involve evaluating the type of kerogen (insoluble organic matter) required to maximize hydrocarbon yields in these areas.

*U.S. GOVERNMENT PRINTING OFFICE: 1978 261-524/116 1-3