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**Solid Earth Geosciences
Research Activities at LASL
January 1 — June 30, 1975**

Compiled by
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SOLID EARTH GEOSCIENCES
RESEARCH ACTIVITIES AT LASL
JANUARY 1 - JUNE 30, 1975

Compiled by
Grant Heiken

ABSTRACT

The Geoscience group at the Los Alamos Scientific Laboratory (LASL) supports existing geoscience-related programs and conducts a basic research program related to energy and earth resources.

Projects supporting the dry hot-rock geothermal energy program include study of drill cores, seismic activity associated with hydraulic fracturing at the drill site, and the thermal state of the Valles Caldera.

Research in igneous processes includes the modeling of large-scale volcanic eruptions such as the one which deposited the Bandelier Tuff around the Jemez Mountains, the petrology of those tuffs, and the dimensions of the magma chamber below the Valles Caldera. Recent activity at Mt. Baker, WA, presented an opportunity to observe increasing fumarolic activity which may precede an eruption. The activity is continuously monitored by two sequence cameras. Samples of the tephra from around the vent have been studied, temperatures were measured, and ground observations were made of the new fumaroles. Every three months a flight is made over the volcano for aerial photography and infrared scanning.

Field studies in the Southern Cascade Mountains were begun to determine the petrochemistry, mode of eruption, and volume of erupted materials for the last 0.5 million years. This study will be used to evaluate the present thermal state and composition of magmas below the range.

Investigations of active volcanoes and their eruptions will provide data for geothermal research on the physical properties of the magma.

I. INTRODUCTION

Current geoscience activities at the Los Alamos Scientific Laboratory (LASL) include the dry hot-rock geothermal energy experiment, the experimental hot-tip drill (Subterrene) seismology, rock mechanics, and igneous processes. Most of these activities support existing applied programs, such as geothermal energy, or are directed toward solving fundamental problems in the geosciences, especially those related to energy and natural resources (Table I).

II. GEOTHERMAL ENERGY

A. Analysis of Cores from the GT-2 Drill Hole

Work continues on petrographic, geochemical, and geochronological analyses of the cores from the GT-2 drill-hole (Table II). Two distinctive igneous units have been recognized in cores of Precambrian rocks from GT-2; a leucocratic monzogranite and a biotite granodiorite. Metamorphic units sampled by the coring include an amphibole-biotite schist and a banded gneiss.

TABLE I

GEOSCIENCE ACTIVITIES AT LASL

Scientific Support of the Dry Hot-Rock Geothermal Energy Project

- Petrographic, chemical, geochronologic analyses of physical properties of GT-2 cores.
- Seismic activity associated with fluid injection at GT-2.
- Heat flow across the Rio Grande rift.

Igneous Processes

- Modeling of volcanic activity of the Valles Caldera and thermal state of the magma chamber associated with it. Seismic determination of the shape of the magma chamber.
- Study of the increasing fumarolic activity at Mt. Baker, WA.
- Petrology, tephrochronology, history, and geothermal potential of the Southern Cascade Range.
- Study of eruption phenomena at Mauna Loa and Kilauea Volcanoes, HI.
- Satellite study of eruption clouds.
- Modeling eruption phenomena in the laboratory.

Geophysics

- Expansion of the LASL seismic network.
- Development of seismic event recorders and a tiltmeter.
- Monitoring seismic activity associated with filling the reservoir behind Cochiti Dam, NM.

Geochemistry

- Experimental alteration of granitic rocks from the GT-2 drill-hole core samples.
- In situ recovery of kerogen from oil shale.
- Trace element analyses of GT-2 drill core.
- Permeability of granitic rocks from the GT-2 drill core.

Subterrene

- Drilling through basaltic lava lakes.

Remote Sensing

- Image analysis and enhancement of LANDSAT imagery.

Planetology

- Petrologic analysis of lunar soil samples.
- Petrology of meteorites.

TABLE II
GT-CORE ANALYSES

- I. Fracture Studies
 - A. Orientation (LASL)
 - B. Spacing (LASL)
 - C. Mineralogy (LASL)
 - D. Chemistry (LASL)
 - E. Microfractures (MIT)
- II. Physical Properties
 - A. Porosity and permeability (University of Toronto)
 - B. Density (US Bureau of Mines)
 - C. Compressive Strength (USBM)
 - D. Tensile Strength (USBM)
 - E. Elastic Constraints (USBM)
 - F. Thermal Conductivity (LASL)
 - G. Specific Surface Energy (USBM)
 - H. Wave Velocities (USBM)
 - I. Dynamic Constraints (USBM)
 - J. Magnetism (University of Oklahoma)
- III. Chemistry
 - A. Whole Rock Analyses (University of New Mexico)
 - B. Mineral Analyses (LASL, UNM)
 - C. Inclusions (UNM, University of Tulsa)
 - D. Experimental Solution (LASL)
 - E. Stable Isotopes (UNM)
- IV. Geochronology
 - A. Rubidium-Strontium (UNM)
 - B. Potassium-Argon (University of Alaska)
 - C. Uranium-Thorium, Lead (US Geological Survey)
 - D. Fission Tracks (USGS)
- V. Petrography (LASL)

The biotite granodiorite extends from a depth of 2588 m to 2928 m. When compared with other Precambrian rock units sampled by GT-2, this rock is remarkably homogeneous. It is characterized chemically by high TiO_2 , K_2O , and P_2O_5 contents.

Mineral separates are being made for radiometric dating.

B. Seismic Activity Associated with Geothermal Experiments at the GT-2 Drill Hole

Equipment is being readied and evaluated to monitor large-scale fluid injection experiments conducted at the Fenton Hill drill site. The winter season has posed many logistical problems and caused damage to the existing seismic network. To date, there have been no hydraulic fracturing experiments capable of generating seismic signals that could be detected by surface stations. Seismic signal generation by hydraulic fractures is being studied in the literature and by personal communication. We conclude that the surface array will not detect fracturing for flow rates of less than 6.31 l/s. The surface noise level is too great to locate fractures with a precision of less than 150 m. Detection and locating sensitivities will be enhanced by placing seismometers in boreholes 30 m deep or greater. Geophones are being clamped into the heat-flow boreholes at the GT-2 site. These are *in situ* having low background noise levels.

C. Heat Flow Across the Rio Grande Rift

The Rio Grande rift system is an en echelon train of elongate, discontinuous tectonic basins with Tertiary and Quaternary volcanism, high heat flow, seismicity, and negative gravity anomalies occurring in New Mexico and Colorado (Fig. 1).

Commencement of volcanism associated with the rift ranges in age from 37 Myr at Latitude 33°N , through 24 to 28 Myr in central New Mexico, to 1 to 10 Myr from 35° to 37°N . Surface heat-flow values of ~ 2.5 heat-flow unit (HFU) ($1 \text{ HFU} = 10^{-6} \text{ cal/cm}^2 \text{ s}$) are associated with volcanism although local highs of ~ 5.5 HFU have been recorded near the Valles Caldera. Reduced (inferred mantle) heat-flow values ≥ 1.8 HFU have been recorded in southern New Mexico, and associated radiogenic heat production ranges from 2.2 to 4.9 heat-generation unit (HGU) ($1 \text{ HGU} = 10^{-13} \text{ cal/cm}^3 \text{ s}$). Contrasting reduced heat-flow measurements for the Basin and Range and Great Plains is from ~ 1.4 to 0.8 HFU, respectively. Hence, high heat flow of the rift relative to other physiographic provinces implies melting temperatures at shallow depths beneath the rift. Local magni-

Fig. 1. Rio Grande rift.

tudes of recorded shallow earthquake swarms range from $1.2 \leq M_L \leq 3.5$. A recurrence relation suggesting a maximum $M_L \sim 6/100$ yr indicates recent tectonism. Bouguer activity anomalies averaging 20 Mgal reach a maximum of ~ 35 Mgal in the San Luis Valley, CO. Stratigraphic relations indicate rifting started in Oligocene time about 25 to 30 Myr ago. Horizontal motion is ~ 5 km of extension but decreases from south to north as shown in Fig. 1. Geologic reconstruction of the basement interface indicates 0.1 mm/yr vertical motion.

III. IGNEOUS PROCESSES

A. Jemez Mountains and Valles Caldera, NM

1. Hydrodynamic Modeling of Volcanic Activity.

The URANUS version of the KACHINA algorithm has been implemented for multiphase hydrodynamic calculations in two dimensions. Work with this new computer code is motivated by weapons system problems in dust lofting, crater formation, and ground shock effects from near-surface and slightly buried

detonations. There is presently no computer code available that will calculate these phenomena, including such necessary physics as changes of phase and radiative dissipation to the ground and air. The KACHINA algorithm developed by Harlow and Amsden (LASL Group T-3) incorporates only the physics necessary to calculate multiphase fluid flow. Modifications that provide for phase transitions and radiative (neutron) heating were made by LASL's reactor safety group and comprise the URANUS algorithm.

The calculations are directed toward studying the Valles volcano explosion responsible for depositing the Bandelier tuff. The work therefore serves the dual purpose of appraising the code as a reactor safety tool and of studying a geologically important problem being observationally pursued in the laboratory.

Figure 2 is a series of plots illustrating the material motion produced in this model calculation of the Valles volcano. The plots show that eruption of gas-charged magma from a 5-km-diam vent produces an air shock that propagates mostly in the vertical direction. Magma of specific gravity 2.7 is ejected, although much of the vent material remains and finally assumes the hydrostatic equilibrium condition initially present in the surrounding rock bed. These calculations treat all materials (vapor and rock) as fluids because there is presently no provision in the code for material strength and fracturing phenomena.

The problem that was solved includes no radiative heating. Time-dependent radiative transfer could best be done using the implicit Monte Carlo method we now use with the YAQUI hydrodynamics code. For time-independent, nongrey or grey calculations, we recommend using the 2D S_n method now used for hotter nuclear fireball problems. An excellent weapon effects code would result by combining these radiation methods and the KACHINA/URANUS algorithm. The code would be similar to the one in the YOKIFER code.

With the exception of rock vaporization effects produced by radiation, the volcano calculation illustrates the phenomenology that would be produced by a shallowly buried nuclear explosion. We believe the KACHINA method can become a valuable tool for studying phenomenology beyond our present capability.

Fig. 2. Computer results showing shock in air and ash from eruption of steam-saturated silicic magma chamber, initially assumed to be at 800°C and 0.1-GPa pressure. Such eruptions were responsible for the Bandelier tuff. The first was 1.4 Myr ago, the second was 1.1 Myr ago. Numbers indicate time in seconds from the beginning of the eruption. These models predict many features which can be field checked, and can be used as research tools to test model parameters and assumptions. (+) are rock or ash particles; (.) are air particles.

Such problems include detonations in massive cabs and bunkers, on barges, above or under water or over coral atolls, and those shallowly buried. Problems encountered in Pacer explosions would be best studied with the proposed program.

2. Petrology of the Jemez Mountains. A field and electron microprobe study of the lithic fragments in the Bandelier tuff is being conducted to determine what rocks are under the Valles Caldera and how they interacted with the Bandelier magma. Distribution of the fragments within the tuff will be mapped and a representative suite of fragments collected. Precambrian fragments erupted in the vicinity of the GT-2 drill site will be compared with GT-2 core to determine how the magma has altered the basement and what changes might be encountered if GT-2 were deepened. If this study produces useful results, it should be applicable to other areas of geothermal potential because ash flow sheets commonly contain abundant lithic fragments.

3. Modeling the Dimensions of the Magma Chamber Below the Valles Caldera. A proposal entitled "Surface Wave Propagation and Modeling of the Valles Caldera Magma Chamber Dimensions," prepared by LASL Group J-9, contains the integration of numerical simulation of wave propagation and seismic records. Parameter studies of models will produce theoretical seismograms that show phase shift and amplitude decrease due to magma chamber dimensions and physical properties. When these are compared with seismic records from the LASL network, an inversion process may provide us with the dimensions of the magma chamber beneath the Valles Caldera.

B. Cascade Mountains

1. Activity at Mt. Baker, WA, 1975. On March 10, 1975, Mt. Baker, WA, a volcano at the north end of the Cascade Range, entered a stage of violent fumarole activity. The new activity is located in the Sherman Crater and caused venting of steam plumes as high as 500 m, rapid melting glacier ice within the crater, and ash deposition as far as 1 km from the vents. We began monitoring this activity in April as a rare chance to study the behavior and thermal state of a Cascade volcano. EG&G flew over Mt. Baker with an infrared scanner

to measure thermal output and with cameras using infrared, color infrared, and black and white film. The imagery and photography clearly show the new fumarole vents, steam, and ash distribution. A ground-based reconnaissance (Fig. 3) of the volcano in late April provided information on the seismic activity, composition of gases and ash, temperature, and state of the crater.

Results of the expedition are outlined in Table III. We are continuing to analyze the photography from overflights and the sequence camera to determine activity changes since March.

From April 29 to May 3, 1975, a portable smoked drum seismograph was installed at Park Butte Lookout in cooperation with Bernard Chouet, Massachusetts Institute of Technology (MIT). Approximately 2-1/2 days of good seismic data (high signal/noise ratio) were obtained, but the last 1-1/2 days of records were obliterated by high wind noise. Preliminary examination of the data shows two teleseism from distant sources and approximately 15 local events, including one of magnitude two. Local events had distinct P- and S-wave arrivals with delays of about 4 s indicating focal distances of the order of 20 km. There is no apparent correlation between times of observed summit activity, such as collapse of ice into the active fumaroles and the seismic events recorded at Park Butte. These two observations suggest that the focal seismicity originates within the interior of the volcano and are not due to activity at the summit. Several of the local events show a gradual buildup and decay of amplitude which could have a different origin. The University of Washington is currently operating seismic stations at three localities near Mt. Baker from which data are telemetered directly to Seattle. This network currently is being expanded to approximately eight stations.

2. Field Studies of Southern Cascade Volcanoes.

A long-term field study of the Southern Cascade Range has been initiated to evaluate the eruptive history, petrology of the eruptive products, and present thermal state of magmas under the range. This may be used to evaluate the geothermal potential. Some of this work is a cooperative effort with the US Geological Survey.

Fig. 3. Fumarole activity in the Sherman Crater of Mt. Baker on August 1974 (above, F. Munich photo) and May 1975 (below, LASL photo). Field of view is approximately 150 m.

3. Petrology of Southern Cascade Lavas:

Lassen Peak and Vicinity, CA. The Lassen Peak area is one of the largest and most active centers of silicic volcanism in the Cascades and exhibits the most fumarole activity. A detailed petrologic study of the recent lavas is under way to determine the chemical evolution of Lassen magmas.

Two active sites are the flanks of Prospect Peak which erupted andesite flows, cinders, and ash (last eruption, 1851) and the Lassen Peak-Chaos Crags center which erupted dacite domes, flows, pumice, and ash (last eruption, 1914-21). Field work during June 1975 revealed that lavas of both these centers show significant petrologic variation

TABLE III

EXPERIMENTS ON MT. BAKER, WA

<u>Experiment</u>	<u>Results</u>	<u>Comments</u>
Seismometer	15 local events probably volcanic in origin, strongest event about magnitude 2.	This is a significantly higher level of seismicity than has been observed on other Cascade volcanoes.
Sequence Camera	Camera is functioning well with a good view of the volcanic plume	Film being processed and analyzed to confirm or deny reports that the activity is increasing.
Spectrograph	Experiment was conducted on steam vent on south side of crater because main vent could not be approached.	Data being analyzed.
Temperature Measurements	Temperature in small but energetic steam vents of west crater wall were 87 to 89°C, or boiling, at that elevation.	Sheathed thermocouple probe proved ideal for temperature measurements.
Alloy Strings	One string was retrieved 1 wk after we placed it and showed pitting of stainless steel and chloride formation.	Further analysis under way at Sandia Labs. String was not subjected to full force of fumarole because it had fallen out, apparently due to rockfall.
Photography	Excellent photographs of the fumaroles were obtained. Comparison with 1974 photos show major changes. Large holes and crevasses in the ice have formed since August 1974. The most energetic, ash producing vent did not exist last August.	
Sample Collection:		
1. Ash	Optical, SEM, x-ray diffraction, and mass spectrometric analysis of ash shows it to be composed of analcite, quartz, iron pyrite, sulfur, and probably chalcopyrite (CuFeS_2).	Analcite is a zeolite commonly formed by hydrothermal alteration of feldspar. The presence of quartz is surprising because quartz is absent in the exposed Baker lavas. Either the interior of the volcano is different from the observed portion, or the source of the ash is deep beneath the cone. Sulfur occurs as spheres, suggesting temperatures of 120°C very near the surface. The vent which produces the ash may therefore be much hotter than the others.
2. Rock Samples	Rock samples were successfully collected but have not yet been analyzed	

with time. The volcanic units were sampled in detail and will be analyzed to determine what processes the magmas are undergoing. Significant findings to date are as follows.

- Basalt inclusion content of Chaos Crags dacite increases from <1 to 30% with time. Textures of the inclusions and the shape of their surfaces reveal that the basalt was molten when mixing occurred.

- Banded pumice¹ erupted from Lassen Peak in 1915 was actually the froth on top of a more homogeneous dacite plug emplaced in the summit of Lassen.

The presence of basaltic inclusions in nearly all the silicic Lassen lavas suggests that the basalt magma is somehow related to the generation of these lava eruptions. Microprobe analysis will be used to study the mixing process and to determine the composition of the parent (unmixed) magmas.

A fumarole area on the northwest flanks of Lassen, which park naturalists report developed in the mid 1960s, was investigated. Steam issued from cracks over an acre of warm ground. The hottest vents were at the boiling point and there was only a weak odor of sulfur.

4. Petrology of Mt. Shasta, CA. Banded pumice similar to the Lassen Peak pumice was found on the upper slopes of Mt. Shasta and is being studied, along with other recent Shasta lavas, to see if magmatic mixing is an important process at this very large andesitic volcano. Temperatures at the summit crater fumaroles remain at the boiling point, and a minor new steam vent has developed since the last observation 1 yr ago. Another interesting field observation was the discovery of numerous granitic inclusions in Shasta andesite, as well as an ultramafic inclusion.

5. History of Explosive Volcanism. Little is known of the explosive volcanic history of the Southern Cascades; most of the efforts here have been concentrated on mapping and petrology of the lavas. To study the age and extent of ash deposits in Northern California, we have started measuring stratigraphic sections of ash deposits, collecting carbon samples for ¹⁴C dating, and sampling sources.

Mt. Lassen, the most recently active and southernmost Cascade volcano, has had an interesting history of explosive volcanism. So far, we have sampled sections from a 1200-yr-old extensive ash flow and fall² that covers much of the northern part of the National Park, ejecta from the ash cloud and volcanic mudflows of 1915-1922 Lassen eruption, and numerous cinder cone deposits, the youngest being formed in 1851. Work on these samples began in late summer 1975. The results will be used to assess the probability of a new

eruption and thermal state of the magma chamber beneath Lassen.

Reconnaissance of Mt. Shasta indicates that the mountain has had an extensive history of lava flows and volcanic mudflows, but has produced little volcanic ash and pumice. Several extensive units sampled here are very old, but dates are yet to be determined.

In contrast, the Medicine Lake Highlands, east of Shasta, has had an extensive history of pyroclastic activity, covering the area with a massive blanket of pumice and ash 1200 yr ago. This area will be studied in detail next year.

C. Eruption Processes

1. Eruption of Basaltic Lavas. Preparations have been completed for a cooperative study with the Hawaiian Volcano Observatory of the US Geological Survey of the next eruption of Mauna Loa and Kilauea Volcanoes, HI. The unique expertise available at LASL will be used for several experiments. The first involves using high-speed and ballistic cameras for a ballistic study of lava fountains. This should allow analysis of the particle size, velocities, and trajectories of melt particles thrown from the vents, and indirectly, the velocity and volume of gas involved in the eruption and viscosity of the magmas. This, combined with data from the Michelson interferometer (next section), will be invaluable in analyzing the degree of natural "pollution" of the atmosphere.

The ejecta involved in the eruptions studied by the above methods will be analyzed by electron microprobe, scanning electron microscope, and several other methods to relate the type of ejecta to the type of eruption. This is critical in evaluating the types of past eruptions at dormant volcanoes, a necessary task when evaluating geothermal potential or volcanic hazards.

The above data collection and analysis will supplement more conventional geologic and geophysical data collected by scientists at the Hawaiian Volcano Observatory.

2. Remote Sensing of Volcanic Gas Compositions.

The composition of volcanic gases during the effusive phases of an eruption continues to be an elusive problem because sampling by conventional methods is so difficult. EG&G has been asked to

prepare, for field operations, a Michelson interferometer for continuous analysis of gas composition during an eruption. The development is complete, the instrument can be mounted in a truck, and it runs off a portable generator. Field trials began on July 1, 1975.

Should this technique work in a field situation, we will be able to determine species of released gases that drive the violent eruptive phase and reach the atmosphere as natural "pollutants." Analysis of the gas phases are important to igneous petrology and the nature of gases released during development of several forms of geothermal power.

3. Analysis of Eruption Clouds (Cooperative Study with the US Geological Survey). Because of the large extent of eruption clouds from explosive volcanic eruptions, they have been assessed only from local, spotty observations or by analysis of the ash fall. The use of earth orbital satellites to observe entire ash clouds will aid in understanding their extent, and indirectly, their hazard in areas of fallout.

Continued eruptions of Sakara-zima Volcano, Island of Kyushu, Japan, have been observed by both the Earth Resources Technology Satellite (ERTS) and by the crews of the Skylab mission. They were able to assess the color, opacity, dimensions, and dispersions of entire eruption clouds.

Puffs representing volcanic explosions were observed from Skylab initially at 0153 GMT on November 27, 1973. A 70-km-long ribbon-like plume, 1.6-km-high, was photographed on December 1. On January 8, 1974, another eruption cloud reached a 260-km length, extended southeast over the Osumi Peninsula, and continued over the ocean where it moved to the northeast, rising to 3.2 km as it was dispersed by strong winds. Near the vent, the cloud was about 4 km wide; at 172 km, it was 86 km wide, dispersed into parallel bands. The unusual form of the volcanic cloud could have been the result of vertical wind shear deforming the plume as it flowed through thermally stable air.

Stereo pairs of the photographs show that the eruption clouds did not penetrate the tropopause to create a stratospheric "dust veil." This is the first direct observational evidence from a

satellite that an explosive eruption with an energy level of 10^{18} ergs may be too small to penetrate the tropopause at 31 to 32°N latitude.

IV. GEOPHYSICS

A. Seismic Instrumentation

1. Portable Seismic Event Recorder. Preliminary planning and design work has been done on a portable digital seismic event recorder. This instrument will give unattended field recordings of microearthquakes and explosions for 1-month intervals. The unit will incorporate earthquake-type signal discrimination and provide a digital magnetic tape output for easy computer analysis.

A low-power seismic package has been built and tested. This package is the type installed at the NCC/LASL (NCC-Navajo Community College) seismograph station near Tsale, AZ. Work has begun to produce this package in sufficient quantity so that it can be used as the main seismic package throughout Group J-9's seismic network.

A new protective container system has been devised to house the equipment installed at the seismograph station sites. The containers will allow easier maintenance during the winter and afford protection from vandalism.

Work on the seismic telemetry system, as outlined in the previous progress report (LA-5956-PR), is progressing well.

2. Development of Tiltmeter and Geodolite.

Preliminary design work is being done on a long base line, fluid-filled tube tiltmeter. New fluids and readout techniques are being considered for lower cost and greater accuracy than existing tiltmeters. This is valuable for predicting earthquakes and volcanic action and for evaluating intruding magma body and geothermal fluid injection problems.

Preliminary work has begun on developing a two-color laser geodolite for precise distance measurements. After development, the geodolite will be used in a survey net across the Valles Caldera and Rio Grande rift, New Mexico, to determine if there is any inflation due to movement of magma by the former and the rate of extension by the latter.

3. Seismic Monitoring of Cochiti Dam Area. To study the effects of crustal loading by the rapid

filling of Cochiti Dam Reservoir in the Rio Grande, New Mexico, seismic monitoring stations were installed at Pankey Peak and at Tetilla Peak. It is anticipated that these stations will allow detection of earthquakes as small as magnitude 0 in the area of the reservoir.

Portable seismic gear was used on the "zero hole" and at 120 m from a 6645-kg blast (charge) at the RRI Cochiti Dam Quarry. The origin, time, and location data are being used to correct the velocity model and station delay times used in our hypo center location program.

V. SUBTERRANE

The Subterrene, being developed at LASL, makes holes by melting rather than chipping or abrading. It will be particularly useful for penetrating rocks at high temperatures, a difficult task by conventional drilling techniques.

It has been proposed that Subterrene be used for penetrating through ponded lava lakes on the Island of Hawaii. This would provide information on the in situ physical properties of basaltic melts and on convection of the melt within the lake.

The information collected by these penetrations will be valuable to Sandia Laboratory researchers who have proposed that lava lakes be used as an energy source.

VI. GEOCHEMISTRY

A. Oil Shale

The experiments done under the geochemistry research program have resulted in a proposal to be funded by the fossil fuels branch of the Energy Research and Development Administration (ERDA). This work will investigate the recovery system using hot, high-pressure water and CO₂ for separating kerogen from oil shale. The experimental work will also investigate the nature of the oil produced and will include a systems analysis study of this method as an in situ recovery system.

B. Trace Element Analyses

All analytical work has been finished on the core samples from GT-2. Data are being evaluated and a comprehensive report is in preparation.

A delayed neutron counter has been designed and is being built that will make rapid measure-

ment of uranium and thorium possible. This counter will be used for uranium analyses on GT-2 cores as well as samples returned from the near normal gradient program and future site program being carried out in Group Q-22.

C. Rock-Water Interaction Studies

Serious corrosion problems have occurred in the high-pressure vessels used in our hydrothermal experiments. The gold plating has become pitted allowing dissolution of the base metal. Evidence of chromium on granite samples by using electron spectroscopy for chemical analysis (ESCA) indicates a deposition of material on test samples. All vessels are being platinum plated to avoid this interference.

D. ESCA Work

A series of clay minerals used as standards, some albites from experiments and one granite sample, were examined using an ESCA instrument that gave data reduced by computer as immediate output. Taking the difference between the binding energy of the silicon and aluminum atoms in these compounds, the maximum observed spread was that between pyrophyllite at 28.65 eV and sodium montmorillonite at 28.15 eV. This difference of 0.5 eV is at least four times the error of the measurement. In all cases the peaks appeared to be a single distribution. Muscovite was measured to determine if the fourfold and sixfold coordination sites could be distinguished. No evidence was found that would distinguish them from each other. The intensities of the peaks seem to correlate with the Al/Si ratio. In all cases, resolution of the signal was about three times worse than the instrumental resolution of the instrument, indicating that sample effects were the governing factor. More work is necessary before this technique can be used for meaningful measurements in this field.

E. Permeability Measurements

An experimental system was used to measure permeability of granites at room temperature and at 200°C. Two series were done; the first using GT-1 rock and the second using GT-2 rock. Measurements were done on samples taken both parallel (||) and perpendicular (⊥) to the axis of the core because we believed that, due to unloading when the

core was cut, the perpendicular sample might show a higher permeability.

To summarize the data, we find the following.

In both GT-1 and GT-2 the permeability is much higher for the high temperature (from 7.5 to 10.6 times).

Also, the perpendicular is twice as permeable as the parallel sample, confirming the unloading hypothesis. For GT-2, the high-temperature permeability is higher (2.5 to 3.6 times) and the perpendicular is much more permeable than the parallel (3.7 to 5.2 times), again suggesting an unloading phenomena.

Comparing GT-1 with GT-2 we find that the most anomalous sample is the perpendicular core from GT-1, probably because the lithostatic pressure on this rock (746 m of overburden) was about 1/3 that of the GT-2 core (2617 m). Cementing and healing intergranular microcracks could be more pronounced in the deep core leading to a lower difference in the permeability between parallel and perpendicular than in the GT-1 case. This is indicated by the data observed.

F. Petrochemistry

The electron microprobe facilities at Arizona State University, Tempe, AZ, and at the NASA-Johnson Space Center, Houston, TX, were used in February, March, and April. Analyses were conducted on a variety of materials: (a) volcanic rocks from Chile, Ecuador, Hawaii, and the southern Cascade Mountains, (b) core samples from GT-2, (c) samples from the hydrothermal alteration experiments being conducted in LASL Group CNC-11, and (d) a basalt sample provided by Group Q-23 which was of interest to the Subterrene experiments.

The results of the analytical work done on many of the volcanic rocks [(a), above] support the concept of andesite formation by mixing basaltic and rhyolitic components. Formation of andesite by this mechanism, therefore, may be a common phenomena and not constrained to small localized areas.

The analyses of fresh and altered samples from the GT-2 cores provided invaluable data used in thermodynamic calculations to anticipate problems with mineral solution and precipitation in an operating geothermal plant.

VII. REMOTE SENSING

Multispectral Landsat images have become a popular source of data for geologists over the past few years. The usefulness of the data is probably limited because of the coarseness of the resolution cell on the ground (57 by 79 m) and because there are only four wide spectral bands covering limited portions of the optical and near-infrared spectrum. To use it as a geological tool for solving applied problems, it is necessary to relate the Landsat image to the materials and the terrain structure actually present on the ground. To this end, we began an analysis of a portion of a Landsat frame consisting of 512 by 512 resolution elements covering a 30- by 40-km area in the Jemez Mountains. This area covers the southwest part of the caldera and includes the region between the Jemez River and the Nacimiento uplift.

During the last quarter of FY 75, our efforts consisted mainly of a preliminary analysis of the spectral qualities of the data along with the development of basic software useful for analysis of multispectral data in general.

In particular, we have performed a principal components transformation on the scene and we have found that nearly 99% of the variance lies in the two principal components. This has permitted us to make an accurate representation of the distribution of the data in the form of a bivariate histogram.

Software has also been developed to produce thematic (color-coded) maps from spectral information. In this scheme, the bivariate histogram can be partitioned into several mutually exclusive cells, and resolution elements (whose spectrum falls into one of these cells) are assigned to one of nine colors. This technique can be useful in identifying similar spectral regions in the scene.

An effort presently is under way to relate digitized geologic maps to the Landsat scene.

Although our effort has been modest, we hope that it can contribute to the development of some practical analysis tools for geological applications of Landsat and other multispectral images.

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APPENDIX

ADMINISTRATIVE MATTERS

I. THE LABORATORIES

Requests for quotations have been sent to manufacturers for an electron microanalysis system; bids have been received and are being evaluated. The laboratory space is available but will require a minor amount of preparation for lighting, air conditioning, and some floor repair. The system desired by Group Q-21 will provide capabilities for electron probe microanalysis and both scanning and transmission electron imaging. It is a versatile, automated system and is capable of quantitative chemical analysis of fine-grained mineral species without the need for mineral separation. Electron microanalysis has revolutionized experimental and analytical petrology in the last 10 yr and has become a fundamental tool in every major geoscience department.

The system will be used for petrologic and morphologic studies of igneous and metamorphic rocks and minerals. In addition to the research activities of Group Q-21, geoscience-related activities of other groups at LASL will be supported by electron microanalysis.

Research in Group CNC-11 is continuing on core samples from GT-2 and on coal and oil shale; electron microanalysis is required on these samples. Activities of Groups Q-23 and Q-22, and collaboration with geoscientists in the latter Group, will be heavily supported by the instrument.

The rock and thin section laboratory is operational. Cutting and polishing equipment has arrived and has been assembled. Currently, samples are being prepared for Group Q-21, but the facility

and expertise of the geochemistry technician will be used by other groups within the Laboratory. Ore minerals and petrographic suites have been purchased to develop a reference collection. These samples are being cataloged; a thin section and/or polished section of each sample will be prepared and kept with the hand specimen. The collection will be used for comparative purposes in future studies.

The Geology Reference Library, a branch of the main LASL Library continues to grow. We are continuing to order a basic set of reference materials which will be incorporated into the set of journals donated by Dartmouth University.

Maps and photographs are being cataloged and will be included in the Library. There will also be a file of all slides and viewgraphs needed for seminars and talks by LASL geoscientists.

A file of satellite photographs of the world's active volcanoes is nearly complete. It is part of the "data files on volcanology" being organized by the International Association of Volcanology and Chemistry of the Earth's Interior. This project was started at the Johnson Space Center, Houston, TX, but has been moved to LASL.

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