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VOL. 1 NO. 1 SEPTEMBER 1978

EARTH SCIENCES

LAWRENCE BERKELEY LABORATORY / UNIVERSITY OF CALIFORNIA

EARTH SCIENCES DIVISION

GEOTHERMAL STUDY AT CERRO PRIETO, MEXICO

LBL geoscientists and technicians have finished their geothermal field work for this season and are now in Berkeley analyzing and evaluating their data.

The Cerro Prieto field, located 35 km south of Mexicali, Mexico, is the only liquid-dominated geothermal reservoir in North America generating electricity. Power production began in 1973. Present output is 75 megawatts (MW), with production of 290 MW planned by 1984.

Geology

Cerro Prieto field is situated in the southern part of the Salton-Mexicali structural trough. Volcanic manifestations in the area include Cerro Prieto (Black Hill), a 260 m high young rhyodacite volcano, northeast of the field. Numerous hot springs, fumaroles and mud volcanoes are located in the area surrounding Laguna Volcano, south of the field.

A major north-northwest striking fault, possibly associated with the Cerro Prieto Fault, cuts across the field. Analyses of the surface geophysical data and downhole lithologic and geophysical logs are needed to determine the existence, position, and offsets of possible east-northeast-striking cross faults.

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In this initial issue of EARTH SCIENCES one report deals with each of the Division's main programs. "Heaters turned on in Sweden" describes an important group of experiments in the Waste Storage Program. "Cerro Prieto" gives the results of Mexican-American field work to explore the potential of a Mexican geothermal field. "Looking for Uranium in the Library" is a report dealing with resource assessment.

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HEATERS TURNED ON IN SWEDEN

Long term rock-heating experiments in an abandoned mine in central Sweden were launched when resistance heaters were turned on in June and July. The study, an important part of the nuclear waste storage project, is being conducted in the Stripa mine, 150 km west of Stockholm.

Mining for iron ore at Stripa began in 1485 and continued intermittently until late 1976. The deposit was discovered at an outcropping of ore on the surface. As mining progressed, it became apparent that the main body of ore was oriented almost vertical to the surface. Today, steep-walled, irregular open pits still mark the hard manual labor done by miners almost five centuries ago. Ultimately, underground workings covered approximately 250 km on 15 levels.

A massive body of granite adjacent to the mined-out iron-ore area of the mine is the site of the present experiments. Cooperating Swedish and American investigators are exploring the various effects of heating a large crystalline rock mass.

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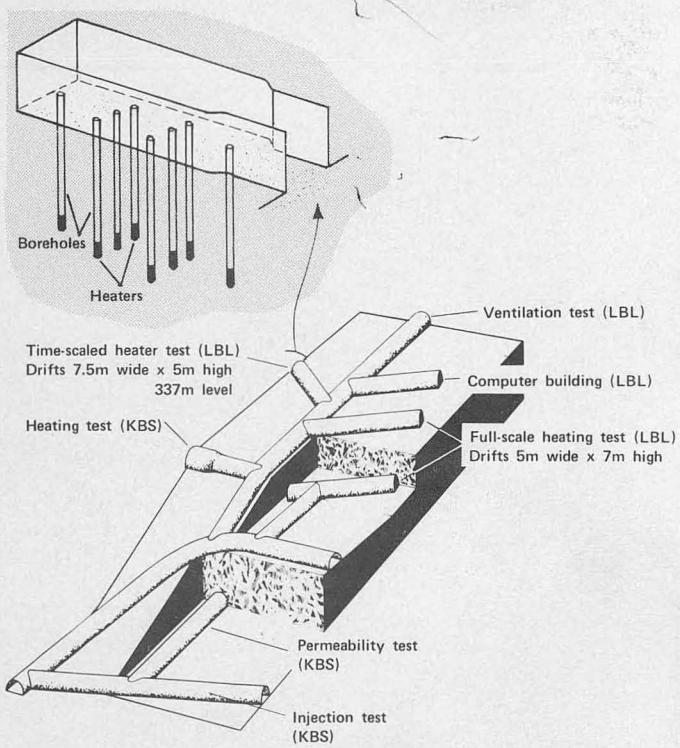
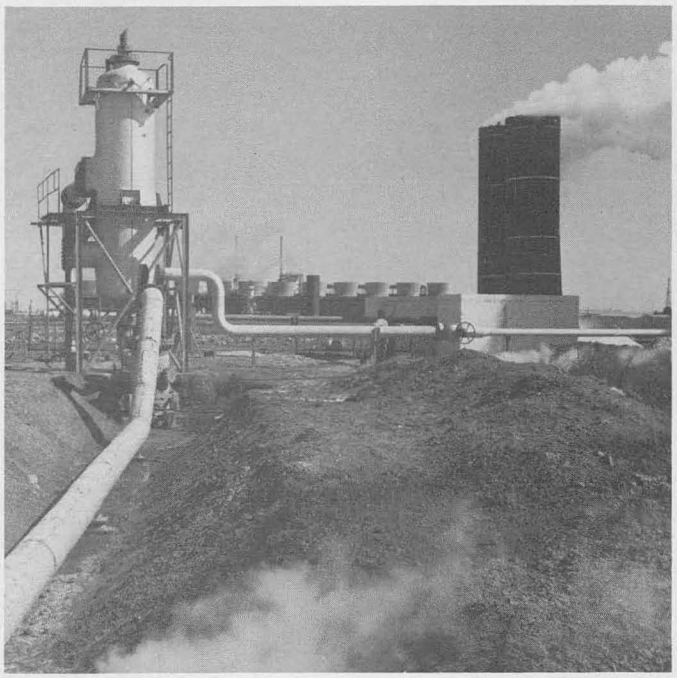


Location of drifts bored in granite rock mass to provide experimental rooms in Stripa mine. Insert shows array of heaters for the time-scaled experiment.



Wellhead installation with separator and steam conducting line at left, silencer at right, and power plant and cooling towers in the background.

Well M-3 at Cerro Prieto reached basement rock (granodiorite) at 2,532 m. This rock is exposed in outcrops in the Sierra Cucapa, 15 km to the west of the geothermal field. Above the basement are interbedded sediments (sandstones and shales) from the late Cenozoic Colorado River delta and fanglomerate and alluvium from the Sierra Cucapa.

The objective of the studies is to develop a better understanding of this geothermal system and of the characteristic responses of the reservoir during continued production. The information gained would also be of value in guiding development of similar geothermal systems in the U.S. and throughout the world.

Principal coordinating organizations for the study are Comisión Federal de Electricidad de México (CFE), and LBL for the United States Department of Energy (DOE). An agreement between DOE and CFE, initiated in 1977, governs the operation of the project. Coordination of the U.S. technical activities is being done by Marcelo Lippmann and Harold Wollenberg of LBL.

Open-File Data Bank

As an aid to the assessment of the Cerro Prieto field, the collection of available data, originally begun in 1975, is being maintained in an open-file data bank at LBL. The holdings as of April 1977 are detailed in LBL-6321, *Open File Data on the Cerro Prieto Geothermal Field*, M.S. Lippmann, B. Domínguez Aguirre, H.A. Wollenberg, and P.A. Witherspoon. Included are reports, reservoir engineering data, well drilling and completion data, topographic maps, temperature logs and geophysical well logs.

Geochemical Studies

A compilation of the geochemical studies detailing and summarizing work carried on over a 12-year period is contained in LBL-7019, *Extensive Geochemical Studies in the Geothermal Field of Cerro Prieto, Mexico*, 1977, A. Mañon, E. Mazor, M. Jiménez, A. Sánchez, J. Fausto and C. Zenizo.

Geophysics

Norman Goldstein, geophysical coordinator for the project, summarizes the results of various geophysical measurements and observations made during the field season, in the paragraphs that follow.

Self Potential — Robert Corwin, UC research geophysicist, in cooperation with CFE geophysicists detected a large anomaly associated with the geothermal

Wells and Power Production

GENERAL DATA

(March 1978)

Electrical power output:	75MW (2 × 37.5MW)
Turbine inlet pressure:	5.27 kg/cm^2 gauge (75 psig)
Exhaust-steam pressure:	89mm Hg abs. (1.7 psia)
Number of wells sending steam to the power plant:	18
Steam production rate:	725 metric tons/hr (1.60 × 10^6 lb/hr)
Total fluid production rate:	2,392 metric tons/hr (5.27 × 10^6 lb/hr)
Fluid enthalpy:	315 kcal/kg (568 Btu/lb)
Range of reservoir temperatures:	250 - 350°C (482 - 662°F)
Range of production well head pressures:	7.0 - 20.5 kg/cm^2 gauge (100 - 290 psig)
Range of total dissolved solids in reservoir brines:	10,000 - 14,000 ppm

Well depth to the top of the reservoir varies from 800 m in the west and 1100 m in the central area to 1400-1800 m toward the south and west.

The steam/water mixture at the wellhead is either sent through a lateral line to a silencer or through a curve to a centrifugal separator, the water being piped to an evaporation pond. The separated steam is controlled by a ball valve, and fed to four main steam lines to the power plant, where secondary centrifugal separators further reduce water content of steam before it enters the turbines. (Guiza 1976, Mãnon 1976*.)

The chemical constituents of the geothermal brines vary in concentration from well to well. Range for pH at 25°C is 8.0-8.4, and the major components** of the separated water from 12 wells are:

	(mg/l)		(mg/l)
Li	12.5-23.0	HCO_3	40-66
Na	5550-9050	Cl	10,000-16,900
K	880-2200	SO_4	5-47
Mg	0.2-3.7	SiO_2	500-1000
Ca	420-840	B	13-21

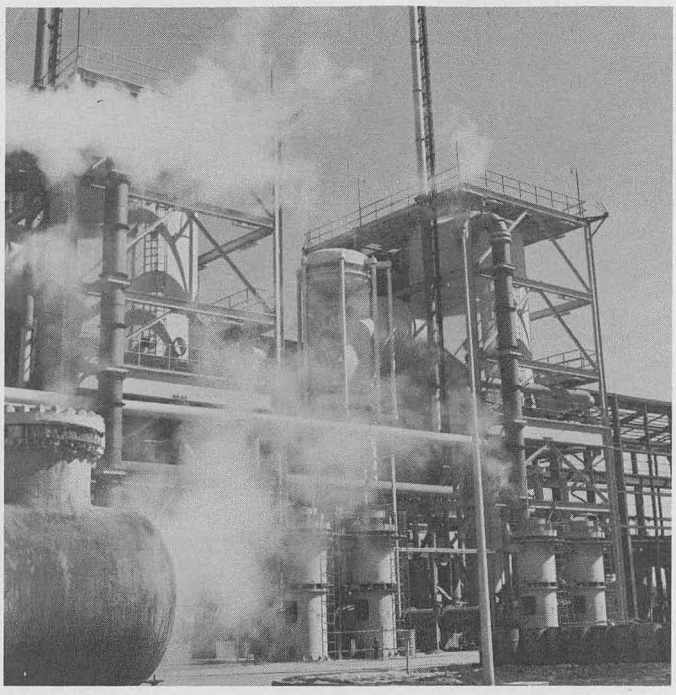
Major gaseous components of 8 wells are:

	(mg/kg)
CO_2	5500-10,100
H_2S	1300-1950

*Guiza L., J., 1976. "Power Generation at Cerro Prieto Geothermal Field," Proceedings 2nd U.N. Symposium on the Development of Geothermal Resources, pages 1976-1978, 1976.

*Mãnon A., M., "Geothermal Potential of Mexico," Circum-Pacific Energy and Mineral Resources, Memoir No. 25, 1976.

**Reed, M. J., "Geology and Hydrothermal Metamorphism in the Cerro Prieto Geothermal Field, Mexico," Proceedings 2nd U.N. Symposium on the Development of Geothermal Resources, pages 539-547, 1976.



View of power plant and barometric condensers.

field. Although it is difficult to interpret the source of such anomalies, their locations with respect to known faults suggest that they could be caused by the movement of thermal fluids along these faults. Corwin reported his findings at the Geothermal Resources Council meeting in Hilo, Hawaii, July 25, 1978.

Precision Gravity — CFE workers installed 60 concrete gravity monuments in and around the field. The elevation of each monument was accurately determined by CFE surveyors. Precise gravity observations were made by LBL-affiliated geophysicists, under the supervision of Roswitha Grannell, Cal State University, Long Beach. Variations in both elevation and gravitational acceleration will be analyzed to determine whether and where net mass changes are occurring within the reservoir and to correlate these changes with geothermal fluid production. Gravity measurements will be repeated at regular intervals.

Electrical Investigations — Two types of electrical surveys were made by LBL personnel. The first type consisted of two very long lines of dipole-dipole dc resistivity measurements which were made over the field in April and May. The electrode arrays used were designed to give information to depths of over 2 km. Purposes of this survey were:

1. to determine whether the geothermal field provides a diagnostic electrical anomaly;
2. to interpret the new data (together with CFE's similar resistivity data from independent surveys) and develop a geologic model of the field in terms of electrical parameters of the subsurface across the valley;
3. to obtain baseline resistivity data which could be used for determining whether changes occur within the reservoir region as a function of time and reservoir production.

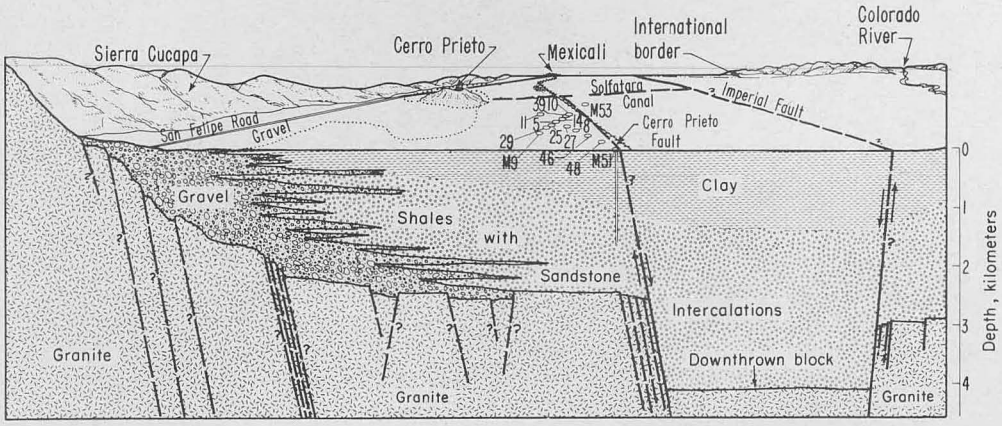
In the second type of electrical survey, several magnetotelluric stations were occupied in the vicinity of the field to determine whether this electrical technique could resolve the basement and crustal structure. These data are being analyzed.

Passive Seismic — The LBL 12-channel portable seismographic system was installed over the Cerro Prieto field for a period of 3 weeks. Local seismic activity was monitored and the results will be compared with similar results obtained by Mexican seismologists in the Mexicali Valley. The purpose is to determine earthquake activity and characteristics associated with the field. The data have not yet been analyzed but the preliminary indication is that activity is normal for the region.

The seismometers were also arrayed to study variations in compressional (P) and shear (S) wave velocities and attenuations across the field. The sources of this energy are the many regional earthquakes whose wavefronts ascend nearly normal to the earth's surface but whose velocities and wave amplitudes are modified by variations in the elastic properties of the rocks through which the waves travel. At geothermal reservoirs already studied, seismic wave properties have helped define the reservoir region. (LBL-7054; see Publications 1977/1978, this issue.)

CERRO PRIETO MEETING

An international meeting, the First Symposium on the Cerro Prieto Geothermal Field, Baja California, Mexico, was held in San Diego, California, September 20 to 22, 1978. Mexican and U.S. geophysicists, geologists and engineers presented results of their studies in the area.



Geological section and partial view of the Mexicali Valley, Baja California, modified from Soto P., S., 1975.*

*Soto P., S., 1975. "Campo geotermico de Cerro Prieto sobre la Falla de San Jacinto y su Posible Ampliación hacia la Falla Imperial." Comision Federal Electricidad, México. Internal Report. June 1975.

Well Tests

Colin Goranson and Ron Schroeder, have summarized the well testing done at Cerro Prieto this season. Interference well tests were made using M-101 as an observation well. Analysis of this data is now nearly completed. In addition, LBL personnel are analyzing the data from production rate tests made on two other wells, for CFE.

Well tests are in progress to study and monitor the development of well M-53 which will be connected to the power plant, and M-104, a standby well.

Principal measurements include well productivity, which is a measure of how long a well will produce at a given rate; transmissivity, which can be used to measure permeability; and storativity, used to measure porosity. Permeability and porosity are quantities employed in geothermal reservoir modeling.

Looking For Uranium In The Library

Six ESD scientists have teamed to use the geological literature to make an initial evaluation of the uranium potential of alkaline igneous rocks of the U.S. Most U.S. uranium (92%) is found in sandstone deposits. In the rest of the world, much of the uranium is found in crystalline rocks. The best chance to increase U.S. potential uranium reserves would be to explore the crystalline rocks among which alkaline intrusives have high uranium contents.

Search of computer data bases and geological indexes for papers dealing with known uranium-containing minerals in alkaline intrusive rocks yielded 1434 references.

Four widely separated alkaline intrusive occurrences had been well studied. These are located at Ilímaussaq, Greenland; Poços de Caldas, Brazil; Bokan Mountain, Alaska; and the Ottawa Graben in eastern Canada. From careful scrutiny of the reports and papers, lists of unique characteristics of each of the four areas were developed. These lists were then used to categorize 69 localities in the U.S. Of the 69, 40 areas had sufficient data to allow classification into one of the four type-locality categories. An appropriate rating scale was applied to such characteristics as:

alkalinity of rock	country rock
petrology and mineralogy	late stage activity
tectonic setting	pathfinder elements
form and age of emplacement	uranium mineralization
	radioactivity

Based on the rating scale, ten sites showed the most promise for exploration. Of these, the area around Magnet Cove, Arkansas, would be the first choice.

The four type-localities that have been or will be mined for uranium are described in the following paragraphs:

On the Kvanefjeld Plateau at Ilímaussaq, Greenland, outcrops of alkaline rocks are estimated to contain 19 million tons of "reasonably assured" reserves of ore averaging 310 ppm U, with additional reserves estimated at 33 million tons of 300-350 ppm U ore.

The Cercado area near Poços de Caldas, Brazil, will produce 500 tons of yellowcake in 1979, expanding production thereafter to approximately 1000 tons per year. The estimated 10,000-15,000 tons of U_3O_8 at Cercado are 1/3-1/2 of Brazil's 1977 uranium reserve.

In the Ottawa Graben in eastern Canada, the Newman deposit on Manitou Island has estimated reserves of 2.9 million tons of niobium-rich pyrochlore ore, containing 0.041 percent U_3O_8.

At Bokan Mountain in southern Alaska, the Ross-Adams deposit has yielded 15,000 tons of ore with a grade of 0.80 percent U_3O_8. This area is presently under extensive exploration by a private company.

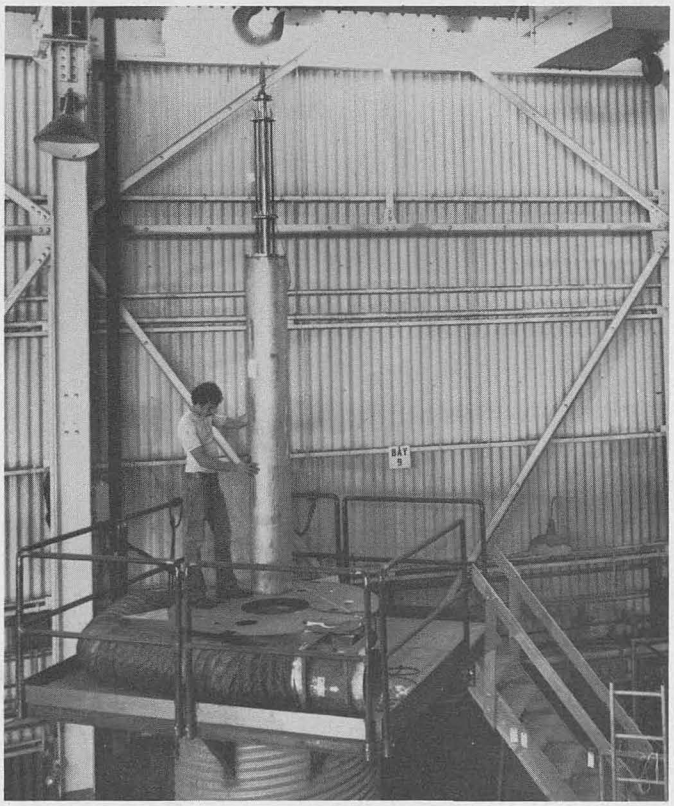
In view of this, exploration of one or more of the most promising sites, like Magnet Cove, might be expected to add to U.S. uranium prospects.

More details on this search for uranium are contained in the recently issued report LBL-7029, *Uranium in Alkaline Rocks*, by M. Murphy, H. Wollenberg, B. Strisower, H. Bowman, S. Flexser, and I. Carmichael.

HEATERS IN SWEDEN *(continued from page 1)*

Principal lead organizations for the study are Kärnbränslesäkerhet (KBS, Nuclear Fuel Safety Program) for Sweden, and LBL for the United States Department of Energy.

As currently designed, canisters for containing radioactive waste accommodate a volume which may have an energy output as great as 5 kW per container. An energy release of this magnitude can produce significant temperature increases (estimated to rise to 300°C) in the



LBL heater-testing facility at Berkeley.

canister emplacement hole and later over the entire rock mass of a repository.

Field experience with crystalline rock is needed as the in situ tests will provide information on structural geology, including fractures, fracture fluids and states of stress, not available from laboratory tests. These experiments employ selected heater arrays for two full-scale and one time-scaled heater experiments.

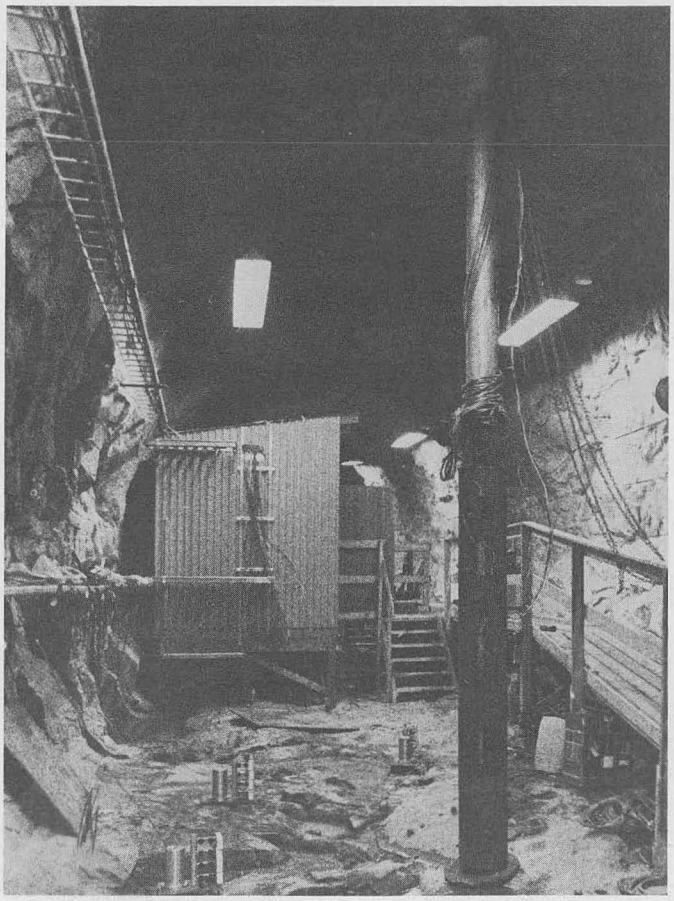
Site data include detailed geologic mapping in three dimensions of the fracture systems in/and around the drifts. Stereophotography of the walls and floors of the drifts and TV logging of the larger boreholes will aid in identifying fracture systems. All boreholes drilled for the study have been surveyed to determine the final coordinates to be used for computer modeling.

Sites for the experiments were instrumented with thermocouples, stress meters, and extensometers which are connected to the Mod Comp IV computer for data storage. The computer is located underground in a drift close to the experimental sites.

Full Scale Experiments

For the full scale heater experiments, two sites were selected in the mine. Two heater boreholes, and 82 other boreholes were drilled to various lengths, and to diameters ranging from 38 mm to 406 mm. The boreholes were cored and all the core samples were logged and photographed. The heaters for these experiments have the same external dimensions and energy output as a waste canister.

One network in the full scale study was designed to heat the rock to predicted failure conditions so that design limits for a repository can be established.



Heater being installed in full-scale heater drift.

Two heaters turned on July 3 have outputs of 5 kW and 3.5 kW respectively. Considerable attention was paid to this event in Swedish TV, radio, and newspaper coverage.

The effects of rock fracture systems on thermal and stress fields are being measured as a function of time.

In one of these experiments, a 5 kW heater is located in the center of a ring of 8 smaller heaters. The large center heater is turned on initially, and when the surrounding rock has reached a stable temperature, the peripheral heaters will be energized. The heating from all 9 will simulate the increased temperatures resulting from the interaction of thermal fields which would be generated by nuclear waste canisters.

Masses of native granite normally contain systems of fractures. Early results have indicated that thermally induced displacements in fractured granite are less than would be predicted for intact rock. This suggests that rock stress will be considerably less than expected for unfractured rock.

Time-Scaled Experiment

The time-scaled heater experiment uses eight 1 kW heaters in an array scaled in such a way that a two-year period of heating will simulate the effects of 20 years of waste storage in a repository.

Investigations and drilling in the time-scaled drift were similar to those done in the full-scale drifts. The heaters were turned on June 1, 1978, an event also well covered by the Swedish media. Heater loads will be gradually decreased to simulate the lowering of energy output that would occur in time with radioactive wastes. It is planned to continue the studies of rock reactions to heating for the two-year heating period, plus the cooling period that follows.

EARTH SCIENCES PUBLICATIONS 1977/1978

The following are recently published LBL and UCID reports, and papers published in scientific journals.

LBL REPORTS

LBL-6363 Mitchell, James K., Frank Guzikowski and Willem C. B. Villet. The Measurement of Soil Properties In-Situ. March 1978.

LBL-6815 Goldstein, N.E., R.A. Norris, and M.J. Wilt. Assessment of Surface Geophysical Methods in Geothermal Exploration and Recommendations for Future Research. April 1978.

LBL-7022 Apps, J.A., L.V. Benson, J. Lucas, A.K. Mathur, and L. Tsao. Theoretical and Experimental Evaluation of Waste Transport in Selected Rocks: 1977 Annual Report of LBL Contract No. 45901AK. (Waste Isolation Safety Assessment Program—Collection and Generation of Transport Data). September 1977.

LBL-7023 Majer, E.L. and T.V. McEvilly. Seismological Investigations at The Geysers Geothermal Field. December, 1977.

LBL-7027 Invitational Well-Testing Symposium. Proceedings. October 19-21, 1977. Berkeley, California. March 1978.

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LBL-7028 Earth Sciences Division Annual Report 1977. LBL.

LBL-7029 Murphy, M., H. Wollenberg, B. Strisower, H. Bowman, S. Flexser, and I. Carmichael. Uranium in Alkaline Rocks. April 1978.

LBL-7031 Abs. Lippmann, M.J., C.F. Tsang and P.A. Witherspoon. A Study of Groundwater Temperature Changes During Aquifer Uses Related to Power Production.

LBL-7032 Preprint Gamble, Thomas D., Wolfgang M. Goubau, and John Clarke. Magnetotellurics with a Remote Magnetic Reference. January 1978.

LBL-7036 Barber-Nichols Engr. Co. Final Report—Direct Contact Heat Exchanger 10K Power Loop Test Series No. 1. (Draft—Volume 1 of 2.) December — 1977.

LBL-7037 Preprint Narasimhan, T.N., and P.A. Witherspoon. Numerical Model for Saturated-Unsaturated Flow in Deformable Porous Media, Part III: Applications. March 1978.

LBL-7039 Pope, W.L., H.S. Pines, L.F. Silvester, P.A. Doyle, R.L. Fulton, and M.A. Green. Optimizations of Geothermal Cycle Shell and Tube Exchangers of Various Configurations with Variable Fluid Properties and Site Specific Fouling. March 1978.

LBL-7040 Pines, H.S., W.L. Pope, M.A. Green, P.A. Doyle, L.F. Silvester and R.L. Fulton. The Thermodynamic and Cost Benefits of a Floating Cooling Geothermal Binary Cycle Power Plant at Heber, California. April 1978.

LBL-7041 Preprint Narasimhan, T.N. The Significance of the Storage Parameter in Saturated-Unsaturated Groundwater Flow. April 1978.

LBL-7042 Jain, Birendra Kumar. A Low Frequency Electromagnetic Prospecting System. April 1978. (D.Eng. Thesis)

LBL-7049 Witherspoon, P.A. and O. Degerman. Swedish-American Cooperative Program on Radioactive Waste Storage in Mined Caverns. May 1978.

LBL-7052 Lundstrom, Lars and Hakan Stille. Technical Project Report No. 2: Large Scale Permeability Test of the Granite in the Stripa Mine and Thermal Conductivity Test. July 1978.

LBL-7054 Majer, Ernest Luther. Seismological Investigations in Geothermal Regions. May 1978. (Ph.D. Thesis)

LBL-7055 Howard, J.H. and W.J. Schwarz. Geothermal Reservoir Engineering Program at Lawrence Berkeley Laboratory. June 1978.

LBL-7056 Abs. Lippmann, M.J. and C.F. Tsang. Three-Dimensional Numerical Simulation of Single-Phase, Non-Isothermal, Fluid Flow in Porous Reservoirs. June 1978.

LBL-7059 Goranson, C. and R. Schroeder. Static Downhole Characteristics of Well CGEH-1 at Coso Hot Springs, China Lake, California. June 1978.

LBL-7064 Tsang, Chin Fu, Gudmundur Bodvarsson, Marcelo J. Lippmann and Jesus Rivera R. A Study of Alternative Reinjection Schemes for the Cerro Prieto Geothermal Field, Baja California, Mexico. June 1978.

LBL-7065 Corwin, Robert F., Sergio Diaz C., and Jorge Rodriguez B., Self-Potential Survey at the Cerro Prieto Geothermal Field, Baja California, Mexico, June 1978.

LBL-7077 Fulton, R.L. Heat Exchanger Module Test. June 1978.

UCID REPORTS

UCID-3999 Beaulaurier, L.O. and P.A. Doyle. Final Report—10 MWe (Gross) Hydrocarbon Turbine/Generator Installation Niland Geothermal Loop Experiment Facility. September 1977.

UCID-4029 McEvilly, T.V. and B. Schechter. East Mesa Seismic Study Report No. 2. November 1977.

UCID-4030 McEvilly, T.V. and B. Schechter. East Mesa Seismic Study Report No. 3. February 1978.

UCID-8009 Barber-Nichols Engr. Co. for Jack Angevine. Final Report: Design Definition of a 500 KW Direct Contact Geothermal Pilot Plant. March 1978.

UCID-8035 Simkin, T.L. and J.E. Noble (eds.). Geothermal Subsidence Research Program—Project Summaries. July 1978. (Preliminary Report.)

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Benson, Larry V. 1978. Fluctuations in the Level of Pluvial Lake Lahontan During the Last 40,000 Years. Quaternary Research, 9: 300-318.

Witherspoon, P. A., Narasimhan, T. N., and McEdwards, D. G. 1978. Results of Interference Tests from Two Geothermal Reservoirs, Journal of Petroleum Technology, 30: 10-16.

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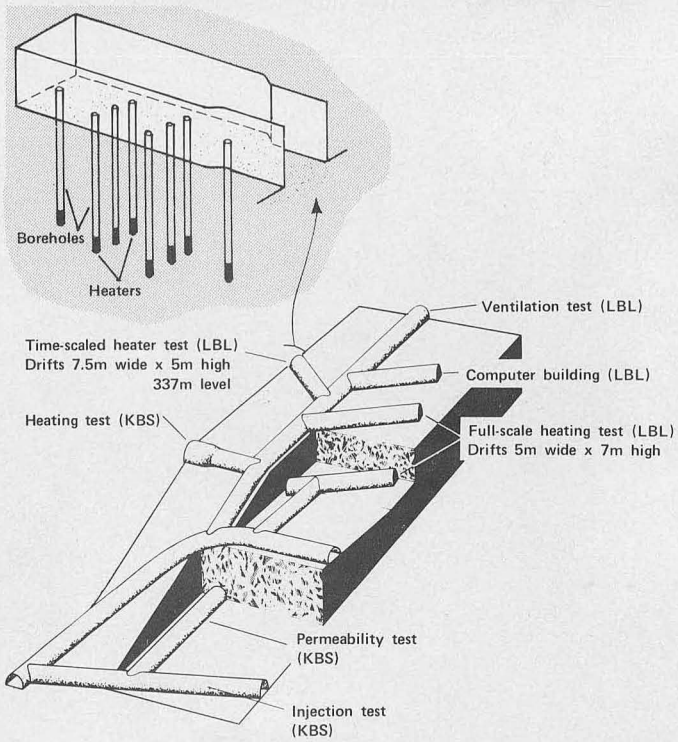

Location of drifts bored in granite rock mass to provide experimental rooms in Stripa mine. Insert shows array of heaters for the time-scaled experiment.

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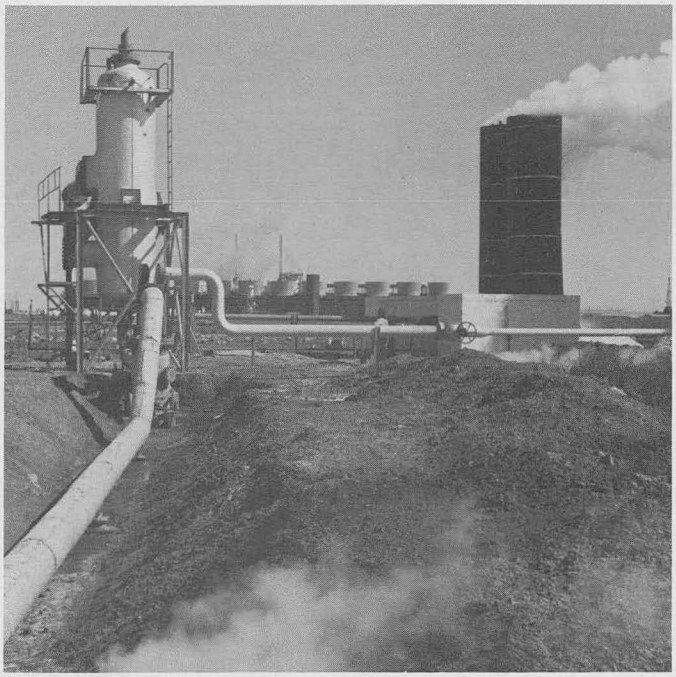


Wellhead installation with separator and steam conducting line at left, silencer at right, and power plant and cooling towers in the background.

Well M-3 at Cerro Prieto reached basement rock (granodiorite) at 2,532 m. This rock is exposed in outcrops in the Sierra Cucapa, 15 km to the west of the geothermal field. Above the basement are interbedded sediments (sandstones and shales) from the late Cenozoic Colorado River delta and fanglomerate and alluvium from the Sierra Cucapa.

The objective of the studies is to develop a better understanding of this geothermal system and of the characteristic responses of the reservoir during continued production. The information gained would also be of value in guiding development of similar geothermal systems in the U.S. and throughout the world.

Principal coordinating organizations for the study are Comisión Federal de Electricidad de México (CFE), and LBL for the United States Department of Energy (DOE). An agreement between DOE and CFE, initiated in 1977, governs the operation of the project. Coordination of the U.S. technical activities is being done by Marcelo Lippmann and Harold Wollenberg of LBL.

Open-File Data Bank

As an aid to the assessment of the Cerro Prieto field, the collection of available data, originally begun in 1975, is being maintained in an open-file data bank at LBL. The holdings as of April 1977 are detailed in LBL-6321, *Open File Data on the Cerro Prieto Geothermal Field*, M.S. Lippmann, B. Domínguez Aguirre, H.A. Wollenberg, and P.A. Witherspoon. Included are reports, reservoir engineering data, well drilling and completion data, topographic maps, temperature logs and geophysical well logs.

Geochemical Studies

A compilation of the geochemical studies detailing and summarizing work carried on over a 12-year period is contained in LBL-7019, *Extensive Geochemical Studies in the Geothermal Field of Cerro Prieto, Mexico*, 1977, A. Mañon, E. Mazor, M. Jiménez, A. Sánchez, J. Fausto and C. Zenizo.

Geophysics

Norman Goldstein, geophysical coordinator for the project, summarizes the results of various geophysical measurements and observations made during the field season, in the paragraphs that follow.

Self Potential — Robert Corwin, UC research geophysicist, in cooperation with CFE geophysicists detected a large anomaly associated with the geothermal

Wells and Power Production

GENERAL DATA
(March 1978)

Electrical power output:	75MW (2 × 37.5MW)
Turbine inlet pressure:	5.27 kg/cm^2 gauge (75 psig)
Exhaust-steam pressure:	89mm Hg abs. (1.7 psia)
Number of wells sending steam to the power plant:	18
Steam production rate:	725 metric tons/hr (1.60×10^6 lb/hr)
Total fluid production rate:	2,392 metric tons/hr (5.27×10^6 lb/hr)
Fluid enthalpy:	315 kcal/kg (568 Btu/lb)
Range of reservoir temperatures:	250 - 350°C (482 - 662°F)
Range of production well head pressures:	7.0 - 20.5 kg/cm^2 gauge (100 - 290 psig)
Range of total dissolved solids in reservoir brines:	10,000 - 14,000 ppm

Well depth to the top of the reservoir varies from 800 m in the west and 1100 m in the central area to 1400-1800 m toward the south and west.

The steam/water mixture at the wellhead is either sent through a lateral line to a silencer or through a curve to a centrifugal separator, the water being piped to an evaporation pond. The separated steam is controlled by a ball valve, and fed to four main steam lines to the power plant, where secondary centrifugal separators further reduce water content of steam before it enters the turbines. (Guiza 1976, Mãnon 1976*.)

The chemical constituents of the geothermal brines vary in concentration from well to well. Range for pH at 25°C is 8.0-8.4, and the major components** of the separated water from 12 wells are:

	(mg/l)		(mg/l)
Li	12.5-23.0	HCO_3	40-66
Na	5550-9050	Cl	10,000-16,900
K	880-2200	SO_4	5-47
Mg	0.2-3.7	SiO_2	500-1000
Ca	420-840	B	13-21

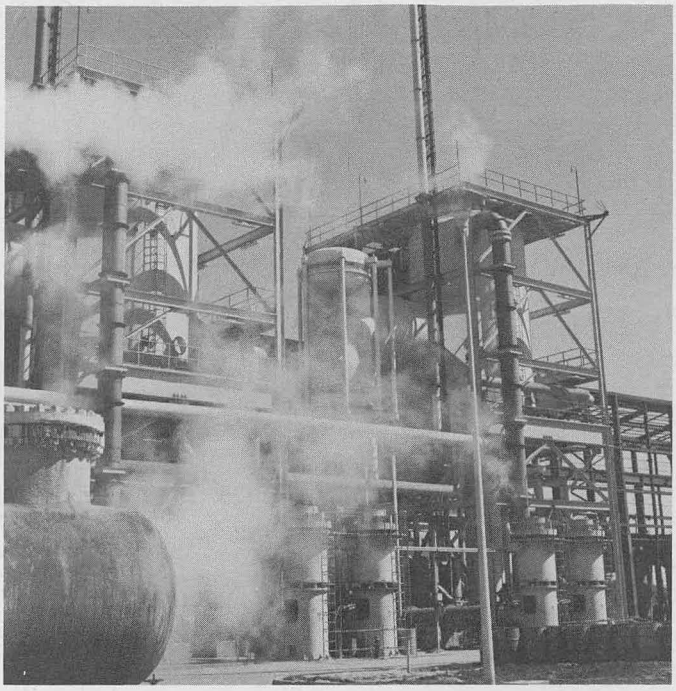
Major gaseous components of 8 wells are:

	(mg/kg)
CO_2	5500-10,100
H_2S	1300-1950

*Guiza L., J., 1976. "Power Generation at Cerro Prieto Geothermal Field," Proceedings 2nd U.N. Symposium on the Development of Geothermal Resources, pages 1976-1978, 1976.

*Mãnon A., M., "Geothermal Potential of Mexico," Circum-Pacific Energy and Mineral Resources, Memoir No. 25, 1976.

**Reed, M. J., "Geology and Hydrothermal Metamorphism in the Cerro Prieto Geothermal Field, Mexico," Proceedings 2nd U.N. Symposium on the Development of Geothermal Resources, pages 539-547, 1976.



View of power plant and barometric condensers.

field. Although it is difficult to interpret the source of such anomalies, their locations with respect to known faults suggest that they could be caused by the movement of thermal fluids along these faults. Corwin reported his findings at the Geothermal Resources Council meeting in Hilo, Hawaii, July 25, 1978.

Precision Gravity — CFE workers installed 60 concrete gravity monuments in and around the field. The elevation of each monument was accurately determined by CFE surveyors. Precise gravity observations were made by LBL-affiliated geophysicists, under the supervision of Roswitha Grannell, Cal State University, Long Beach. Variations in both elevation and gravitational acceleration will be analyzed to determine whether and where net mass changes are occurring within the reservoir and to correlate these changes with geothermal fluid production. Gravity measurements will be repeated at regular intervals.

Electrical Investigations — Two types of electrical surveys were made by LBL personnel. The first type consisted of two very long lines of dipole-dipole dc resistivity measurements which were made over the field in April and May. The electrode arrays used were designed to give information to depths of over 2 km. Purposes of this survey were:

1. to determine whether the geothermal field provides a diagnostic electrical anomaly;
2. to interpret the new data (together with CFE's similar resistivity data from independent surveys) and develop a geologic model of the field in terms of electrical parameters of the subsurface across the valley;
3. to obtain baseline resistivity data which could be used for determining whether changes occur within the reservoir region as a function of time and reservoir production.

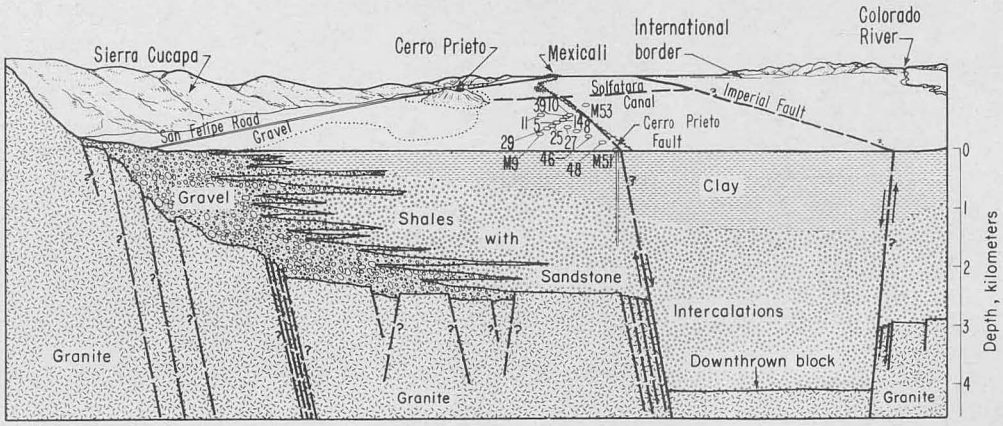
In the second type of electrical survey, several magnetotelluric stations were occupied in the vicinity of the field to determine whether this electrical technique could resolve the basement and crustal structure. These data are being analyzed.

Passive Seismic — The LBL 12-channel portable seismographic system was installed over the Cerro Prieto field for a period of 3 weeks. Local seismic activity was monitored and the results will be compared with similar results obtained by Mexican seismologists in the Mexicali Valley. The purpose is to determine earthquake activity and characteristics associated with the field. The data have not yet been analyzed but the preliminary indication is that activity is normal for the region.

The seismometers were also arrayed to study variations in compressional (P) and shear (S) wave velocities and attenuations across the field. The sources of this energy are the many regional earthquakes whose wavefronts ascend nearly normal to the earth's surface but whose velocities and wave amplitudes are modified by variations in the elastic properties of the rocks through which the waves travel. At geothermal reservoirs already studied, seismic wave properties have helped define the reservoir region. (LBL-7054; see Publications 1977/1978, this issue.)

CERRO PRIETO MEETING

An international meeting, the First Symposium on the Cerro Prieto Geothermal Field, Baja California, Mexico, was held in San Diego, California, September 20 to 22, 1978. Mexican and U.S. geophysicists, geologists and engineers presented results of their studies in the area.



Geological section and partial view of the Mexicali Valley, Baja California, modified from Soto P., S., 1975.*

*Soto P., S., 1975. "Campo geotermico de Cerro Prieto sobre la Falla de San Jacinto y su Posible Ampliación hacia la Falla Imperial." Comision Federal Electricidad. México. Internal Report. June 1975.

Well Tests

Colin Goranson and Ron Schroeder, have summarized the well testing done at Cerro Prieto this season. Interference well tests were made using M-101 as an observation well. Analysis of this data is now nearly completed. In addition, LBL personnel are analyzing the data from production rate tests made on two other wells, for CFE.

Well tests are in progress to study and monitor the development of well M-53 which will be connected to the power plant, and M-104, a standby well.

Principal measurements include well productivity, which is a measure of how long a well will produce at a given rate; transmissivity, which can be used to measure permeability; and storativity, used to measure porosity. Permeability and porosity are quantities employed in geothermal reservoir modeling.

Looking For Uranium In The Library

Six ESD scientists have teamed to use the geological literature to make an initial evaluation of the uranium potential of alkaline igneous rocks of the U.S. Most U.S. uranium (92%) is found in sandstone deposits. In the rest of the world, much of the uranium is found in crystalline rocks. The best chance to increase U.S. potential uranium reserves would be to explore the crystalline rocks among which alkaline intrusives have high uranium contents.

Search of computer data bases and geological indexes for papers dealing with known uranium-containing minerals in alkaline intrusive rocks yielded 1434 references.

Four widely separated alkaline intrusive occurrences had been well studied. These are located at Ilímaussaq, Greenland; Poços de Caldas, Brazil; Bokan Mountain, Alaska; and the Ottawa Graben in eastern Canada. From careful scrutiny of the reports and papers, lists of unique characteristics of each of the four areas were developed. These lists were then used to categorize 69 localities in the U.S. Of the 69, 40 areas had sufficient data to allow classification into one of the four type-locality categories. An appropriate rating scale was applied to such characteristics as:

alkalinity of rock	country rock
petrology and mineralogy	late stage activity
tectonic setting	pathfinder elements
form and age of emplacement	uranium mineralization
	radioactivity

Based on the rating scale, ten sites showed the most promise for exploration. Of these, the area around Magnet Cove, Arkansas, would be the first choice.

The four type-localities that have been or will be mined for uranium are described in the following paragraphs:

On the Kvanefjeld Plateau at Ilímaussaq, Greenland, outcrops of alkaline rocks are estimated to contain 19 million tons of "reasonably assured" reserves of ore averaging 310 ppm U, with additional reserves estimated at 33 million tons of 300-350 ppm U ore.

The Cercado area near Poços de Caldas, Brazil, will produce 500 tons of yellowcake in 1979, expanding production thereafter to approximately 1000 tons per year. The estimated 10,000-15,000 tons of U_3O_8 at Cercado are 1/3-1/2 of Brazil's 1977 uranium reserve.

In the Ottawa Graben in eastern Canada, the Newman deposit on Manitou Island has estimated reserves of 2.9 million tons of niobium-rich pyrochlore ore, containing 0.041 percent U_3O_8.

At Bokan Mountain in southern Alaska, the Ross-Adams deposit has yielded 15,000 tons of ore with a grade of 0.80 percent U_3O_8. This area is presently under extensive exploration by a private company.

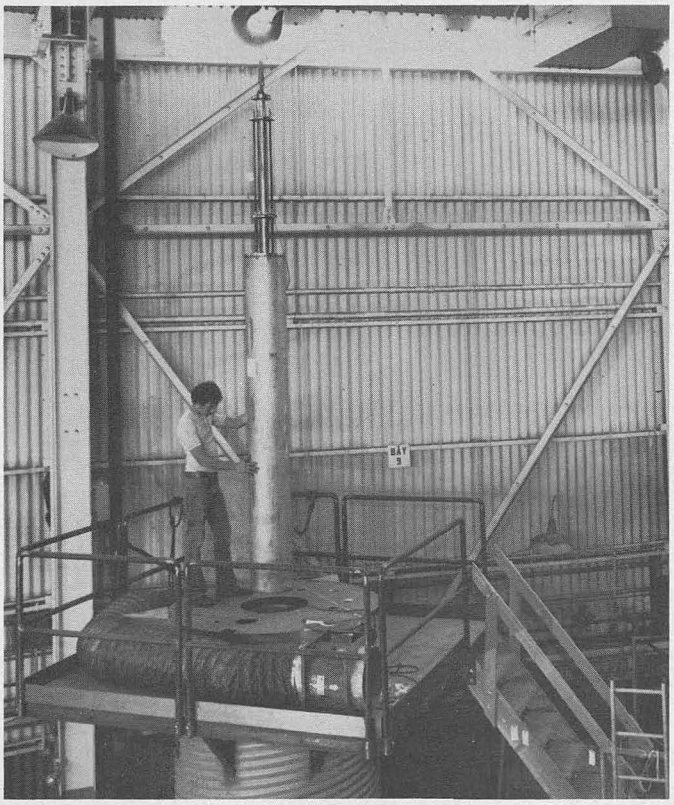
In view of this, exploration of one or more of the most promising sites, like Magnet Cove, might be expected to add to U.S. uranium prospects.

More details on this search for uranium are contained in the recently issued report LBL-7029, *Uranium in Alkaline Rocks*, by M. Murphy, H. Wollenberg, B. Strisower, H. Bowman, S. Flexser, and I. Carmichael.

HEATERS IN SWEDEN *(continued from page 1)*

Principal lead organizations for the study are Kärnbränslesäkerhet (KBS, Nuclear Fuel Safety Program) for Sweden, and LBL for the United States Department of Energy.

As currently designed, canisters for containing radioactive waste accommodate a volume which may have an energy output as great as 5 kW per container. An energy release of this magnitude can produce significant temperature increases (estimated to rise to 300°C) in the



LBL heater-testing facility at Berkeley.

canister emplacement hole and later over the entire rock mass of a repository.

Field experience with crystalline rock is needed as the in situ tests will provide information on structural geology, including fractures, fracture fluids and states of stress, not available from laboratory tests. These experiments employ selected heater arrays for two full-scale and one time-scaled heater experiments.

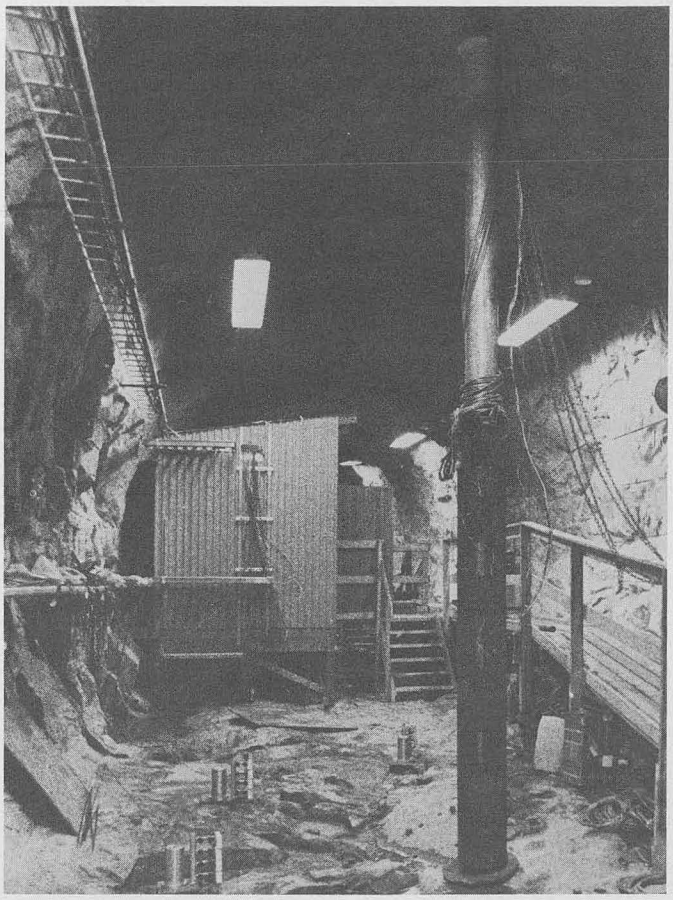
Site data include detailed geologic mapping in three dimensions of the fracture systems in/and around the drifts. Stereophotography of the walls and floors of the drifts and TV logging of the larger boreholes will aid in identifying fracture systems. All boreholes drilled for the study have been surveyed to determine the final coordinates to be used for computer modeling.

Sites for the experiments were instrumented with thermocouples, stress meters, and extensometers which are connected to the Mod Comp IV computer for data storage. The computer is located underground in a drift close to the experimental sites.

Full Scale Experiments

For the full scale heater experiments, two sites were selected in the mine. Two heater boreholes, and 82 other boreholes were drilled to various lengths, and to diameters ranging from 38 mm to 406 mm. The boreholes were cored and all the core samples were logged and photographed. The heaters for these experiments have the same external dimensions and energy output as a waste canister.

One network in the full scale study was designed to heat the rock to predicted failure conditions so that design limits for a repository can be established.



Heater being installed in full-scale heater drift.

Two heaters turned on July 3 have outputs of 5 kW and 3.5 kW respectively. Considerable attention was paid to this event in Swedish TV, radio, and newspaper coverage.

The effects of rock fracture systems on thermal and stress fields are being measured as a function of time.

In one of these experiments, a 5 kW heater is located in the center of a ring of 8 smaller heaters. The large center heater is turned on initially, and when the surrounding rock has reached a stable temperature, the peripheral heaters will be energized. The heating from all 9 will simulate the increased temperatures resulting from the interaction of thermal fields which would be generated by nuclear waste canisters.

Masses of native granite normally contain systems of fractures. Early results have indicated that thermally induced displacements in fractured granite are less than would be predicted for intact rock. This suggests that rock stress will be considerably less than expected for unfractured rock.

Time-Scaled Experiment

The time-scaled heater experiment uses eight 1 kW heaters in an array scaled in such a way that a two-year period of heating will simulate the effects of 20 years of waste storage in a repository.

Investigations and drilling in the time-scaled drift were similar to those done in the full-scale drifts. The heaters were turned on June 1, 1978, an event also well covered by the Swedish media. Heater loads will be gradually decreased to simulate the lowering of energy output that would occur in time with radioactive wastes. It is planned to continue the studies of rock reactions to heating for the two-year heating period, plus the cooling period that follows.

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LBL-7023 Majer, E.L. and T.V. McEvilly. Seismological Investigations at The Geysers Geothermal Field. December, 1977.

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