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THE U.S. DEPARTMENT OF ENERGY'S GEOTHERMAL RESERVOIR TECHNOLOGY PROGRAM

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ABSTRACT

Geothermal reservoir engineering is an important aspect of the Department of Energy's Geothermal Technology Division, geothermal research and development program. Reservoir engineering-related research, a component of all geosciences activities, is of particular importance in the context of Hydrothermal Reservoir Research. Three closely related research activities (Brine Injection, Reservoir Definition, and Caldera Reservoir Investigations) are now combined under the more general heading of Reservoir Technology. Scientific investigations, as part of the Salton Sea Scientific Drilling Program, also contribute greatly to the understanding of the behavior of high-temperature hydrothermal convection systems. With the creation of the Geothermal Technology Organization, where geothermal research will be cost-shared with industry, it is anticipated that a number of research topics will be brought to the point where the geothermal industry can rapidly put new technology into use.

OVERVIEW

Program Objectives

The U.S. Department of Energy's (DOE) geothermal research and development programs, administered through the Geothermal Technology Division (GTD), have been organized to achieve two major objectives. First, is to advance the state of the art of the technology to exploit hydrothermal resources. The current emphasis is on geoscience and energy conversion technology R & D that will increase the effectiveness of second generation flash and binary electric systems. The performance goals to meet this objective are:

1. Expand the current knowledge of hydrothermal reservoirs and improve reservoir analysis techniques to reduce the uncertainty of predicting reservoir performance by a factor of 5.

2. Develop techniques for monitoring fluid migration to enable better management of the recharging of hydrothermal reservoirs so as to increase reservoir lifetimes by a factor of 2.

3. Continue laboratory research and field testing of improved drilling components that will reduce the cost of geothermal wells by 20 percent.

4. Continue research to improve the efficiency of binary cycle systems by 30 percent.

The second major objective is to provide the technical basis that will allow industry to make investment decisions in the future regarding the development of unconventional geothermal energy resources -- geopressured Gulf Coast strata containing hot brine and dissolved methane, hot low-permeability rock (hot dry rock), and high-level silicic magma bodies in the western U.S. These "advanced" resource types have the potential for contributing significantly to the regional and national energy picture. The DOE/GTD is pursuing research of these more advanced forms of geothermal energy, ahead of industry, due to the high risks and uncertainty involved with initial development work. The performance goals set for the advanced resources programs are:

1. Geopressured-Geothermal - Development of accurate reservoir performance models and energy extraction technologies capable of 20 percent thermal efficiency.

2. Hot Dry Rock - Develop the necessary technology to extract energy from hot low-permeability rock through a man-made fractured reservoir and maintain the thermal drawdown at less than 10 percent over a 10-year period.

3. Magma - Develop technology to accurately locate and outline a magma body, and extract thermal energy to provide multi-year thermal recovery data.

Organization and FY 1987 Budget

The DOE/GTD geothermal program has been organized functionally into two sub-programs -- Geothermal Geosciences Technology and Geothermal Conversion Technology. The

GEOTHERMAL GEOSCIENCES TECHNOLOGY	GEOTHERMAL CONVERSION TECHNOLOGY
• Hydrothermal Reservoir Research	• Hard Rock Penetration
• Geopressured Resources Research	• Permeability Enhancement
• Hot Dry Rock Reservoir Research	• Hydrothermal Conversion
• Magma Energy Research	• Geopressured Conversion Research
	• Hot Dry Rock Conversion Research
	• Magma Conversion Research

Table 1: DOE/GTD Geothermal Research Programs

Geothermal Geosciences Technology sub-program concerns the technologies used to locate and predict subsurface characteristics of geothermal resources. Conversion Technology includes the technologies dealing with providing access to reservoirs, production and energy conversion. The various component parts of the Geothermal Geosciences Technology sub-program and the Geothermal Conversion Technology sub-program are listed in Table 1, while the FY 1987 budget for all GTD programs is summarized in Table 2.

RESERVOIR ENGINEERING-RELATED RESEARCH

Reservoir Technology

Within the context of the Geothermal Geosciences Technology sub-program, Reservoir Technology, a subset of Hydrothermal Reservoir Research, combines three closely-related research efforts -- Brine Injection, Reservoir Definition, and Caldera Reservoir Investigations. The three are closely coordinated and maintain well-defined goals.

Historically, reservoir analysis procedures from the petroleum industry have been adapted to geothermal resource investigations, and have been successfully applied to reservoirs with intergranular permeability. Use of these same techniques has been less successful in defining geothermal fields dominated by fracture permeability -- the condition that exists in most high-temperature geothermal fields. Experience suggests that the high flow rates required for a successful geothermal project must come from fracture permeability.

The attention given to geothermal reservoir analysis then is to create the necessary "tools" to determine reservoir size and the nature of fluid flow. Today, geothermal reservoirs are better understood, but there are still important areas that need to be investigated. The two most important areas of attention are (1) determining production capabilities of reservoirs, and (2) interpreting the geophysical signature of reservoirs.

In cooperation with industry, new experimental well testing methods have been devised for production and injection modes under the Reservoir Technology Program by researchers at Stanford University, Lawrence Berkeley Laboratory (LBL) and Idaho National Engineering Laboratory (INEL). Flow in fracture networks is being investigated by using laboratory and theoretical models of discrete fractures and stochastically distributed fractures. This work is necessary in order to predict more accurately reservoir longevity and maximum energy recovery.

New geophysical methods and new interpretations of old methods used by the petroleum and mining industries have proven to be useful in characterizing geothermal reservoirs. In addition to the aforementioned organizations, other institutions involved in the development of geophysical methods and interpretation include the U.S. Geological Survey (USGS), Lawrence Livermore National Laboratory (LLNL), and the University of Utah Research Institute (UURI). Emphasis on analyzing geophysical data is directed at producing two- and three-dimensional models of reservoirs, and surveying to locate fractures from the surface and within wells. Experimental methods that are currently being investigated are:

- Passive Seismic Monitoring of Injected Fluid (LLNL)
- Vertical Seismic Profiling (LBL)

VALUE IN $ X 1000	FY 1987 BUDGET
HYDROTHERMAL INDUSTRIALIZATION	2,000
GEOPRESSURED	4,000
GEOTHERMAL TECHNOLOGY DEVELOPMENT	14,150
Hot Dry Rock Research	8,000
Hydrothermal Research	2,950
Hard Rock Penetration Research	1,400
Magma Energy Extraction Research	500
Salton Sea Scientific Drilling Program	1,300
PROGRAM DIRECTION	780
GEOTHERMAL LOAN PROGRAM	72
TOTAL	21,002

Table 2: GTD Program Budget - FY 1987

- Time-Domain Electromagnetic Surveys (USGS & LBL)
- Controlled-Source Audio Magnetotellurics (UURI)
- Deep Magnetotelluric Surveys (UURI & LBL)

Using these geophysical studies in conjunction with structural models, researchers are focusing on determining the location, orientation, extent, and aperture of fractures in reservoirs.

The consequences of injection of spent brine is important to geothermal development because injection must take place in order that adequate reservoir pressures be maintained for production. The resultant pressure pulse is desirable; however, the reduction of reservoir temperature produced by the thermal pulse, and the chemical effects of the injected fluid within the reservoir rock can be detrimental since they reduce the amount of thermal energy recoverable.

In order to better predict the effects of the injection of spent brine, research is being performed on the use of soluble tracers to track injected fluid through the reservoir to the production wells. The research emphasis has been to develop tracers that will (1) maintain thermal and chemical stability at high temperatures, and (2) be detectable in minute quantities in large volumes of fluid. Synthesis and testing of fluorinated hydrocarbons is underway at UURI, and research on activable tracers (excitation by neutron activation) is being done at Stanford.

Numerical modeling of tracer transport in fractures is being carried out at INEL and at Stanford.

All research carried out as part of the Reservoir Definition and Brine Injection program elements is being synthesized into structural geologic models which will be refined by considerations for local geology. Geologic modeling provides a check on the agreement between geophysical and hydrologic data sets. Structural models, which will be necessary for industry engineers to develop strategies for resource development, are being formulated by scientists at LBL and UURI.

Within the program element of Caldera Reservoir Investigations, DOE/GTD is cost-sharing with industry participants several deep thermal gradient test wells within the Cascades volcanic region of the Pacific Northwest. The approximately 4,000 foot wells are intended to provide relevant data concerning the deep thermal regime of the region below the prevailing shallow, cold groundwater system. Recently, three wells were drilled with reported success (Figure 1). Two of the wells, completed near the Newberry Caldera in west-central Oregon, were drilled to depths of 4,000 ft and 4,500 ft. Another well, drilled near Breitenbush Hot Springs, Oregon, was completed to a depth of 4,800 ft. All of the wells have provided the opportunity to obtain meaningful heat flow and temperature gradient information from below the level of influence of the shallow groundwater system. This system has been found to extend downward to depths of roughly 2,000 ft. Drilling at a fourth location, near Crater Lake, Oregon, was suspended due to loss of circulation and certain requirements imposed by the U.S. Forest Service. Drilling may be resumed at the site next year following treatment of the lost circulation problem.

Downhole studies in the research wells have confirmed the usefulness of Time-Domain EM surveys. The TDEM survey, performed by the USGS, is likely to be a useful technique for determining the subsurface location of the base of the shallow groundwater system in the Cascades region.

Evaluation of the geophysical logs in conjunction with alteration studies of core and cuttings is underway at UURI in an effort to develop log interpretation methods. Emphasis is placed upon (1) formulation of a model for magmatic heat sources in the Cascades; (2) formulation of a model for fracture permeability in the Cascades; and (3) determination of methodologies that can lead to the discovery of buried geothermal systems in the Cascades.

Within the overall scheme of Reservoir Technology, it is essential that communication be maintained with the geothermal industry. Workshops are held to provide a forum for discussions with industry on current field development-related problems. The direction of future Federal cost-shared research is greatly influenced by the results of these discussions.

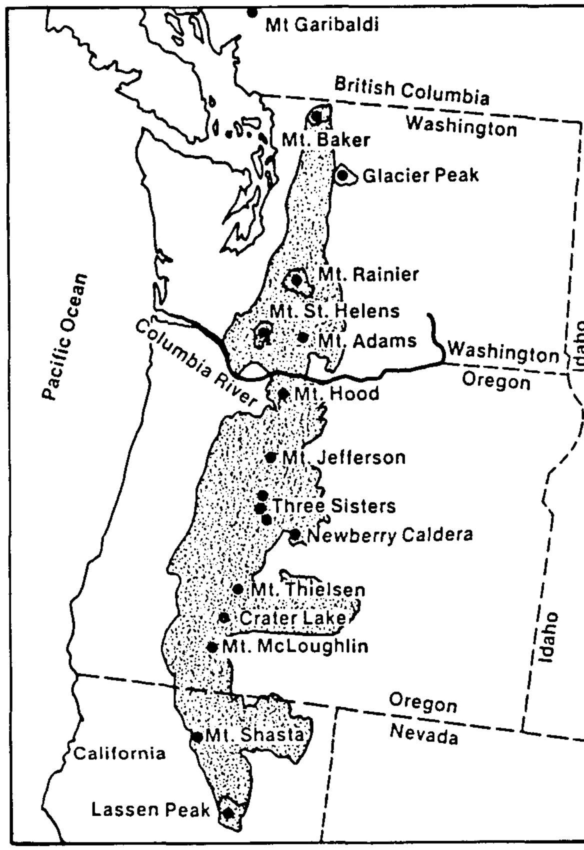

Figure 1: Cascades Regional Setting

<u>Salton Sea Scientific Drilling Program (SSSDP)</u>

The SSSDP is a program involving the sampling and testing of a scientific geothermal well that was drilled in the Salton Sea Geothermal Field (SSGF) of California's Imperial Valley (Figure 2). The program is jointly sponsored by the U.S. Department of Energy, the U.S. Geological Survey and the National Science Foundation, and involves Bechtel National, Inc. as the principal contractor, Kennecott Corporation as the resource owner, other industry participants and numerous research institutions. The original objective of the project was to penetrate the "roots" of a known hydrothermal system to obtain fluid and rock samples to be made available to government, academic and industry researchers; test the deeper geothermal zones to evaluate energy potential; and provide for a better understanding of heat and mass transfer processes within a magma-driven hydrothermal system. More than 30 scientific investigations have been funded by the participating agencies.

The well was drilled to depth of 10,564 ft in March 1986, and a reservoir temperature of more than 350°C was measured. During and shortly after the drilling phase, two short-duration flow testing and fluid sampling sessions were conducted and several suites of commercial and research geophysical well logs were obtained. More than 725 feet of core was recovered and cutting samples were retrieved throughout the drilling process.

Plans for continued studies include the requirement to repair a damaged liner within the well, obtain equilibrium temperature and pressure profiles, and perform a long-term (30-day) flow test in cooperation with Kennecott Corporation. As part of the long-term flow test, the deepest reservoir would be isolated and tested, and high quality fluid samples would be collected an analyzed.

Technological "fall out" from the project has already occurred through the commercial availability of some of the high-temperature (dewared) slickline logging tools. Developed cooperatively by scientists and engineers at Sandia National Laboratories and Los Alamos National Laboratory, the tools include (1) dewared mechanical, pressure, temperature and flow probes designed by Sandia and built by the Kuster Company; (2) an electronic-memory pressure and temperature probe developed by Sandia; and (3) a 2-liter downhole fluid sampler developed by Los Alamos, that may be coupled to a Sandia-built power pack and control unit for non-conducting wireline operation.

Preliminary indications are that the deep hydrothermal system of the SSGF was not fully penetrated by drilling. The fractured, hydrothermal convection system could extend several thousand feet below the bottom of the well.

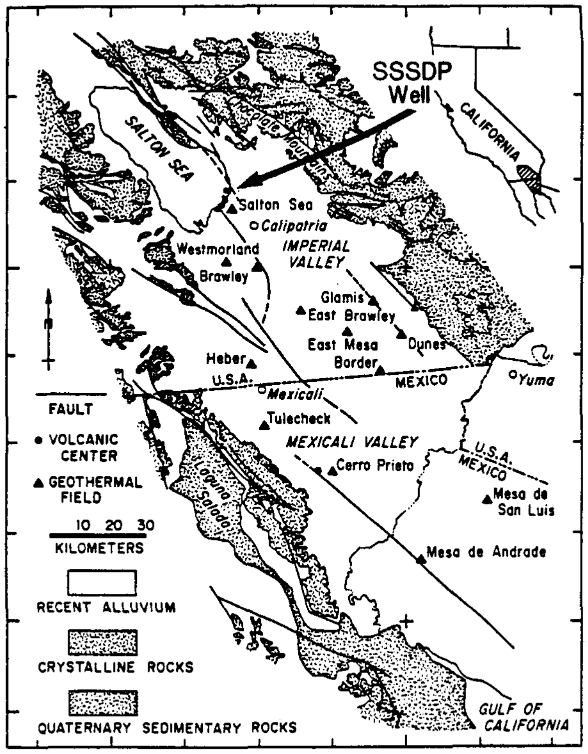

Figure 2: Salton Sea Geothermal Field Regional Setting

Geothermal Technology Organization

As part of DOE's continuation of cooperative research with industry, the objective of a newly established Geothermal Technology Organization, or GTO, will be to foster cost-shared technology development in the areas of geothermal reservoir research and geothermal conversion research. Through the formation and operation of the GTO, non-profit funding arrangements will be made between DOE (represented by INEL) and industry partners to conduct research in all aspects of geothermal energy, exclusive of drilling research.

GTO-funded projects will address research to improve technology for locating, characterizing, developing, and utilizing geothermal resources. Areas of research may include high-temperature instrumentation, reservoir modeling, analysis and interpretation of geophysical data, reservoir stimulation, materials testing, well field design, fluid treatment, and materials compatibility.

In initial meetings with industry representatives, a favorable response has been indicated. The establishment of the GTO will follow the approach taken in establishing the Geothermal Drilling Organization (GDO). A charter and agreement will be established between DOE and the GTO, using GDO documentation as the framework. Projects will be identified, GTO participants determined, and requests for proposals will be issued, selected, and awarded on a cost-shared basis (49% DOE, 51% industry partners). Participation in GTO projects will be required by at least two member companies.

CONCLUSIONS

The DOE/GTD Reservoir Technology Program, the Salton Sea Scientific Drilling Program, and the establishment of the Geothermal Technology Organization are critical Federal efforts to assist U.S. industry in geothermal resource development. The Reservoir Technology Program is assisting industry in developing technology to more effectively locate hydrothermal systems and characterize the commercial developability of those systems. Specific efforts to better understand the nature of high-temperature hydrothermal systems are flow testing and sampling of fluids and rock, and geophysical logging in the SSSDP. The GTO, through cost-shared participation by industry, will provide a means to focus more attention on specific problems hampering field developers. All of these efforts combined result in an improving economic picture for geothermal energy and make U.S. geothermal technology and expertise more attractive in the world marketplace.