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ADVANCES IN GEOTHERMAL RESEARCH

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ABSTRACT

The accomplishments of the various elements of the geothermal research and development program of the Department of Energy during 1988 are outlined. It is noted that research advances will help to place the geothermal industry in a better technical position to meet the challenges of an increased energy demand in the 1990's, as predicted by DOE. Recent federal technology transfer initiatives are identified and preliminary results of an analysis of all energy sources in the U.S. vis-a-vis geothermal's ranking in the total energy resource base, the accessible resource base, and energy reserves are presented.

TECHNOLOGY TRANSFER

Thank you for inviting me to participate in the 14th Annual Stanford University Geothermal Reservoir Engineering Workshop. I know of no more effective technology transfer forum than this one. It provides splendid support both to the general technology transfer mission of the Department of Energy and the specific efforts of the Geothermal Technology Division.

Since your presence here indicates your interest in technology transfer, you may be interested in some of the government's initiatives to facilitate this function. Of note among these initiatives is the President's April 10, 1987, Executive Order No. 12591 on Facilitating Access to Science and Technology. The overall thrust of the Executive Order is to ensure that Federal agencies and laboratories assist universities and the private sector in broadening the technology base by moving new knowledge from the research laboratory into development of new products and processes. It has provisions for establishing consortia among laboratories, universities, and industry. DOE's new policies with respect to intellectual property and its continuing efforts to improve its procedures will carry out the mandate of Executive Order 12591. The Department strongly believes that research results and intellectual property rights should be transferred to the private sector in a manner which provides incentives for commercialization, provides the proper accountability for public funds, supports the missions of the national laboratories, assures that adequate rights are retained to accomplish government purposes, and assures that the laboratories serve as resources to industry rather than competitors.

Improvements have been made by the Department in recent years to reduce institutional barriers to the transfer of technology from the national laboratories; e.g., provisions have been made for more flexibility for laboratory staff to consult for industry, and for class waivers for patents originating from user facilities and work-for-others agreements. A computer software policy to allow contractors to copyright and license software has been completed, and the Assistant Secretary of Defense Programs is implementing, consistent with DOE's national security responsibilities, a program for identifying technology transfer mechanisms and incentives that accelerate commercialization of defense technologies. Undersecretary Donna Fitzpatrick recently stated: "The Department believes that defense programs are a prime source of valuable applied technology and a national asset in the management of industrial technologies whereby advances in new technologies in one field spur advances in another."

ENVIRONMENTAL ISSUES

In addressing the Department's policy on another issue of considerable significance, Secretary Herrington recently stated that the U.S. responses to environmental issues "will be most effective over the long term if they seek to stimulate technological innovation and to ensure that the marketplace has sufficient information to make appropriate choices." He indicated that such a response to the "greenhouse effect" is currently far from available: "Research on the causes and possible solutions is still incomplete and should be pursued expeditiously."

In a preliminary look at geothermal power plants vis-a-vis carbon dioxide emissions, GTD found that the CO_2 emissions of U.S. geothermal power plants for which data are available range from zero to 11 percent of those of a Western coal plant. Almost all of

them emit less than 5 percent of the CO_2 that would be emitted by a coal plant of the same capacity. Binary plants, of course, would release no gases into the atmosphere.

We are now pursuing a project to gather detailed CO_2 data from specific geothermal plants, develop a scenario for each Known Geothermal Resource Area (KGRA), project CO_2 emissions, and compare them with fossil emissions. The study will then determine what the technology options would be if CO_2 reductions were ever to be mandated at the state or federal level and whether R&D assistance would be needed to enhance available technologies or to develop new ones.

PROJECTED POWER DEMAND

If, as the Department now believes likely, power demand increases markedly in the 1990's, the geothermal industry does not need any environmental "hang-ups" to prevent it from participating to the fullest extent desirable. A new DOE report entitled "United States Energy Policy - 1980-1988" finds that if power demand grows just 2 percent annually, the nation will need about 100 GW of additional electric generating capacity by the year 2000 over that currently under construction. This increase would be the equivalent of 100 nuclear power plants and an increase of one-sixth of existing capacity. The figure may be conservative, however, since demand projections based on the first half of the 1980's suggest that during periods of economic growth, electricity demand grows at about the same rate as economic output. Thus, if annual GNP growth is greater than 2 percent, it is likely that electricity demand growth will be higher. In 1987, for example, GNP grew by 3.3 percent and electricity demand was up 4.7 percent. A finding of the report that may be of even more interest to the geothermal community is that it is likely that every region of the country will need new generating capacity by the early 1990's.

If GTD technology objectives -- arrived at with input from nearly all sectors of the geothermal community -- are achieved, the geothermal industry will be in a better technical position to meet the challenges of an increased power market in the next decade. To the extent that space permits, I would like to tell you about some of GTD's accomplishments of last year which keep us on the road to objective achievement.

HYDROTHERMAL RESEARCH

Reservoir Technology

Reservoir Analysis - The emphasis of this task in 1988 was on methods to replace costly drilling as the only means for providing evidence that a reservoir is adequate to support power generation for the expected life of a proposed plant -- i.e., to extend the information gained from one well to the field around it, thus reducing the number of wells needed for this purpose. Specific accomplishments included the discovery that borehole breakouts indicate varying stress directions in individual blocks of rock, inversion codes for interpretation of borehole-to-borehole and borehole-to-surface resistivity surveys, and the Medicine Lake Volcano teleseism experiment.

The Medicine Lake work in 1988 involved seismic tomographic data gathered at Medicine Lake in 1986 by the U.S. Geological Survey and the Lawrence Berkeley National Laboratory. Derived from eight explosions in a 50 km area from the caldera, these geophysical results provided one of the best data sets yet achieved. The 1986 studies focused on using the data to measure delay times in the rocks; in the 1988 studies, more sophisticated interpretation procedures were applied to the same data to try to determine the saturation of the rocks. The results to date are shown in Exhibit 1. In this geological cross section, the horizontal lines with angled hatchures represent the previous velocity model from the seismic refraction study; the high velocity core of the volcano is shown (5.7 km/s, subsolidus dike and intrusion complex); the suspected magma chamber with at least partial melt in the low-velocity, high attenuation body in the center of the caldera is identified; and the area where steam is believed to be present is indicated as "boiling water."

Exploration Technology - The exploration task is designed to develop techniques to locate and characterize geothermal resources in young siliceous volcanic environments, particularly in areas with deep circulation of groundwater. Gathering of the geological, geophysical, and geochemical field data, acquired by cost-sharing several deep heat flow holes with industry in the Cascades Range of the Pacific Northwest was completed in 1988. The data will be integrated in reservoir models which will serve as a tool for locating geothermal resources hidden by deep movement of groundwater in the Cascades Range.

Brine Injection - The injection task focuses on techniques to predict the intensity and timing of the thermal, chemical, and hydrologic effects of injection in order to provide methods to reduce temperature and pressure degradation in geothermal reservoirs. Accomplishments in 1988 included: 1) models for the interpretation of injection tests in fractured reservoirs, 2) techniques to use tracer test results to design optimal injection schemes, and 3) a dual permeability model to simulate flow in fractured rock with secondary porosity. These are all techniques for maintaining reservoir pressure while avoiding thermal breakthrough to the producing zone.

Geothermal Technology Organization - The GTO, the joint DOE/industry group that jointly funds technology development efforts that will provide immediate benefits to the geothermal industry in the areas of reservoir performance and energy conversion, began one project in FY 1988 -- a microseismic study of The Geysers geothermal field. GEO Operator Corp. and the Unocal Geothermal Division are the industry participants.

Salton Sea Scientific Drilling Task - The testing facility was reconditioned in 1988, and a successful 20-day production flow test was conducted, with flow rates up to 700,000 pounds/hour of hot 260°C (500°F) brine. Ancillary studies of brine chemistry, waste disposal, and microseismic detection also were carried out.

Hard Rock Penetration

Lost Circulation Control - R&D was undertaken to develop a basic understanding of the two-phase (solid/liquid) flow phenomenon that dictates fracture plugging mechanics for single-particle, high-temperature, and multiple constituent lost circulation materials. In addition, the plugging characteristics of high-temperature lost circulation materials were measured under a range of temperature and pressure conditions.

Rock Penetration Mechanics - Activities during 1988 included the development of a concept for a core drilling system for deep thermal regimes, and, working with industry suppliers, the completion of two designs for insulated drill pipe. Analysis of acoustical data telemetry through the drill string was completed, and testing of a laboratory scale model of the drill string transmission system showed excellent agreement between theory and lab data.

Instrumentation - A User Group was formed to promote the use and further development of a computer code to calculate the forces on a bit and bottom-hole assembly that will permit optimization of well design. In addition, a new lower power transmitter was fabricated and added to a prototype radar fracture mapping tool designed to locate fractures in a rock formation that do not intersect the wellbore. Field tests in 1988 showed that it can detect distinct targets in non-uniform geologic media.

Geothermal Drilling Organization - In 1988, a high-temperature borehole televiewer, being developed for casing inspection and fracture mapping in the open wellbore, was assembled and successfully demonstrated in a hot well owned by Unocal in Long Valley, California. A test of a tool for deploying an expanding foam in lost circulation zones at The Geysers showed insufficient expansion of one type of foam under field conditions. However, three field tests at The Geysers of a downhole air turbine for directionally drilling geothermal wells gave promising results, and led to design modifications of the transmission assembly. Temperature-resistant elastomer materials were screened for suitability for use in the fabrication of drill pipe protectors.

Conversion Technology

Heat Cycle Research - In 1988, supercritical tests of the Heat Cycle Research Facility with the condenser at the near vertical position with the propane family of working fluids was completed, as was Phase I of the relocation of the HCRF from the Geothermal Test Facility at East Mesa, California, to the property of the nearby B.C. McCabe binary plant. The second phase of the relocation was initiated, including installation of a two-dimensional expansion nozzle and a reaction turbine. The application of the new Kalina concept to geothermal power cycles was completed, and data from previous experiments with a near horizontal condenser were evaluated.

Materials Development - Major 1988 activities included downhole testing of advanced high-temperature 300°C (572°F) lightweight cements for well completions, which produced very promising results; initial steps for conducting tests of polymer-lined heat exchanger tubing; and completion of an analysis of high-temperature elastomers for use in geothermal sealing applications.

Advanced Brine Chemistry - In 1988, the interim brine equilibrium model for silica, calcite, and carbon dioxide was completed; the model will now be expanded to additional minerals in order to make it a more realistic simulator of the thermodynamic conditions under which problems will occur in geothermal power plants from scale deposition, corrosion, and suspended solids. In addition, laboratory tests of prototype particle meters were conducted using a high-temperature, high-pressure synthetic brine so that technical problems experienced in field tests could be corrected. An ultrasonic particle meter was tested at the Salton Sea Scientific Drilling Project to learn how the instrument would perform under actual field conditions; a report on its performance is forthcoming.

Other research conducted under the brine chemistry task is the series of experiments underway on the use of a biochemical technique to concentrate and remove toxic metals from wastes: the leaching of metals by micro-organisms from sludge-like residues that result from the precipitation of minerals from spent geothermal brines before injection.

GEOPRESSURED-GEOTHERMAL

Well Operations

The well operations project involves field activities to obtain information on reservoir performance under production conditions, surface handling systems, disposal well injection procedures, brine chemistry and scale inhibitor treatment, and automation. The Pleasant Bayou well, located in Brazoria County, Texas, near Houston, was placed back in production in May 1988, after being treated with a scale inhibitor, and has been flowing at about 20,000 barrels per day. The Gladys McCall well located in Cameron Parish, Louisiana, was subjected periodically to high rate flow tests at over 25,000 barrels per day of brine for over two years. It produced a total of over 27 million barrels of brine and nearly 676 million scf of methane, and was the subject of the breakthrough in geopressured scale inhibition treatment. It was shut in during October 1987, and is undergoing a long-term pressure build-up test to help in understanding the drive mechanisms of geopressured reservoirs. The Willis Hulin well was drilled in Vermilion Parish, Louisiana, as a commercial gas producer. It penetrated an unusually good geopressured zone at about 20,000 feet, and when it was no longer operable as a gas well, DOE agreed to assume ownership from the Superior Oil Co. Most of the physical parameters of the Hulin well differ from those of the experimental wells drilled specifically for geopressured brine production, and it thus provides the opportunity to facilitate determination of drive mechanisms under another set of downhole conditions. In addition, the higher expected temperature and gas content make fluid from the Hulin well substantially more valuable per unit volume than fluid from the design wells. Annular pressures at the wellhead were monitored on a regular basis in 1988, site facilities were upgraded in preparation for workover activities, and a safety evaluation of well pressure buildup was performed.

Geoscience and Engineering Support

The 1988 accomplishments of this project included: 1) refined mapping of Pleasant Bayou reservoir sandstone within the fault block; 2) development of simplified geologic models; 3) continued analysis and interpretation of the multirate flow tests of the Gladys McCall as well as shut-in data; and 4) the conclusion that environmental monitoring at the Gladys McCall has not shown any detrimental environmental effects attributable to the long-term testing (microseismic, water quality, and subsidence).

Energy Conversion

The construction of a "hybrid" power conversion system designed to utilize both geothermal heat and methane was begun in 1988 at the Pleasant Bayou well site, and a power generation experiment is scheduled to begin there early in 1989. Flow testing of the well has been resumed in preparation for the experiment.

HOT DRY ROCK

Fenton Hill Operations

The focus of the Fenton Hill Operations project in 1988 was preparing for the upcoming Long-Term Flow Test (LTFT) of the Phase II reservoir. This test is a significant milestone in hot dry rock research because of the information it will provide on reservoir impedance, thermal drawdown, energy output, and water consumption. The significant 1988 accomplishment was completion of the repair of the well used to produce heated water from the man-made reservoir. The repair was accomplished by redrilling into the existing reservoir and sidetracking the well around the damaged section. This work will enable optimum production during the LTFT of the reservoir scheduled to begin in 1990.

Scientific and Engineering Support

Accomplishments in 1988 included a re-analysis of the micro-earthquakes resulting from the massive hydraulic fracturing experiment of 1983 using improved mapping methods and initiation of a programming effort toward automation. A prototype borehole televiewer was also completed, and the injection borehole was surveyed.

MAGMA

Long Valley Operations

The key achievement of this project in 1988 was finalizing selection of an exploratory drill site in the Long Valley caldera in California which was approved by a DOE review panel. Permits for operation at the site were initiated, and preliminary site work completed. A science guide for supporting scientific measurements in the exploratory well was developed during a workshop attended by over sixty researchers.

Laboratory and Engineering Support

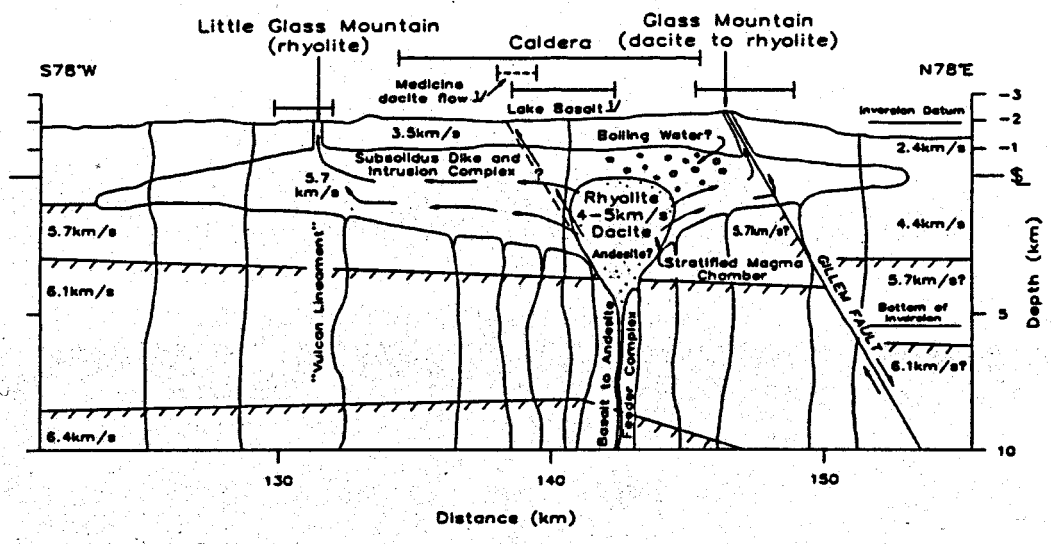
Research continued in 1988 on the energy extraction and geochemistry/ materials tasks. Advances were made in evaluating magma convection, overall energy extraction analysis, analysis of energy conversion systems, understanding thermal fracturing processes, examining the reaction of potential heat exchanger materials with magmatic fluids, evaluating mass transport near the heat exchanger, and collecting laboratory data related to potential hazards during drilling.

WHY CONTINUE GEOTHERMAL R&D?

A new study in preparation for the Deputy Assistant Secretary for Renewable Energy provides another indication of the importance of continuing geothermal R&D and achieving our objectives. In analyzing the energy sources in the U.S. and standardizing the definitions of all sources, the preliminary finding is that geothermal energy within six kilometers of the earth's surface -- seven for geopressured -- accounts for 42.7 percent of the U.S. total energy resource base, as shown in Exhibit 2. The total resource base is defined as the total physically available energy-- identified and undiscovered -- regardless of whether or not it can be practically or economically extracted. However, geothermal accounts for only 4.4 percent of the U.S. accessible resource base -- the portion of the resource base that can be exploited within known or developing technology -- and 3.8 percent of U.S. energy reserves -- those portions that are economically recoverable under current conditions. With improved technology we can greatly increase geothermal's portion of both the accessible resource base and the reserve category, making a significant contribution to the nation's energy supply.

EXHIBIT 1

CROSS SECTION OF MEDICINE LAKE VOLCANO
FROM SEISMIC TOMOGRAPHY



(Source: Three Dimensional Velocity and Attenuation Structure at Medicine Lake Volcano, California, from Seismic Tomography, J. S. Evans, U. S. Geological Survey, J. J. Zucca, Lawrence Livermore National Laboratory)

EXHIBIT 2*

U. S. GEOTHERMAL RESOURCES

TOTAL RESOURCE BASE[a]		U.S. ACCESSIBLE RESOURCE BASE[b]		U.S. RESERVES[c]	
Quads	BBOE[d]	Quads	BBOE[d]	Quads	BBOE[d]
1,505,408	255,910	22,588	3,840	247	42
(42.7% of Total U.S. Energy Resource Base)		(4.4% of Total U.S. Accessible Energy Resource Base)		(3.8% of Total U.S. Energy Reserves)	

* Still subject to review by the U.S. Geological Survey.

[a] The total resource as specified in USGS Circular 790, but modified by the National Academy of Sciences to include resources within 6 kilometers of the surface and with a heat value > 80°C (except for hydrothermal, which is > 40°C). Geopressured resources are included to a depth of 7 kilometers.

[b] The accessible resource as specified in USGS Circular 790, but modified by the National Academy of Sciences to include only accessible resources within 6 kilometers of the surface and > 80°C, except for hydrothermal resources which are > 40°C. Geopressured resources to a depth of 7 kilometers are also included.

[c] The reserve as specified in USGS Circular 790, but modified by the NAS. In addition, low temperature (>40°C) hydrothermal 30-year resources form USGS Circular 892 are added to the total.

[d] Billion barrels of oil equivalent.