LBL-29045

Lawrence Berkeley Laboratory
UNIVERSITY OF CALIFORNIA

EARTH SCIENCES DIVISION

Presented at the DOE Geothermal Program Review VIII,
San Francisco, CA, April 18–20, 1990, and
to be published in the Proceedings

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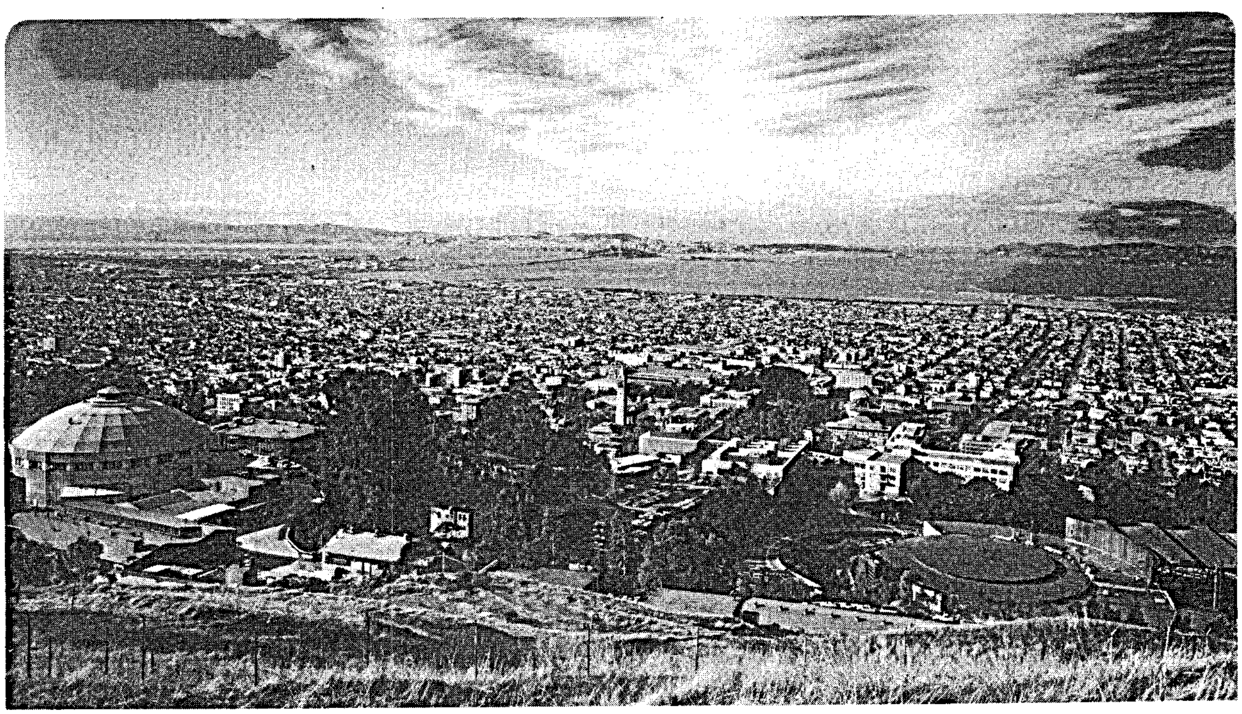

Prepared for the U.S. Department of Energy under Contract Number DE-AC03-76SF00098.

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This work was supported by the Assistant Secretary for Conservation and Renewable Energy, Geothermal Division, of the U.S. Department of Energy under Contract No. DE-AC03-76SF00098.

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Abstract

The Geothermal Technology Division of the Department of Energy is redirecting a significant part of its Reservoir Technology funding to study problems now being experienced at The Geysers. These include excessive pressure drawdown and associated decline in well flow rates, corrosion due to high chloride concentration in the produced steam and high concentration of noncondensible gases in some parts of the field. Lawrence Berkeley Laboratory (LBL) is addressing some of these problems through field, laboratory and theoretical studies.

Introduction

The first power plant at The Geysers came on-line in 1960. Initially the development of this vapor-dominated geothermal system was at a slow rate; not until the early 1970s did it acclerate. During the 1971–1981 period the yearly average increase in installed capacity was 67 MWe. Between 1982 and 1989 the development intensified substantially; during that period the generating capacity at the field grew at a rate of 180 MWe/year (Barker *et al.*, 1989). At the present time the total installed capacity at The Geysers is about 2000 MW.

Starting in 1987, problems with the amount and quality of the steam produced at The Geysers became evident. There was a decline in the steam supply in response to decreasing reservoir pressures. In addition, in some parts of the field the steam began corroding valves and pipes caused by the presence of HCl, and in others areas, the noncondensible gas content in the steam was high to the extent of affecting turbine performance. Because of these problems, the electrical power output is substantially below the total installed capacity at the field; about 400 MWe of the installed capacity was not being used during June, 1989 (Mock, 1989).

There is general agreement that in order to stabilize reservoir pressures, and possibly reduce the corrosiveness of the steam and its noncondensible gas content, it will necessary to expand present injection operations at The Geysers; about 20 to 25 percent of the mass extracted from the reservoir is currently being reinjected. However, some Geysers operators have had mixed results. Even though the rate of reservoir pressure decline was reduced by water reinjection, some wells started to produce a steam-water mixture (i.e., a high-permeability flow path existed between the injection and production wells).

Evidently all injection operations will have to be carefully designed to be able to recover most of the heat stored in the reservoir rocks and reduce possible negative effects on producing wells. The design will have to take into consideration the reservoir fracture network and the subsurface movement of the injectate; this information has to be determined on the basis of well log data, and tracer and other well test results.

In 1989, the geothermal operating companies requested assistance from the Geothermal Technology Division (GTD) of the US Department of Energy (DOE) in view of the serious nature of the problems at The Geysers. A significant part of GTD's Reservoir Technology is now directed toward research activities relevant to Geysers issues. During the present Fiscal Year 1990 funding for about $900,000 has already been approved for these activities. The funded projects are described in a March 16, 1990 letter from Marshall Reed (GTD) to The Geysers operators. Because of budget constraints, a number of other projects are awaiting funding (these are also described in the above-mentioned letter).

GTD is seeking industry's support in cost-sharing its Geysers research effort during this and future fiscal years. For this purpose, personnel of GTD and GTD-funded organizations have had several meetings with industry representatives to discuss the proposed research. As a result, some projects have been cost-shared by industry under the Geothermal Technology Organization. Recently, LBL has been designated by GTD as the Lead Laboratory for Geysers research and has been requested to coordinate the DOE research effort and to provide the geothermal operators with a point of contact for joint projects between industry and GTD-funded organizations. A meeting in Santa Rosa, CA, is being organized for June to further discuss the proposed research program.

LBL Research on The Geysers

About $250,000, half of the FY90 budget assigned to LBL for Reservoir Technology, is being directed toward projects relevant to The Geysers field. These include: (a) Geysers Database, (b) Injection Modeling, (c) Seismic Monitoring in the NW Geysers, (d) Development of a Downhole Fluid Sampler and (e) Fracture Studies. Other studies have been proposed and are in need of funding, such as the study of interference effects at The Geysers. We are actively seeking industry's support for these projects.

Geysers Database

LBL has developed a comprehensive computerized database of The Geysers with support from the California State Lands Commission (SLC) and the DOE.

The bulk of the data consists of production and injection histories for 221 wells, obtained from the California Division of Oil and Gas. The well histories consist of flow rates, wellhead pressures and temperatures and shut-in pressures. Other data include well locations, directional surveys, lithologic logs, steam entries, topographic data, heat flow data, pressure transient tests and geochemical data (Fig. 1). This information was obtained from SLC files and other sources. All available open file data, as well as proprietary information on State wells, are included in the database.

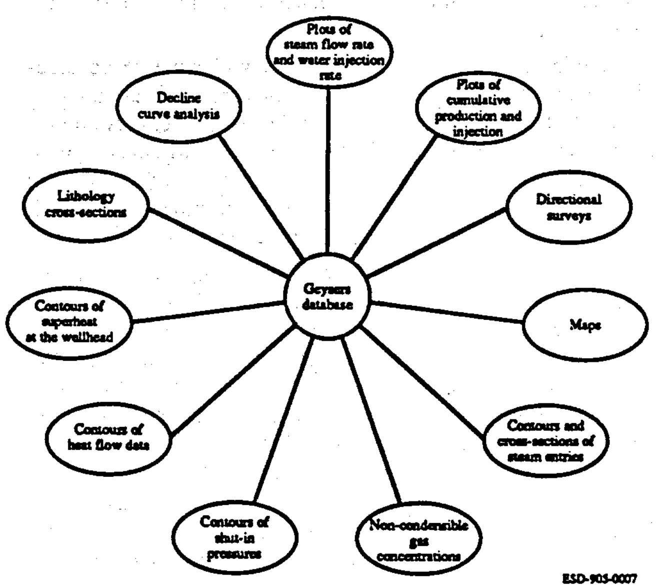

Figure 1. Capabilities of LBL's Geysers database system (from Ripperda and Bodvarsson, 1988).

A major effort was devoted to the development of a computerized base map that can display well names and locations, power plants, roads, lakes, townships, sections and county and lease boundaries. The data used in the development of the base map came from many different sources, including reports prepared by Unocal, United States Geological Survey and Geothermal Resources Council. Some of the data were digitized from SLC maps.

Other software development includes the capability to display lithologic data, steam entries and directional surveys. After specification of any number of wells, the software provides a plot of well locations with actual well tracks, and a lithologic cross section that includes steam entries, casing shoes and well directions.

Currently, the database is being expanded with data required for the DOE Geysers researchers. LBL is communicating with the operators in an effort to obtain data needed for the current research effort. Of particular interest are data on past and current tracer tests that will help quantify the beneficial (and detrimental) effects of reinjection.

Injection Modeling

As mentioned before, significant increase in reinjection may be the only possible means of reducing the current rate of pressure decline and considerably increasing the overall energy recovery from the system. One problem of primary interest is how much of the injected water is boiled off and extracted at the production wells. The operators have conducted various tracer tests and carefully monitored the isotope concentrations in producing wells. The results obtained are mixed, with a large percentage of the injected water being produced in some areas and a much smaller one in others. Therefore, it would be most useful to numerically investigate this problem in order to fully understand the effectiveness of reinjection in the past, as well as for designing future reinjection operations.

In the past few years LBL has been conducting research on fluid reinjection especially by incorporating chemical transport into geothermal reservoir studies (Gaulke, 1986; Tulinius *et al.*, 1987; and Amistoso *et al.*, 1990). Perhaps the most thorough evaluation of reinjection effects was that of Amistoso *et al.* (1990) for the Palinpinon geothermal field in The Philippines. They matched the total performance of all wells within the field in terms of flowrate decline, pressure decline, chloride concentration in the produced fluids and thermal decline in some production wells.

The Palinpinon study yielded detailed evaluation of fracture porosities, permeabilities and spacings which are the primary parameters controlling the movements of chemical and thermal fronts. This methodology will be applied to selected Geysers data sets to evaluate the dispersivities of the injected fluids and the resulting impact on the pressure decline.

Microseismic Monitoring of the NW Geysers

In a joint project with Coldwater Creek Operator Corporation (CCOC), LBL has begun collecting, processing and interpreting microearthquake (MEQ) data from the 16-station array deployed by CCOC at the Northwest Geysers geothermal field.

The first task is to bring the existing array into a state of routine operation to insure the collection of MEQ data, and to maintain the array in a routine data gathering mode. Another task is to process the existing data (Fig. 2) in order to refine the velocity model for precise location of events and designing future reinjection and calibration studies. This will help in the analysis of new MEQ data.

The main objective of the project is to demonstrate the utility of high-resolution MEQ data for (a) identifying high-permeability paths in the reservoir, (b) aid in locating future in-fill wells and (c) monitor the effects of injection. Another purpose is to develop a three-dimensional model of the reservoir showing (a) the P- and S-wave velocity structure, (b) the Poissons ratio model and (c) the structural model of the area based on the location of MEQs assumed to indicate high-permeability flow paths.

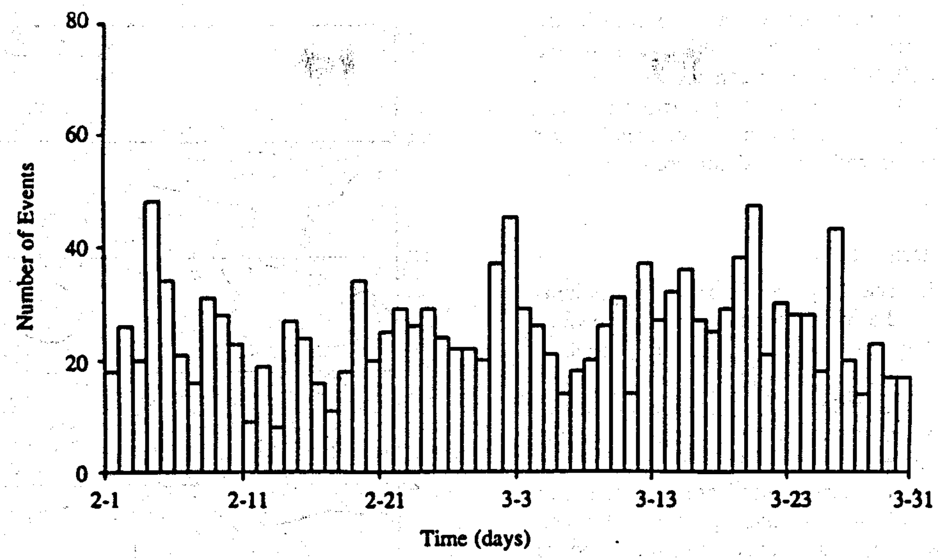

Figure 2. Microearthquake events per day in the NW Geysers during February and March 1989 (from J. Weiser, 1989, GEO internal report).

Development of A Downhole Fluid Sampler

The appearance of corrosive steam in the northern part of The Geysers field has caused serious development problems, and could be affecting others in the future. Presently, it is not clear whether the HCl in the steam has a magmatic origin (i.e. degassing of deep igneous intrusion) or is generated by the hydrolysis of chlorides present in the reservoir rocks (mainly Franciscan graywackes). The collection, chemical analysis and interpretation of downhole samples would greatly increase our understanding of the genesis and transport of HCl.

In order to obtain larger volumes of deep reservoir fluids (there is the possibility that only steam might be collected at depth), LBL has begun the design and fabrication of a flow-through six-liter downhole sampler. The design of the new instrument will be based mainly on that of existing one- and two-liter capacity samplers (Fig. 3; Solbau *et al.*, 1986). The only substantive difference will be addition of an electrical timing device attached at the top to initiate valve closure. This will allow the sampler to be deployed using a simple wireline.

The new sampler will have a 3.5 in. diameter and a length

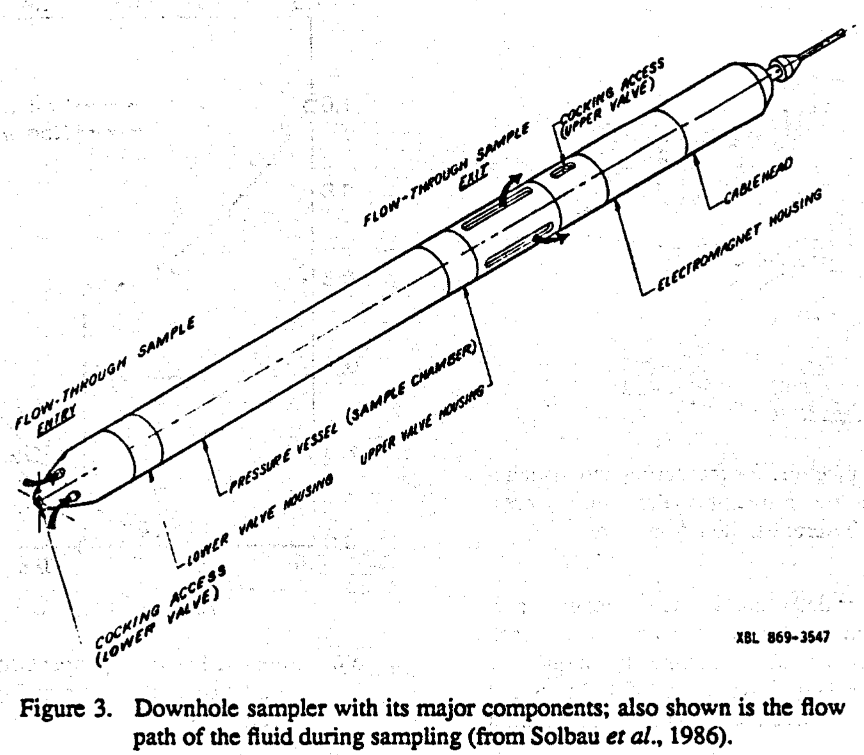

Figure 3. Downhole sampler with its major components; also shown is the flow path of the fluid during sampling (from Solbau *et al.*, 1986).

of about 10 ft. The deward timing mechanism will be designed to withstand temperatures of up to 350°C for up to three hours, time enough for the sampler to be lowered, closed and retrieved from a deep well. All parts in contact with geothermal fluids and the cooled condensate sample (possibly with high HCl content) will be fabricated from a chemically inert titanium alloy. The sampler will be rated for pressures up to 5,000 psi.

Multiphase Flow in Fractured Rocks

Fluid movement in The Geysers reservoir is predominantly through fractures; the rock matrix recharges the fractures in response to production-induced pressure drawdown. In the fractures of the "normal" upper vapor-dominated reservoir, only steam is flowing, while in the deeper hotter reservoir, a mixture of steam and brine seems to be present. On the other hand, throughout the entire system multiphase fluid flow is dominant in the rock matrix (Pruess and Narasimhan, 1982). An understanding of fracture relative permeability and fracture-matrix interflow is crucial in evaluating the response of The Geysers reservoir to steam production and liquid reinjection.

With this in mind, LBL has initiated a combined experimental and theoretical program to study multiphase flow in fractured rocks. Two-phase flow in rough-walled fractures is being visualized and measured in the laboratory. Figure 4 illustrates our experimental setup that utilizes the "Hassler sandwich" technique (Hassler, 1944; Rose, 1987) for measuring fracture relative permeabilities and capillary pressures. Assembly of this apparatus is nearing completion.

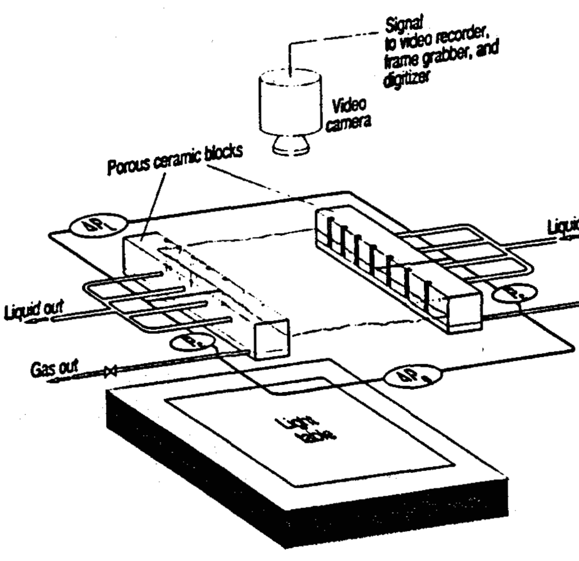

Figure 4. Sketch of the apparatus for measuring and visualizing multiphase flow in fractures (Pc: capillary pressure; Pg: gas pressure; PL: liquid pressure).

Conceptual models for determining fracture relative permeability are being developed, based on fracture void space geometry which is measured using casting techniques or obtained from statistical methods (Cox *et al.*, 1990; Pruess and Tsang, 1990). The acquired fracture geometry information

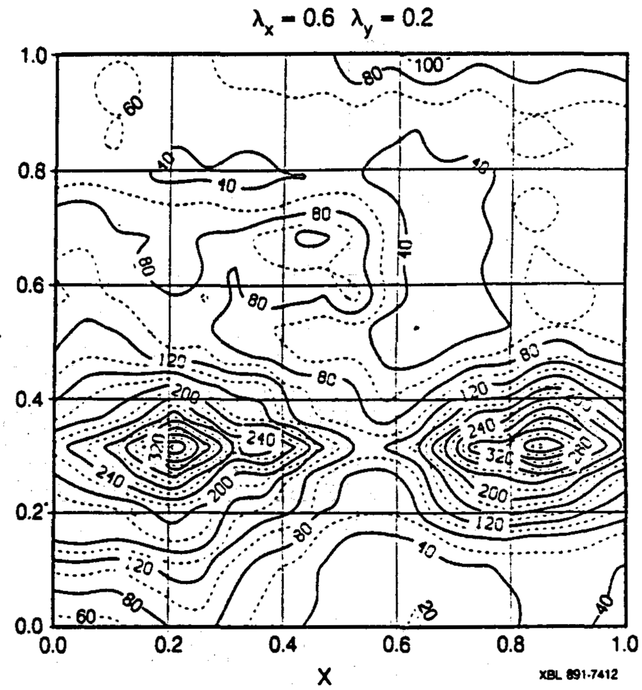

Figure 5. Contour diagram of a lognormal aperture distribution with anisotropic correlation; apertures in μm (from Pruess and Tsang, 1990).

(Fig. 5) is being incorporated into numerical models to compute fracture relative permeability parameters (Fig. 6). The resulting relative permeabilities will be useful in gaining insight into the response of fluid-depleted fractured reservoir

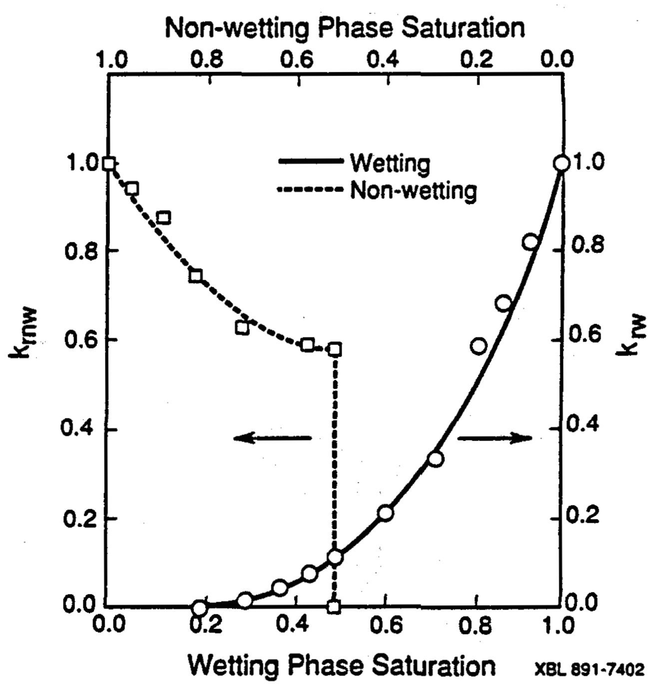

Figure 6. Simulated relative permeability curves for the aperture distribution shown in Fig. 5 (from Pruess and Tsang, 1990).

zones subjected to steam production and injection of cooler waters.

Acknowledgments

We thank Mark Jasper for his help in producing the paper. This work was supported by the Geothermal Technology Division, under the Assistant Secretary for Conservation and Renewable Energy of the U.S. Department of Energy, through contract DE-AC03-76SF00098.

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