MASTER

LBL-9326

CONF - 790906 - - 5

To be presented at the 1979 Annual Meeting,
Geothermal Resources Council, Reno, NV,
September 24-27, 1979

STATUS OF GEOTHERMAL RESERVOIR ENGINEERING RESEARCH PROJECTS SUPPORTED BY USDOE/DIVISION OF GEOTHERMAL ENERGY

J. H. Howard and W. J. Schwarz

July 1979

Prepared for the U. S. Department of Energy
under Contract W-7405-ENG-48

LAWRENCE BERKELEY LABORATORY
UNIVERSITY OF CALIFORNIA BERKELEY

DISCLAIMER

STATUS OF GEOTHERMAL RESERVOIR ENGINEERING RESEARCH PROJECTS
SUPPORTED BY USDOE/DIVISION OF GEOTHERMAL ENERGY *

J. H. Howard and W. J. Schwarz

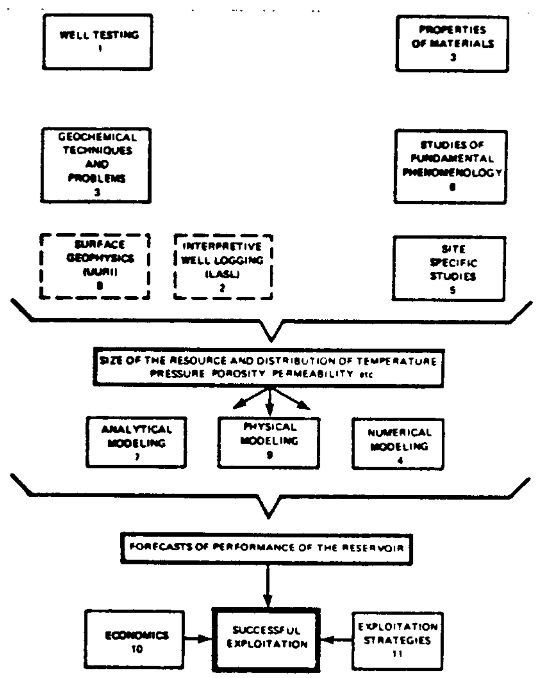
Earth Sciences Division
Lawrence Berkeley Laboratory
University of California
Berkeley, California 94720

ABSTRACT

In the fall of 1977, the U. S. Department of Energy (DOE), Division of Geothermal Energy (DGE) proposed that Lawrence Berkeley Laboratory (LBL) assume lead responsibility, on DGE's behalf, for geothermal reservoir engineering. This summary discusses briefly the DOE/DGE-sponsored geothermal reservoir engineering research program which includes LBL in-house research and research done by others through LBL. LBL in-house research has emphasized improvement of well test analysis methods and the development of geothermal reservoir performance simulators. Work by others has included 18 separate contracts on a variety of technical and scientific projects. Altogether, 29 distinguishable research topics have been addressed. Fourteen institutions, including eight private companies, have interacted with the program. Table 1, along with figures 2 and 3 summarizes the status of the work.

INTRODUCTION

The purpose of this paper is to review the program of geothermal reservoir engineering related research that has been supported by the U. S. Department of Energy, Division of Geothermal Energy, through Lawrence Berkeley Laboratory. Administratively, the program consists of two parts: (1) Work done at LBL, (2) work contracted for by LBL and done by a variety of organizations other than LBL. The primary responsibility assigned to LBL was (1) to define and resolve technical and scientific problems related to successful exploitation of geothermal reservoirs. In addition, implicit in the assignment was the desire that the program (2) help promote the establishment of an industry-wide geothermal reservoir engineering community and (3) help assure the education of personnel who would staff this community in the future. The document, LBL-7000 (Lawrence Berkeley Laboratory, 1978) explains details of the process that lead to the broad outline for research shown in Figure 1. This outline addresses all conceivable activities that relate to successful exploitation of a geothermal resource and goes beyond reservoir engineering in a restricted sense. Those activities in the top third of the figure (e.g., well logging) pertain to the acquisition, synthesis, and interpretation of information related to a working description of the reservoir, in particular to estimates of its size, and to a description of the distribution of temperature, porosity, pressure, and permeability within it. Those activities in the central third of the figure pertain to the development of the capability to reproduce and forecast reservoir performance. The two activities in the bottom third of the diagram, namely economics and exploitation strategies, must be factored into good planning for successful exploitation of a geothermal reservoir, which is the ultimate goal of the effort.



XBL 796-2000

Fig. 1 Broad outline of geothermal reservoir engineering related research activities.

The program has been executed in a way consistent with the priorities laid down by the industry advisory group which helped draft the planning document. The priorities assigned are shown by numerals in the box for the activity (Fig. 1). Implementation of the program as originally defined (LBL-7000) has been carried out mainly by LBL. However, the University of Utah Research Institute has had the lead role for research on surface geophysics, and Los Alamos Scientific Laboratory has had the lead role for well logging.

WORK ON TECHNICAL AND SCIENTIFIC PROJECTS RELATED TO SUCCESSFUL EXPLOITATION OF GEOTHERMAL RESERVOIRS

Although Fig. 1 provides a broad view of the various research areas considered when the program began, Figs. 2 and 3 are more useful in explaining the many projects that have been considered. Furthermore, these figures can be related to Table 1, wherein certain details on the work are given. The projects can be grouped as follows:

A. The synthesis of available sets of data and other information related to geothermal reservoir engineering: Items 1, 10, 11, 12, 14, 105, 106 (Table 1). For example, item 12 is a summary of all available data on the Wairakei, New Zealand, geothermal field.

B. The establishment of techniques of measurements of interest to geothermal reservoir engineers: Items 3, 4 (Table 1). For example, item 4 concerns measurements at the wellhead of noncondensibles in the flow-stream.

C. The analysis of measurements in order to define the characteristics of a geothermal reservoir: Items 2, 6, 15, 16, 17, 18, 101, 104 (Table 1). For example, item 2 is concerned with evaluating the theoretical basis of the James method.

D. The generation of new data important to geothermal reservoir engineering practice: Items 5, 7, 8, 9, 21, 22, 23 (Table 1). For example, item 7 is concerned with procedures to mitigate mud damage.

E. The establishment, improvement, or application of simulators that describe and forecast geothermal reservoir performance: Items 13, 20, 102, 103 (Table 1). Item 103 is the LBL-developed simulator "SHAFT 78," that models heat and fluid transport in porous media.

It is subjective and also difficult to measure the value of the overall program in terms of projects under way or completed since the beginning of the program. However, the following should be noted:

1. All identified major concerns have been addressed by qualified groups whose abilities to work on the project has been favorably reviewed by selection committees made up mainly of non-LBL personnel.

2. A steady stream of publications, including both volumes in the GREMP (Geothermal Reservoir Engineering Management Program) series and in the quarterly Newsletter from GREMP, has been established.

CREATION OF AN INDUSTRY-WIDE GEOTHERMAL RESERVOIR ENGINEERING COMMUNITY AND THE EDUCATION OF PERSONNEL

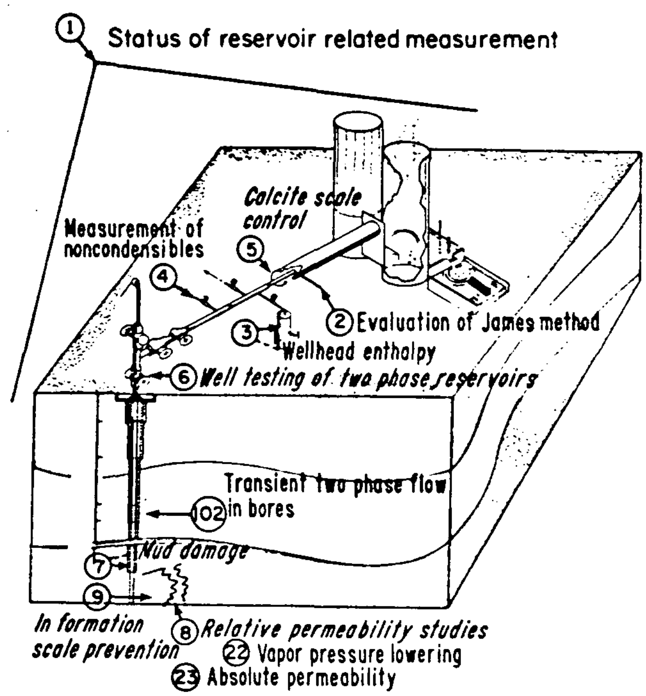
Support provided by USDOE/DGE for research has had a positive effect on creating a geothermal reservoir engineering community and on the education of personnel. This conclusion is supported by several lines of reasoning. Forty organizations have submitted proposals to the program, and 14 have been supported. Contractor organizations, including LBL, have participated actively in professional society meetings (e.g., Pruess et al. 1978).

Altogether, more than two dozen students have been recognized to be part of the program through reference to them in contracts. Also, in particular, Stanford University has reported employment of eight students by geothermal companies subsequent of their graduation; they constitute a highly significant group to the future of geothermal resource development.

CONCLUDING REMARKS

Our own judgment of the program is that it is progressing well. However, two aspects that need more attention are as follows:

1. Relating the results of research to identified technical problems at specific geothermal sites. As an example, it would be useful to know from industry how critical are concerns over mud damage at their specific development sites, how important are readings on wellhead enthalpy, and so on. Cooperation from industry in providing such feedback is vital.



XBL796-2001

Fig. 2 Summary diagram of well system and near-bore research projects.

2. Economics. Although conceived as an area of work in the original program plan, no effort has been put on this topic in keeping with the recommendation of the advisory group to GREMP. It is very difficult, therefore, to place other research in an economic framework and judge its importance with respect to the crucial questions of economics and geothermal resource development.

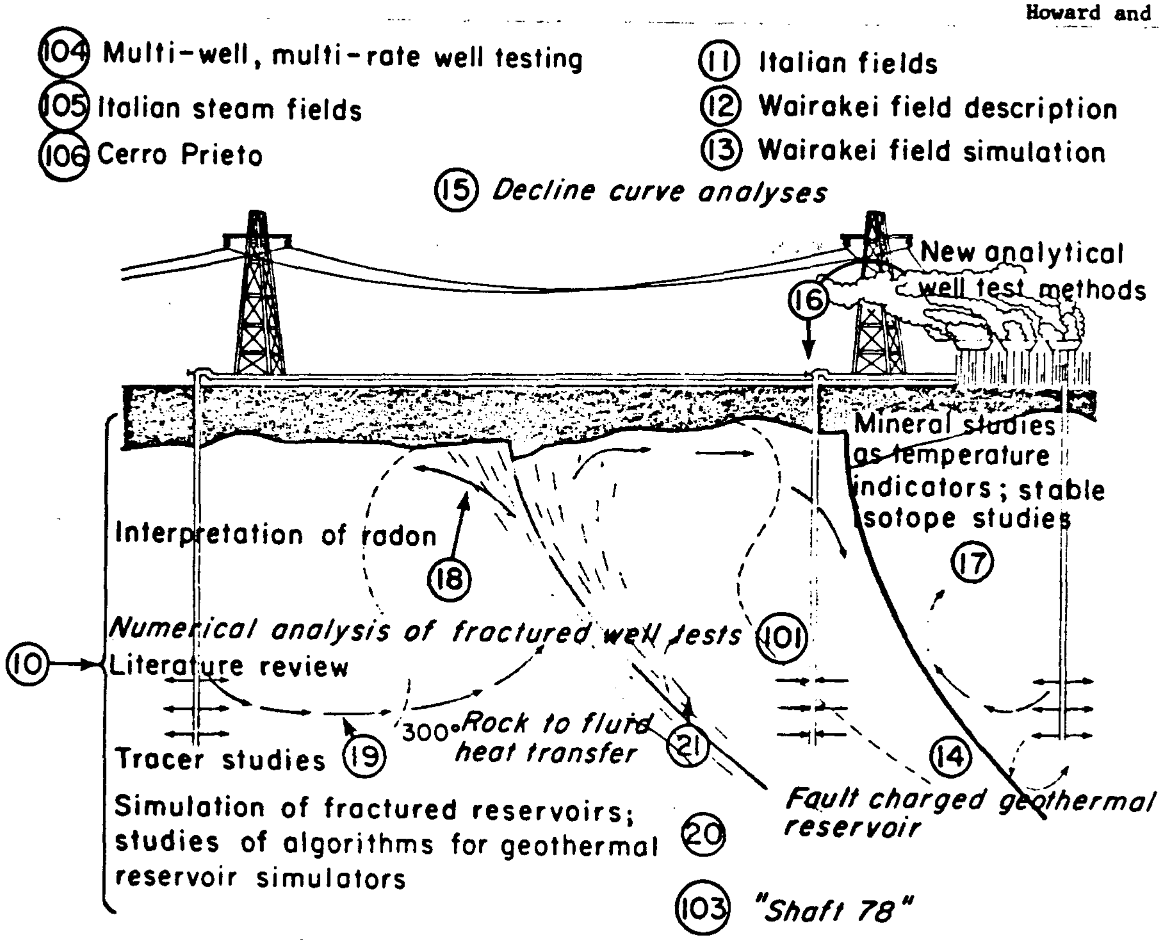


Fig. 3 Summary diagram of mainly field-wide research projects. XBL 795-7435

Future work of the program should emphasize the application of research and heavier support to problems of major economic consequence.

ACKNOWLEDGMENTS

This article was prepared for the U. S. Department of Energy under contract W-7405-ENG-48. We wish to thank Dr. J. W. Salisbury and his associates at DGE/HQ for their support to the program.

REFERENCES

Note: Space allows for listing of only final GREMP series documents. A complete bibliography, including referenced progress reports, is available from the authors.

Cliff, W. C., Apley, W. J., and Creer, J. M., 1979, Evaluation of potential geothermal well-head flow sampling and calorimetry methods: Lawrence Berkeley Laboratory, GREMP Series #7, 25 p. (LBL-9248).

Elders, W. A., Hoagland, J. R., Olson, E. R., McDowell, S. D., and Collier, P., 1978, A comprehensive study of samples from geothermal reservoirs: University of California, Riverside, UCR/IGPP-78/26, 264 p. (Also GREMP Series #4; LBL-9088).

Harrison, Roger and Randall, Georgia, 1979, Annotated research bibliography for geothermal reservoir engineering: Lawrence Berkeley Laboratory, GREMP Series #1, 261 p. (LBL-8664).

Kassoy, D. R., and Goyal, K. P., 1979, Modeling heat and mass transfer at the Mesa anomaly, Imperial Valley, California: Lawrence Berkeley Laboratory, GREMP Series #3, 171 p. (LBL-8784).

Lamers, Michael D., 1979, An appraisal of measurement methods for geothermal well system parameters: Lawrence Berkeley Laboratory, GREMP Series #6, 40 p. (LBL-9090).

Lawrence Berkeley Laboratory, Earth Sciences Division, 1977, Geothermal reservoir engineering management program plan (GREMP plan): Lawrence Berkeley Laboratory, LBL-7000, 136 p.

Pritchett, J. W., Rice, L. F., and Garg, S. K., 1978, Summary of reservoir engineering data: Wairakei geothermal field: Lawrence Berkeley Laboratory, GREMP Series #2, 25 p. (LBL-8669).

Pruess, Karsten, Zerzan, J. M., Schroeder, R. C., and Witherspoon, P. A., 1979, Description of the three-dimensional two phase simulator "SHAFT78" for use in geothermal reservoir studies: Soc. Petr. Engrs., AIME, Fifth symposium on Reservoir Simulation, Denver, Colo., 16 p.

Vetter, O. J., 1979, Scale inhibitor tests at East Mesa: Lawrence Berkeley Laboratory, GREMP Series #5, 52 p. (LBL-9089).

Table 1. Summary of Geothermal Reservoir Engineering projects supported by USDOE/DGE through Lawrence Berkeley Laboratory.

ID #	Brief project name	Contractor	Brief summary of work
1.	Status of reservoir related measurements *	Measurement Analysis Corp.	A comprehensive appraisal of measurement needs and instrumentation for geothermal applications has been completed, indicating that commercially available technology and instrumentation exists <u>in principle</u> for all wellhead and process plant measurement requirements, except two-phase flow (Lamers, 1979).
2.	Theoretical basis for James method	University of Hawaii	This project has just been started. Its purpose is to understand the theoretical basis of James empirical method for estimating mass flow and enthalpy (Cheng,1979).
3.	Measurement of enthalpy at wellhead	Battelle Pacific Northwest Laboratory	Several calorimetry methods for measuring geothermal wellhead enthalpies were evaluated. A mixing tee condenser was recommended when cooling water is available. When not, a multiphase tank was recommended. Work has started on engineering drawings of a sampling system and mixing tee condenser (Cliff et al., 1979).
4.	Measurements of noncondensible gases at wellhead	TerraTek	Engineering design of a device with the capability to monitor noncondensible gas concentrations continuously in geothermal discharges has been completed (Harrison et al., 1979).
5.	Control of calcite precipitation by additives *	Vetter Research	Scale inhibitor tests performed at Republic Geothermal Inc. East Mesa wells have shown that Dequest can economically eliminate calcite precipitation in the discharge flow stream (Vetter, 1979).
6.	Analysis of well tests of two-phase reservoir	Intercomp	Comparison of Intercomp's proprietary geothermal well bore and reservoir simulators with the experimental and numerical results from three other models has been completed. Data on two-phase well tests are currently being assembled for analysis (Aydelotte and Taylor, 1979).
7.	Formation damage of drilling mud	TerraTek	Laboratory simulation of drilling mud damage to geothermal reservoir rocks has been initiated. Parameters to be considered are pressure, temperature, reservoir fluid chemistry, mud composition, and time (Buttera, 1979).
8.	Relative permeability of steam and water	Stanford University	Relative permeability data have been collected by Counsil (1978).
9.	Calcite formation by inappropriate production practices	Republic Geothermal Inc.	Carbonate rich geothermal brine is being passed through containers of granular materials in order to evaluate the mechanism and rate of calcite precipitation within the pore space. The ultimate practical purpose of the activity is to plan remedial "acid jobs" on calcite-fouled geothermal wells (Michaels, 1979).
10.	Literature review of reservoir exploitation *	TerraTek	An annotated bibliography covering reservoir modeling, exploitation strategies, and interpretation of production trends has been prepared (Harrison and Randall, 1979).
11.	Study of the Travali Radicondoli geothermal areas in Italy	Stanford University	Geology and pressure-production history of Serrazzano reservoir have been reviewed. Bottomhole temperatures and pressures have been calculated from wellhead measurements. Areal distribution of pressure has been mapped for seven different times spanning the last 15 years. A conceptual model of Travali Radicondoli geothermal field was developed on the basis of the available field data (Miller et al., 1978).
12.	Data collection for the Wairekei field, New Zealand *	Systems, Science and Software	All geological, geochemical, geophysical, and wellbore data from January, 1953 to December 1976 has been collected and synthesized (Pritchett et al., 1978).
13.	Simulation of past and future performance at Wairakei, New Zealand	Systems, Science and Software	With the data collected and synthesized (#12 above), an attempt is under way to match the pressure and enthalpy history during past production of the Warakei field (Pritchett et al., 1979).
14.	Prototype of a fault-charged geothermal reservoir *	University of Colorado	A physical, viable mathematical model of an unexploited geothermal system has been constructed in terms of a fault zone controlled charging of a reservoir (Kassoy and Goyal, 1979).
15.	Review of decline curves appropriate to geothermal reservoirs	E. Zais and Associates	This project is to review decline curve procedures used in the petroleum industry, determine which procedures are applicable to geothermal systems, and establish a theoretical basis for applicability. Project has just started.
16.	New analytical well test methods for geothermal engineering	Stanford University	The utility of parallelipiped models has been investigated (Ramey et al., 1978).
17.	Studies of mineral facies and stable isotopes and their relations to geothermal reservoirs	University of California, Riverside	Cuttings and core samples, obtained from the six wells drilled during the year 1977 were studied and interpreted to define the current temperatures in the field (Elders et al., 1978).
18.	Understanding the significance of radon in geothermal reservoirs	Stanford University	The variation of radon associated with geothermal reservoir production has been analyzed and interpreted for several reservoirs throughout the world (Kruger et al., 1978).
19.	Studies of the use of tracers in geothermal reservoirs	(under negotiation)	
20.	Study of basic formulation of simulators of geothermal reservoirs	Princeton University	Multiphase flow equations have been derived for a deformable porous medium. Equations for heat and mass transfer in a fractured reservoir have also been formulated. A computer code BIFEPS (Block Interactive Finite Element Processed Scheme) has been developed to solve nonlinear transient problems with one or two governing equations in two or three dimensions. (Pinder et al., 1978).
21.	Studies of heat transfer from rock to fluid	Stanford University	Heat flow from rock to water has been studied as a function of a number of parameters including the size of rock fragments (Kruger et al., 1979).
22.	Vapor pressure lowering phenomena of geothermal fluids	Stanford University	The project demonstrated that vapor pressure may be lowered as a consequence of a number of chemical and petrophysical parameters (Miller et al., 1979).
23.	Absolute permeability of geothermal fluids	Stanford University	The effects of temperature and chemical composition of the rock types on relative permeability has been investigated (Miller, et al., 1978)
101.	Numerical analysis of well tests of fractured reservations	LBL	Analysis of fractured well response during testing using numerical models has been studied. Results compare favorably with analytical solutions (Narasimhan and Palen, 1979).
102.	Transient two-phase flow in geothermal bores	LBL	A code simulating transient two-phase flow in bores has been written and compared against limited field data (C. W. Miller, 1979).
103.	Geothermal reservoir simulator SHAFT 78	LBL	A code to simulate mass and heat transport in porous media has been written and applied to hypothetical and real examples (Pruess et al., 1979).
104.	Multiple well, variable rate well test analysis	LBL	The ANALYZE code has been proven capable of this kind of analysis (McEdwards, 1979).
105.	Study of Serrazzano Castelnuevo geothermal area, Italy	LBL	SHAFT 78 is being used to reproduce past performance and forecast reinjection of liquid (Schroeder et al., 1979).
106.	Study of the Cerro Prieto area, Mexico	LBL	A very comprehensive case study at Cerro Prieto is being carried out cooperatively with the Mexican government (Lippmann et al., 1978).

* Project completed.

TECHNICAL INFORMATION DEPARTMENT
LAWRENCE BERKELEY LABORATORY
UNIVERSITY OF CALIFORNIA
BERKELEY, CALIFORNIA 94720