

**STATUS OF GEOTHERMAL RESERVOIR ENGINEERING MANAGEMENT  
PROGRAM ("GREMP") - DECEMBER, 1979**

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## ABSTRACT

In the fall of 1976, 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 the management of a program of support of research related to geothermal reservoir engineering. Since its inception, this activity, known as "GREMP" has included 18 separate contracts on a variety of technical and scientific projects. Altogether, 23 distinguishable research topics have been addressed. Fourteen institutions, including eight private companies, have contracted with the program. Table 1, along with Figures 2, 3, and 4, summarizes the status of the work as of December, 1979.

All high priority elements of the original program that were assigned to LBL for implementation have been addressed except for investigations of "properties of materials." In the future the program should emphasize this neglected element as well as assure meaningful evaluation, preferably in the field, of the applicability of research supported to date.

## INTRODUCTION

The purpose of this paper is to review the Geothermal Reservoir Engineering Management Program ("CREMP") that has been supported by the U. S. Department of Energy, Division of Geothermal Energy, through Lawrence Berkeley Laboratory. The primary responsibility assigned to LBL was (1) to define and promote resolution of 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 establishment of an industrywide 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 led 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 describe, match 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.

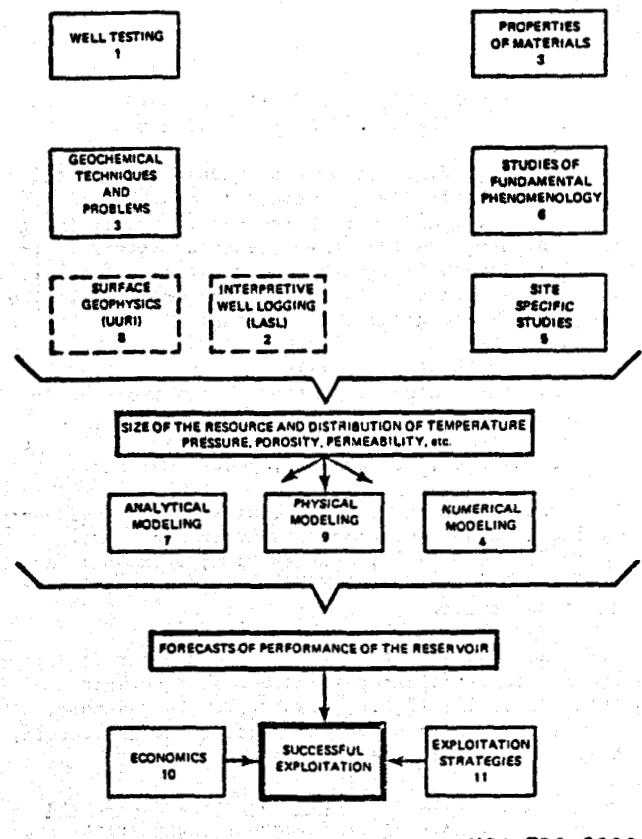


Fig. 1. Broad outline of geothermal reservoir engineering related research activities.

The program has been executed in a way consistent with the priorities laid down by the primarily industry advisory group which helped draft the planning document, namely LBL-7000. 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 responsibility for research on surface geophysics, and Los Alamos Scientific Laboratory has had the lead responsibility for well logging.

LBL in-house research in geothermal reservoir engineering has interfaced with the GREMP program in a complementary way. Details of the LBL in-house program are given in Lawrence Berkeley Laboratory, Earth Sciences Division, Annual Report 1978, LBL-8648 and the Annual Report 1979 (in preparation).

#### 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 data and other information related to geothermal reservoir engineering: Items 1, 10, 11, 12, 14 (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 measurement of interest to geothermal reservoir engineers: Items 3, 4 (Table 1). For example, item 4 concerns measurements at the wellhead of noncondensables in the flow stream.

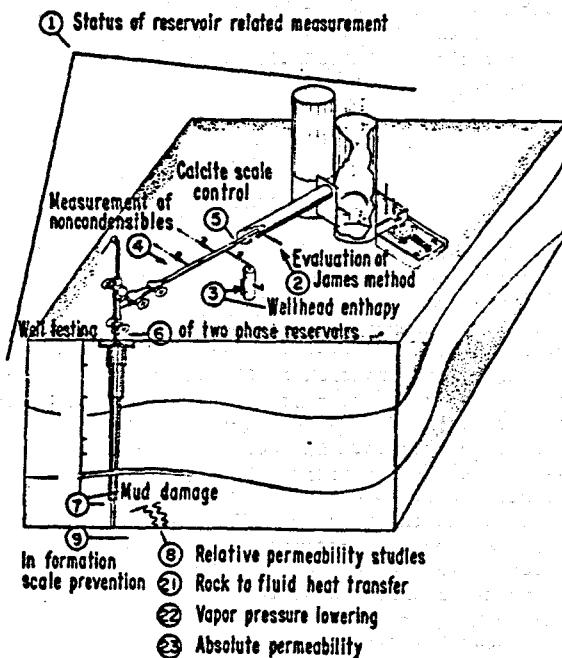
C. The analysis of measurements in order to define the characteristics of a geothermal reservoir: Items 2, 6, 16, 17, 18, (Table 1). For example, item 2 is concerned with evaluating the theoretical basis of the James method.

D. The generation of new insights and new data important to geothermal reservoir engineering practice: Items 5, 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 performance of the geothermal reservoir and bore system. Items 13, 20 (Table 1).

The projects relate to the original GREMP plan as shown in Figure 4. As indicated on the figure, five projects have been supported in well testing: six in geochemical techniques and problems, one in numerical modeling, two in site-specific studies, six in fundamental research, and two in analytical modeling. (The assignment of certain projects to one element or another could be debated, inasmuch as certain projects have features common to more than one element. For instance, Colorado could have been listed as a site-specific study or a numerical modeling study, but the principal feature of the work was its emphasis on an analytical model.) As categorized here, no work has been supported on properties of materials, physical modeling, economics, and exploitation strategies.

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 published by the program.



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

## SITES

- (11) Travali / Radicondoli fields
- (12) Wairakei field description
- (13) Wairakei field simulation

## WELL FLOW ANALYSIS

- (14) Decline curve analyses
- (15) New analytical methods

- (16) Literature review

## SIMULATORS

- (17) Algorithms for geothermal reservoir simulators

## STUDIES

- (18) Mineral studies as temperature indicators; stable isotope studies
- (19) Interpretation of radon
- (20) Tracer studies

- (14) Fault charged geothermal reservoir

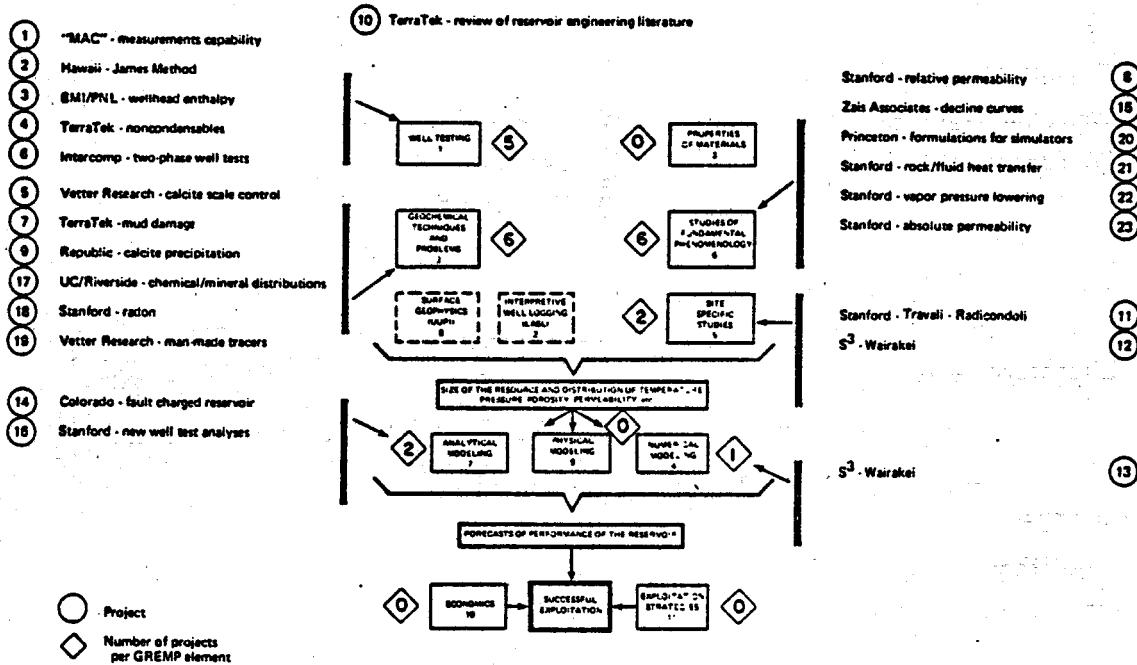
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Fig. 3. Summary diagram of mainly field-wide research projects.

## 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 borne out by several lines of reasoning. Forty organizations have submitted proposals to the program, and 14 have been awarded contracts. Contractor organizations, including LBL, have participated actively

in professional society meetings. Altogether, more than two dozen students have been recognized to be part of the program through reference to them in contracts. A number of students have been employed by the geothermal industry subsequent to their graduation; they constitute a highly significant group to the future of the geothermal industry.



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Fig. 4. Summary of projects with respect to elements of original GREMP plan.

#### CONCLUDING REMARKS

Three aspects of the program that need further consideration are as follows:

1. Relating the results of research to specific identified technical problems at 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.
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 question of economics and geothermal resource development.

3. Capability to forecast reservoir performance. Perhaps the "bottom line" for reservoir engineering is the capability to reliably forecast reservoir and well performance. At least two steps are required in order to confirm that this capability exists: (1) demonstrate that, because of its sound theoretical basis, a simulator does, in fact, model a completely known real, controlled physical experiment and (2) demonstrate the application of the simulator to a real field problem and verify it as well as data with which to verify it allow.

How these considerations will be resolved is yet to be decided. In the future, the GREMP program will probably emphasize the demonstration of available research results. Presumably such emphasis can be done while keeping in mind the importance of addressing more fundamental questions and topics on which technological advances are built. Additional effort on conceptualizing properties of materials (e.g., relative permeability as a function of temper-

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 in principle for all wellhead and process plant measurement requirements, except two-phase flow (Lamers, 1979).
2.	Theoretical basis for James method	University of Hawaii	The purpose of this project 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 reviewed. A mixing tee condenser was recommended for use when cooling water is available. When not, a multiphase tank was recommended. Work on engineering drawings of a sampling system and a mixing tee condenser (Cliff et al., 1979a) have been prepared (Cliff et al., 1979b).
4.	Measurements of noncondensable gases at wellhead	TerraTek	Engineering design construction and testing of a device with the capability to monitor noncondensable 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	Favorable comparison of Intercomp's proprietary geothermal wellbore and reservoir simulators with the experimental and numerical results from three other models has been completed. Data on two-phase well tests have been assembled for analysis (Aydelotte and Taylor, 1979) and the Hawaiian well HCP-4 has been studied.
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 (Butters, 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 better 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 Wairakei 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 and subsidence history during past production of the Wairakei 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).

Table 1. Summary of Geothermal Reservoir Engineering projects supported by USDOE/DCE through Lawrence Berkeley Laboratory (continued).

ID#	Brief project name	Contractor	Brief summary of work
15.	Review of decline curves appropriate to geothermal reservoirs	E. Zais and Associates	The purpose of 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.
16.	New analytical well test methods for geothermal reservoirs	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	Vetter Research	A program of literature review and laboratory evaluation of tracers suitable for use in geothermal reservoirs has been initiated.
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).

\* Project completed.

#### ACKNOWLEDGEMENTS

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Note: A complete bibliography, including referenced progress reports, is available from the authors.

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