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## EARTH SCIENCES DIVISION

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BRINE INJECTION STUDIES

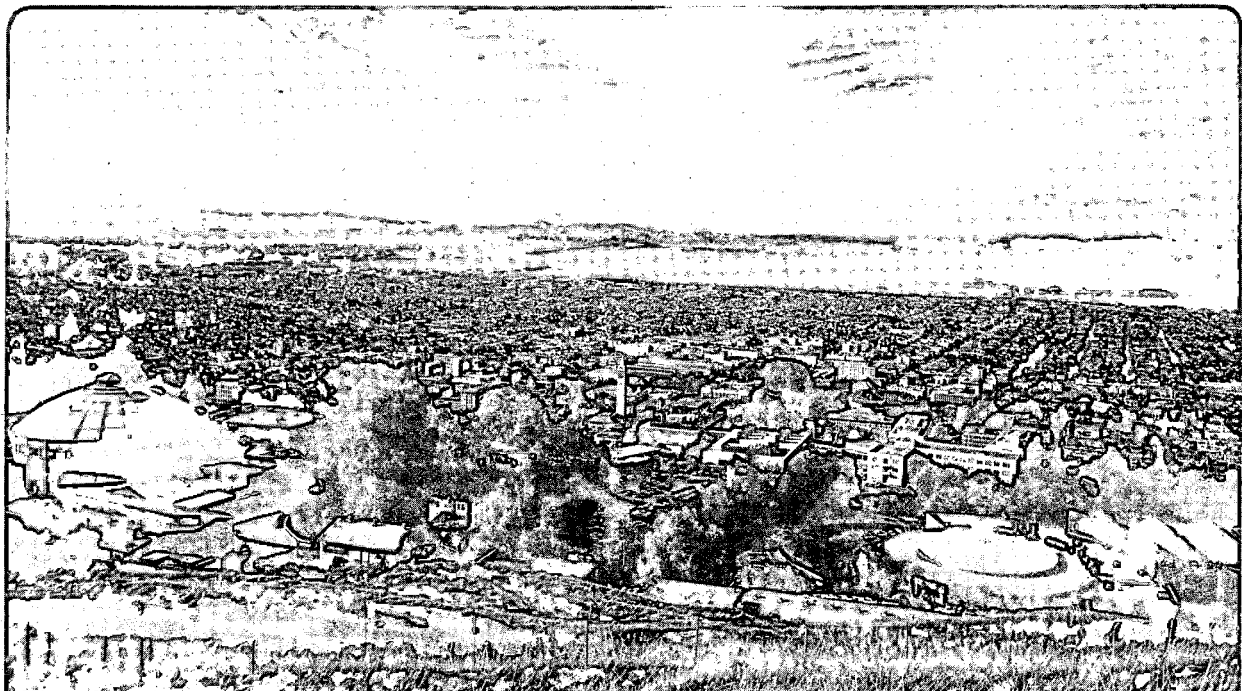
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# Brine Injection Studies

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## ABSTRACT

The program of the Lawrence Berkeley Laboratory in Brine Injection Technology is comprised of field and theoretical activities. Emphasis is given to the study of migration of injection fluids and compositional effects in the reservoir, and optimizing the heat extraction from geothermal systems. A joint injection test program with industry has also been initiated. The results of the FY1985 effort and the proposed plans for FY1986 are described.

## INTRODUCTION

The overall purpose of the Lawrence Berkeley Laboratory Brine Injection Project is to develop and demonstrate methods for predicting, monitoring and analyzing the short- and long-term response of geothermal reservoirs to fluid reinjection. The project addresses the main reservoir engineering issues in brine injection (Table 1), which can be summarized by the following three statements: (1) predict, control and monitor the movement of the injection plume, (2) maintain, and if possible increase, the injection capacity of the wells and (3) optimize the production-injection system to enhance the heat extraction from the reservoir and reduce thermal degradation of producing wells.

## SUMMARY OF MOST IMPORTANT FY1985 ACTIVITIES

*Modeling of sharp fronts.* Numerical dispersion is a serious problem in modeling sharp (thermal or compositional) fronts associated with injection plumes. A second-order upwind/central difference method for convection-diffusion type of equations that greatly reduces numerical diffusion errors has been developed (Lai et al., 1985). On Figure 1 a comparison between the sharpness of a modeled front using the conventional upwind-difference numerical scheme (graphs on the left) is compared, for different injected volumes, with that obtained with the new approach (graphs on the right). A much sharper front, that closely matches analytical results, is given by Lai et al.'s method.

Table 1. Main Issues In Brine Injection

- Prediction and monitoring of migration of injection fluids
- Maintaining well injectivities
- Analysis of heat extraction and compositional effects in geothermal reservoirs during injection
- Development and improvement of mathematical tools to model processes relevant to the migration of injected fluids in the reservoir

*Compositional Effects.* We developed the capability of modeling heterogeneous reactions between solid phases and gaseous components under geothermal reservoir conditions which has been applied to study the origin of CO<sub>2</sub> in the Larderello field (Pruess et al., 1985). This effort complements our previous modeling work on H<sub>2</sub>O/CO<sub>2</sub> mixtures for different phase compositions (O'Sullivan et al., 1985).

The dissolution and precipitation of silica in nonisothermal systems are being studied, including the corresponding changes in reservoir porosity and permeability (Lai et al., 1985b; Verma and Pruess, 1985). Equilibrium as well as kinetic relationships for silica-water reactions have been developed and incorporated into existing LBL computer codes.

*Heat Extraction Studies.* This year we completed the modeling of Stanford's heat extraction experiments using the method of "multiple interacting continua" (MINC; Pruess and Narasimhan, 1985). A chapter of a Lam et al. (1985) report, describing the LBL modeling code and involvement in the project, was contributed by K. Pruess.

To more accurately describe fractured geothermal reservoirs the MINC method was extended to include variations in fracture spacing. This will allow a more realistic modeling of the heat transfer between irregularly shaped rock blocks and adjoining fractures.

*Analysis of Injection Test in Fractured Reservoirs.* Models to analyze injection tests in geothermal systems have to consider nonisothermal effects and the fractured nature of the reservoir; otherwise wrong permeability-thickness products will be obtained. Cox and Bodvarsson (1985) studied pressure transients resulting from nonisothermal injection into horizontal and vertical fractures with variable rock matrix and fracture parameters (Figure 2). They show that the pressure is greatly controlled by the movement of the thermal front through the fractures, because of the temperature-dependent fluid properties. These effects are quite different than those derived for porous systems because of unlike thermal front advance rates. This study also describes differing pressure data analysis procedures that depend on the geometry (vertical versus horizontal) of the fractures and the properties of the injected and reservoir fluids.

*Evaluation of Composite Reservoir Systems.* A new technique was developed for evaluating well interference test data in radially symmetric composite reservoirs (Benson and Lai, 1985). By analyzing variations in the apparent storage coefficient, both the mobility ( $k/\mu$ ) and the size of the inner region can be calculated. The technique is particularly useful for evaluating heterogeneous systems where the intersection of several faults or hydrothermal alteration has created a zone of high (or low) permeability region in the center of geothermal field. The method has been applied to characterize the Klamath Falls, Oregon, system (Figure 3).

*Joint DOE-Industry Injection Tests.* In collaboration with Magma Power Company and Dow Chemical USA, LBL began an injection monitoring program at the East Mesa KGRA. LBL is interpreting falloff test data being collected by the operators and is designing future joint injection and falloff tests. LBL is also evaluating wireline log data to determine the stratigraphy and identify fracture zones that might intersect a deeper injection well (Well 84-7).

#### PROPOSED PLANS FOR FY1986

An outline of LBL's FY1986 Brine Injection Program as proposed to DOE is given below. The final program will be determined based on discussions between DOE and LBL program managers.

##### Subtask 1: Migration of Injection Fluids

- 1A. Perform laboratory experiments to study dispersion of phase fronts.
- 1B. Improve techniques for resolving chemical fronts.
- 1C. Demonstrate a numerical method for explicitly tracking phase fronts.
- 1D. Perform generic studies to find optimal injection well depths and locations.

##### Subtask 2: Heat Extraction Efficiency

- 2A. Continue development of the MINC-method for reservoirs with arbitrary fracture distributions.
- 2B. Develop methods for determining fracture porosities.

##### Subtask 3: Compositional and Geomechanical Effects

- 3A. Implement a more realistic description of brines into numerical codes (non-condensable gases, dissolved solids, chemical reactions).
- 3B. Perform generic studies of compositional effects in injection (including rock-fluid interactions, mixing of waters of different composition).
- 3C. Investigate and evaluate the occurrence of thermal stress cracking near injection wellbores.

##### Subtask 4: Field Case Studies

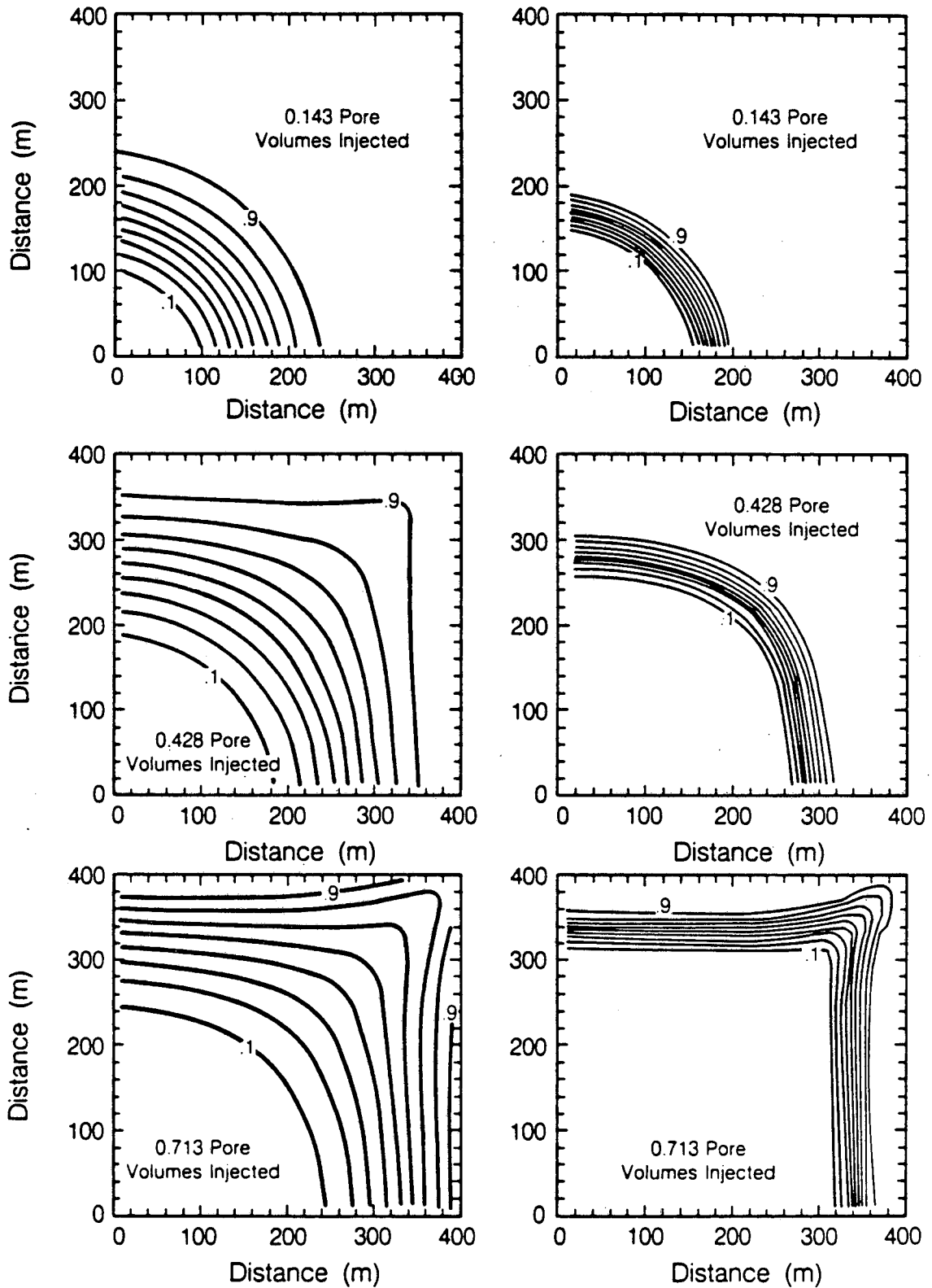
- 4A. Apply the MINC-method to a "real" fractured porous media reservoir.
- 4B. Design, implement and analyze injection tests in porous or fractured media reservoirs (subject to field access).

#### ACKNOWLEDGEMENTS

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Figure 1. Comparison between results using the conventional first-order upwind difference scheme (left column graphs) and the monotonized upwind central difference scheme of Lai et al., 1985b (right column graphs). Fluid is injected in the lower left corner and extracted from the upper left corner of the system, lines represent isocons.

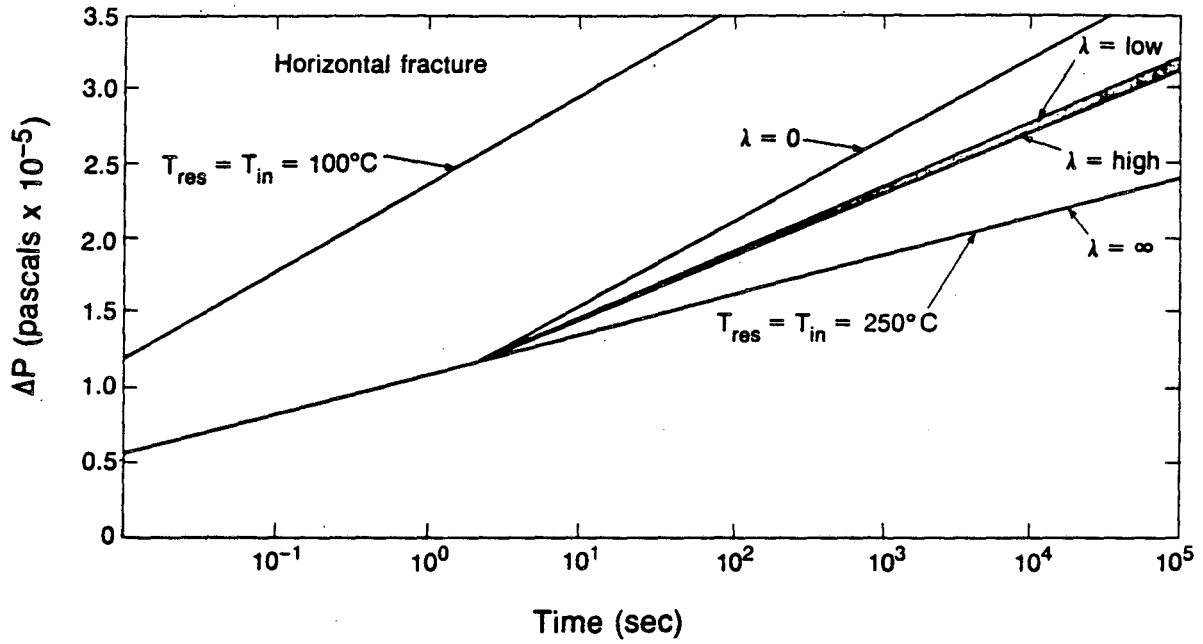


Figure 2. Pressure transients data for nonisothermal injection into a horizontal fracture (Cox and Bodvarsson, 1985).

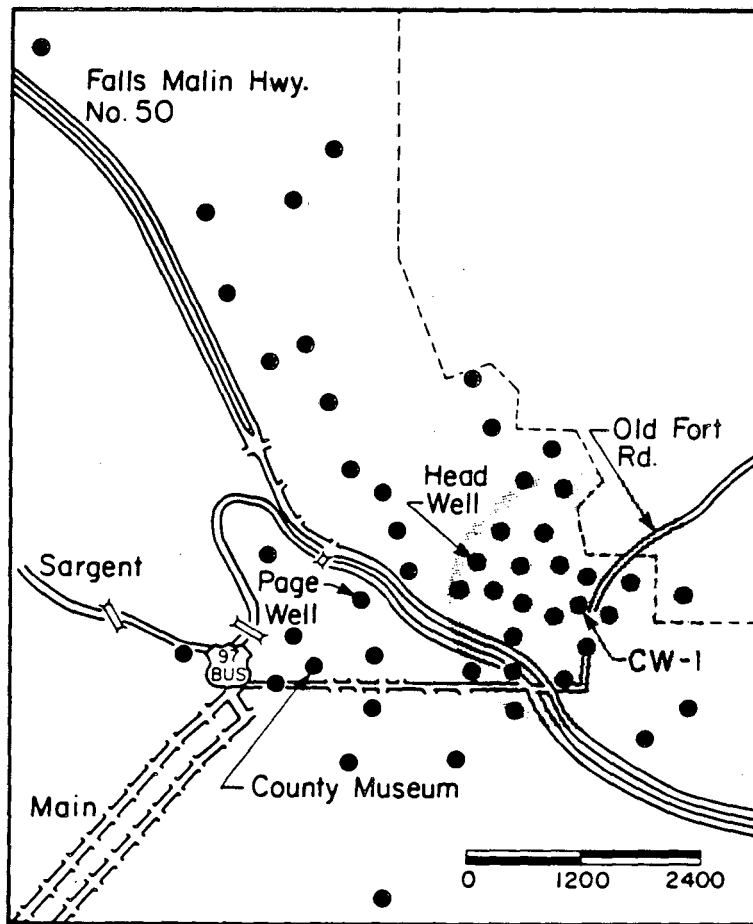


Figure 3. High-permeability region inferred in the Klamath Falls geothermal field based on the composite-reservoir analysis of Benson and Lai (1985).

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