SGP-TR-92

- Injection Technology - Geothermal Reservoir Engineering Research at Stanford

Principal Investigator:
Roland N. Home

September 1985

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October 1, 1984 through September 30, 1985

Stanford Geothermal Program
Interdisciplinary Research in
Engineering and Earth Sciences
STANFORD UNIVERSITY
Stanford, California

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PREFACE

The Stanford Geothermal Program conducts interdisciplinary research and training in engineering and earth sciences. The central objective of the Program is to carry out research on geothermal reservoir engineering techniques useful to the geothermal industry. A parallel objective is the training of geothermal engineers and scientists for employment in the industry. The research is focused toward accelerated development of hydrothermal resources through the evaluation of fluid reserves, and the forecasting of field behavior with time. Injection Technology is a research area receiving special attention. The Program is geared to maintain a balance between theoretical, laboratory, and matching field applications.

Technology transfer is an integral part of the Stanford Geothermal Program. Major activities include a Geothermal Reservoir Engineering Workshop held annually, and weekly Seminars held throughout the academic year. The Workshop has produced a series of Proceedings that are a prominent literature source on geothermal energy. The Program publishes technical reports on all of its research projects. Research findings are also presented at conferences and published in the literature.

Geothermal reservoir engineering research at Stanford has gained considerable breadth through the Program's international cooperative projects, There are research agreements with Italy, Mexico, New Zealand, and Turkey. These international projects provide a wide spectrum of field experience for Stanford researchers, and produce field data with which to develop and test new geothermal reservoir engineering techniques.

The Stanford Geothermal Program was initiated under grants from the National Science Foundation in 1972 and continued under contracts from the Ener-

gy Research and Development Administration and the subsequent Department of Energy since 1977. This year, the Reservoir Technology activities are included in the Fifth Annual Report to the Department of Energy under contract DE-AC03-80SF11459, which was initiated in fiscal year 1981. The Injection Technology activities are the subject of this report and are included in this First Annual Report to the Department of Energy under contract DE-AS07-84ID12529. The report covers the period from October 1, 1984 through September 30, 1985.

The successful completion of the Stanford Geothermal Program's objectives depends on significant help and support by members of federal agencies, the geothermal industry, national laboratories, and university programs. These are too many to acknowledge by name. The major financial contribution to the Program is the Department of Energy through its San Francisco and Idaho offices. We are most grateful for this support and for the continued cooperation and help we receive from the agency staff.

Roland N. Horne

1. INTRODUCTION

The Injection Technology portion of the Stanford Geothermal Program in fiscal year 1985 was divided into several task areas, as defined in the Department of Energy contract DE-AS07-84ID12529. Three of the task areas were carried out within the Petroleum Engineering Department and one within the Civil Engineering Department.

The injection of spent geothermal fluids has rapidly become a pressing research problem in reservoir engineering. Although injection has the potential of maintaining reservoir pressure, world-wide experience from liquid-dominated fields indicates that rapid thermal breakthrough can occur. The cold fluid short-circuits from the injection well to production wells along high conductivity fractures. A powerful method for investigating such flow is the use of external tracers. A balance between theoretical and experimental studies is sought. One goal is to develop new methods of observing reservoir behavior and to test these new methods in the field.

SECTION 2. INJECTION TECHNOLOGY

SECTION 2.1 - EFFECTIVE TAYLOR DISPERSIVITY IN A FRACTURE

This project is under the direction of principal investigator Prof. Roland N. Home, and research assistant Lawrence W. Bouett.

The experimental work begun by Gilardi **(1984)** to investigate Taylor dispersivity in a fracture is continued in the present work; however new data acquisition hardware has been obtained to facilitate the experimental procedure.

The experimental apparatus is a Hele-Shaw cell (Fig. 2.1) through which a tracer solution is flowed as a step input. The advance of the front is monitored by three parallel rows of **thirty-two** electrodes each. Concentration of the tracer at each electrode is measured by a KEITHLEY/das Series 500 Data Acquisition System as a voltage. A software driver has been written to scan, record and organize the raw data. Curve fitting of the data will be performed as before by the VARPRO curve-fitting subroutine. Data acquisition rates with the new hardware and driver can be as much as twice as high as with the previous system, with the same 12-bit accuracy.

The KEITHLEY/das Series 500 Data Acquisition System comprises a box external to a COMPAQ microcomputer, in which **are** a self-contained power supply and ten slots for a variety of circuit boards or cards. The boards used in the current configuration are an Analog Measurement Module (AMM1), an Analog **Output** Module (AOM1) and three **Analog** Input Modules (AIM3's). The **AMM1** card performs the functions of analog signal conditioning and switching and **A/D** conversion, The AOM1 card provides high-speed analog **output** through its own D/A converter, Each AIM3 card offers 32 channels of single-ended input and provides high-speed multiplexing and gain amplification.

The software driver is completely menu-driven and permits investigation of tracer front propagation not only in one dimension but also in two dimension$. This means that a broader investigation may be undertaken than was previously possible.

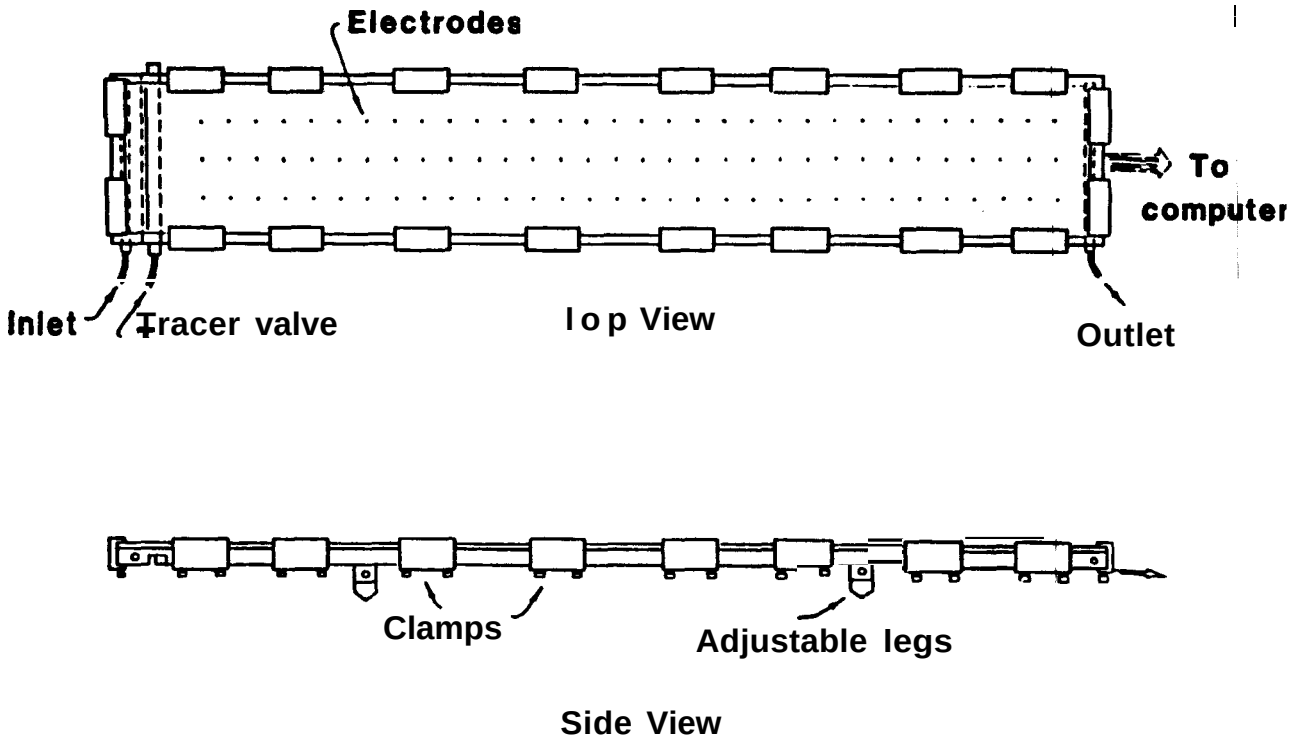

Figure 2.1: Hele-Shaw model of fracture flow

The menu-driven software driver has been written and tested successfully using dummy input and output data. It contains several new input and output options not previously available such as specifying the length of the run, delay between data sets, frequency of screen updating of data, data backup and method and timing of data reorganization. Input data is not processed until after a run is completed, thus allowing a scan of the electrodes in as brief a time as possible. Scan time of all 96 electrodes is of the order of 0.200 seconds. The new data acquisition hardware has been installed, calibrated and tested successfully using the new driver.

A calibration program has been written and a test stand has been built so that individual electrode performance may be monitored. It is anticipated that precise error analysis may then be performed following an experimental run.

Circuit boards are being constructed which will permit the analysis of either one- or two-dimensional flow without further modification. This means that as experimental investigations proceed the data acquisition system will require no further modification; only the flow apparatus will have to be reconfigured to suit the flow regime under investigation.

The problem of the sagging of the glass upper plate described by Gilardi will be solved by the construction of a steel frame Blanchard ground to within 0.001 inch to which the glass is attached. The frame prevents the glass from deforming during an experimental run yet permits the investigator the visual capability required to clear the apparatus of air bubbles before a run.

SECTION 2.2 - ANALYSIS OF INJECTION-BACKFLOW TRACER TESTS

This project is under the direction of principal investigator Prof. Roland N. Horne, and research assistant Ibrahim Kocabas.

Tracer tests have been the basic means of characterization of the flow mechanisms through various reservoir rocks. So far, interwell tracer tests have been proven to be a useful technique to determine the interconnections between the injectors and the producers. The single well (injection-backflow) tests, on the other hand, have been proposed as tools for characterizing the flow field within the radius of influence around the injectors.

This study has been concerned with the quantitative interpretation of the tracer return profiles obtained from injection-backflow tests. So far, three basic models have been developed to represent the tracer transport through fractured media. The first model assumes a Taylor Dispersion within the fracture and neglects the interaction between the tracer in the fracture and the adjacent rock matrix. The second one, on the other hand, considers the simultaneous diffusion of the tracer in and out of the matrix and assumes that only convection takes place in the fracture. Then the third model combines these two processes - dispersion within the fracture and diffusion into the adjacent matrix.

The governing equations of the tracer transport according to these models have been derived and solved for linear, one-dimensional and unidirectional flows previously in earlier projects of the Stanford Geothermal Program. However, these solutions are not applicable to the injection-backflow tracer tests, because of the the change in the flow direction during the backflow periods. In this work, the convection-dispersion and matrix diffusion models have been applied to the analysis of the return profiles from the injection-backflow tracer tests. First, solutions of governing equations for linear, unidirectional and one-dimensional flows were determined. Then the necessary changes in the derivation were made to account for the change in flow direction during

the backflow period. Finally these equations were solved with the appropriate initial and boundary conditions according to two different injection conditions - continuous injection and slug injection cases.

The main objective of the study is to be able to recover the parameters governing the tracer transport mechanism within the reservoir. A nonlinear optimization technique was employed to fit the models to the return profiles so that the optimum values of the governing parameters can be determined. The optimization process was performed by using a program VARPRO developed by the Computer Science Department at Stanford. For all of the solution equations, there is only one nonlinear parameter to be recovered from the curve fitting. The nonlinear parameter for the convection dispersion model is :

$$a = \frac{u}{\sqrt{\eta}} = \frac{u}{\sqrt{\frac{2}{105}\frac{\delta^2 u^2}{D}}} = \sqrt{\frac{105}{2}\frac{D}{\delta^2}}$$

where

δ : fractureaperture

u : average flow velocity within the fracture

D : molecular diffusivity

η : effective Taylor dispersivity

Also, for the matrix diffusion model the nonlinear parameter is given by,

$$\alpha = \frac{\sqrt{D_e \phi}}{\delta}$$

where

D_e : effective diffusivity

ϕ : porosity of the adjacent matrix

δ : fractureaperture

In attempt to test the method with real field data, the solution equations for continuous injection cases of both models were applied to four sets of field data obtained

from injection-backflow tracer tests at Raft River and East Mesa geothermal fields. From these analyses, the first observation made is that the matrix diffusion model gives better fits than the convection-dispersion model in every case. As far as the convection dispersion model itself is concerned, it was found to give far better results on the short injection period tests than it did when the injection period was longer.

The matrix diffusion model, on the other hand, fits all sets of the data equally well and the fits are excellent. However, there is one important point to be considered. Since D_e, a parameter independent of the nonlinear dependent parameter a, is a function of temperature, porosity, molecular diffusivity and the geometry of the rock and since it was assumed that the porosity and the fracture aperture is constant along the path travelled by the tracer fluid, the values of the nonlinear parameters obtained from the analysis of the data sets of the same well have to be the same. However, it was found that the numerical values obtained for the same parameter were not always the same, even though the fits to both sets were excellent. It was observed that the larger the difference between the two injection periods the higher the difference in the numerical values of the same parameter. The study considered the reason for the difference and which value should be considered as the true value. The reason for the different numerical values was found to arise from the effects of the injection periods. Since the assumption of constant fracture aperture and uniform porosity is not absolutely true, the analysis obtains an average value of the physical properties over the distance travelled by the tracer fluid. Therefore, the longer the injection period the longer the distance travelled by the fluids and, of course, the closer the the results to the true average values.

Finally, the poor fits obtained from the application of the convection-dispersion model to the long injection period test data can be explained as follows. If the injection time is short, then the amount of the tracer diffusing into the matrix will be small, Hence, the contribution to the dispersion within the fracture will come mainly from the

Taylor dispersion. As the injection period increases, the effect of the interaction between the adjacent matrix and the fluid in the fracture becomes the dominant mechanism of dispersion. Since the convection-dispersion model does not include the matrix diffusion, it fails to give good fits to the data obtained from the long injection tests.

Figures 2.2 and 2.3 show two typical results of curve fitting the continuous injection case solutions of both models to the data obtained from a well in East Mesa. Since these are the best fits in each case, comparison of the two figures shows the better match obtained with the matrix-diffusion model.

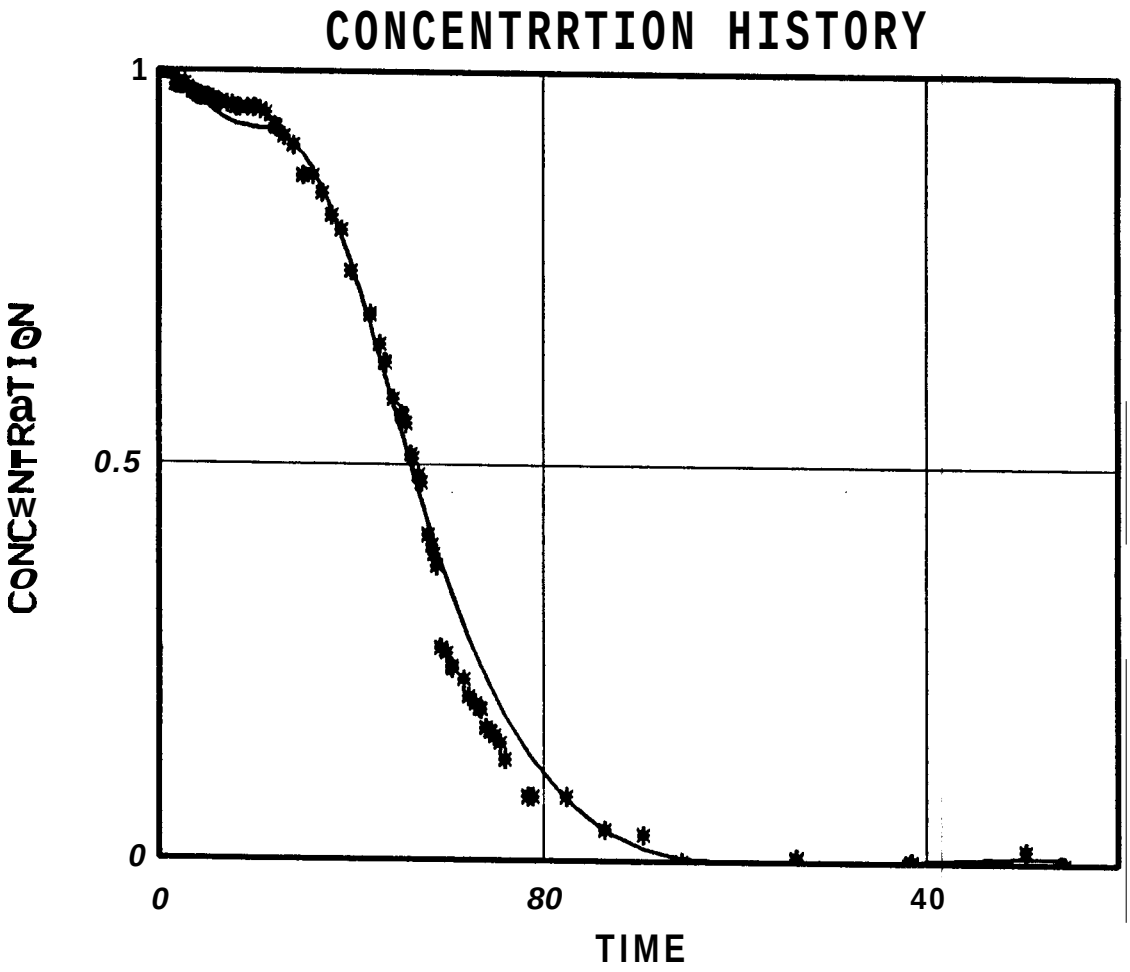

Figure 2.2: Match **to East Mesa data using** matrix **diffusion** model

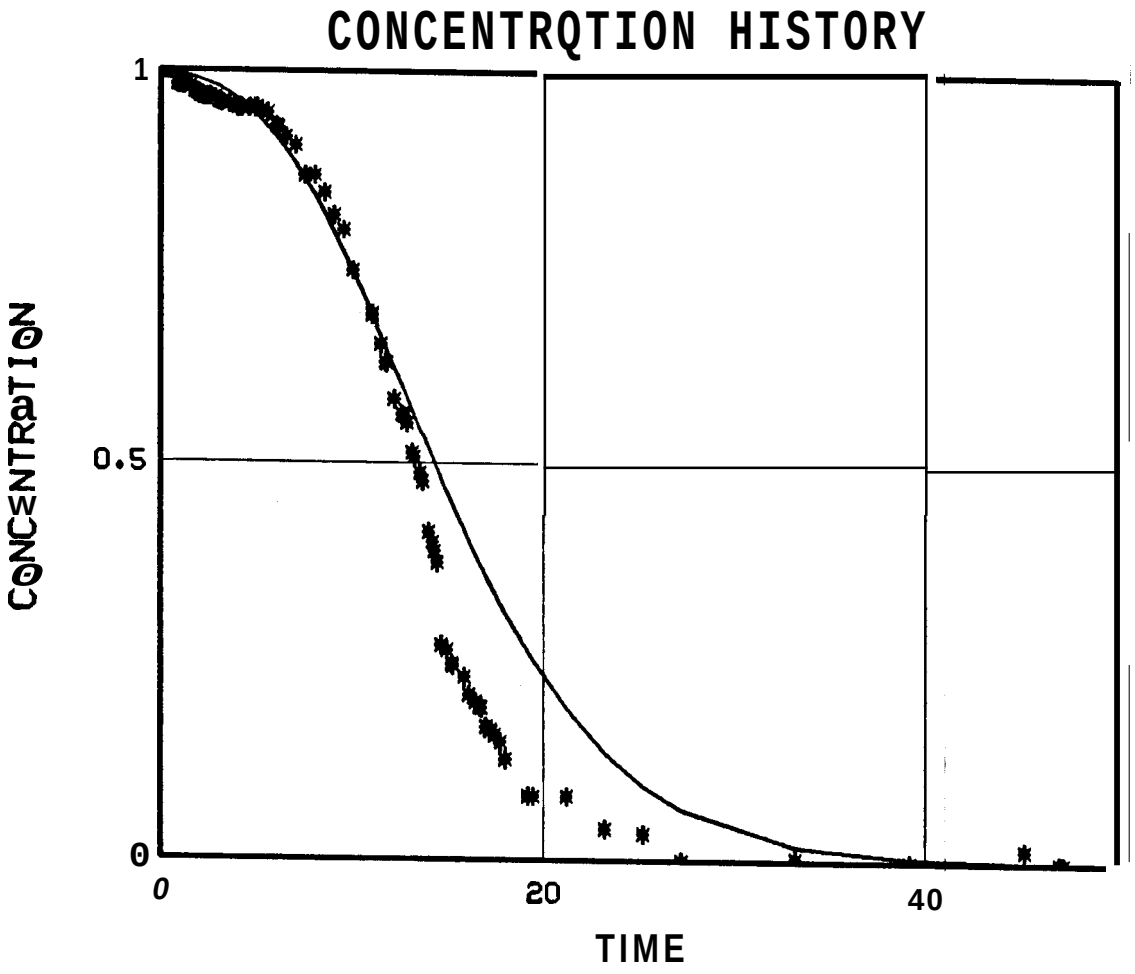

Figure **2.3:** Match to East Mesa **data using** correction-dispersion mode]

SECTION 2.3 - ACTIVABLE TRACERS

This project is under the direction of faculty associate Prof. Paul Kruger, and research assistant C. Chrysikopoulos.

A major effort completed during the current year was the study of the thermal stability of indium tracer chelated with the organic ligands ethylenediaminetetraacetic acid (EDTA) and nitrilotriacetic acid (NTA). The choice of the element indium as an activable tracer to enhance sensitivity in reinjection studies was based on a combination of the criteria defining an ideal geothermal-liquid activable tracer. The two chelating agents form strong, soluble complexes with a variety of elements, and were chosen to enhance the solution stability of the selected tracer. The properties of these organic ligands at elevated temperatures required evaluation. Venezky and Moniz (1969) reported that EDTA in aqueous solutions is stable up to 200°C. They observed a secondary degradation process at this temperature in which the decomposition products retain chelating ability. At higher temperatures primary degradation occurs forming products without evident chelating characteristics. Martell et al. (1975) reported that NTA does not cleave at temperatures up to 260°C but decomposes above 290° through a stepwise decarboxylation. Since information available in the literature is based primarily on free organic ligands, the thermal stability of indium chelated complexes required experimental determination.

The study concentrated mainly on the laboratory investigations needed to provide a linkage between current information about indium chelated tracers and their unknown behavior in liquid-dominated geothermal systems. The experimental work consisted of two parts. First, batch experiments were carried out at room temperature to evaluate and compare the time stability of indium solubility as EDTA and NTA complexed ions. Second, thermal stability measurements of the indium chelates were performed for reservoir temperatures of 150, 200, and 240°C, to determine thermal decomposition rates from the experimental data.

Gold plated pressure vessels of approximately 40-ml volume, provided by the U.S. Geological Survey, Menlo Park, were employed for the high temperature experiments. The choice of gold plated pressure vessels was dictated by the desire to minimize interactions between tracer solution and vessel wall. The pressure vessels were housed in an air-bath at constant temperature within ±0.5°C. The samples were activated with the Stanford Linear Accelerator Center (SLAC) ^{252}Cf neutron irradiatioh source at a thermal neutron flux of $2x10^{6}$ n cm^{-2} s^{-1}. Measurement of 54.12 minute ^{116m}In radioactivity was performed by y-ray NaI(Tl) scintillation spectroscopy with a multichannel analyzer in the Stanford Environmental Engineering laboratory.

The indium standard solution was prepared by dissolving high-purity indium metal in concentrated HNO_3. The disodium salts of analytical reagent grade EDTA and NTA were used for the ligand standards. Milli-Q reagent grade deionized water was used as solvent. The indium solution was acidified to reduce adsorption onto container walls. The pH of the organic ligand standards was adjusted to a pH slightly above the last pK value of the corresponding ligand, because chelating agents are polyprotic acids and usually only the fully deprotonated form of the acid gives complexes with the metal ion. The indium tracer solutions were formed with a chelon to metal mole ratio of 10 to increase the stability of the indium-chelate complexes.

The time stability experiments at room temperature (20-22°C) were conducted over a two month period. Stock solutions of indium chelated tracers at a concentratiod of 505 mg/l were prepared and stored in glass containers with ground glass stoppers! At regular intervals two 5-ml samples of tracer solution were transferred by pipette from each glass container to 15-ml polystyrene centrifuge tubes. After centrifugation at 3500 rpm for ten minutes, 2-ml of the supernatant liquid were transferred from each centrifuge tube to 6-ml Wheaton scintillation capsules for neutron irradiation and γ-ray spectroscopy. The thermal stability high temperature experiments were conducted over 20 to 30 day periods. The pressure vessels were filled with 10-ml of tracer solutioq

and were sealed with teflon discs to prevent sample leakage. Geothermal reservoir temperatures were simulated with an air-bath. The vessels were taken from the air-bath and quickly quenched by immersion in a cool water-bath. The samples were transferred to centrifuge tubes and the detection of the soluble indium concentration was performed with the same analytical procedure as the one described for the room temperature experiments.

Results of the tracer time stability investigations are given in parts A and B of Figure 2.4. The average concentration of 502 mg/l indicates that there was no change in the soluble indium concentration during the experimental time. Any unchelated indium ions would be expected to adsorb onto container walls and to precipitate as indium hydroxide. The precision of the analytical procedure was estimated to be ±14 mg/l. The error bars express only the counting error of the radioactivity measurements.

The experimental data from the high temperature runs are given in parts C and D of Figure 2.4. At 150°C, both chelated tracers were stable over the experimental period of 20 days. At 200°C, the soluble indium concentration of the InEDTA tracer solutions remained constant for 16 days, and then decreased with a measured rate constant of $k_{obs} = 0.09\ d^{-1}$. The time lag before the occurrence of any significant change in the total soluble indium concentration can be attributed to the secondary degradation products of EDTA. The thermal decomposition of InNTA at 200°C showed a first order reaction with a measured rate constant of $k_{obs} = 0.16\ d^{-1}$. At 240°C the data were not suitable for quantitative analysis because the time required for the first few pressure vessels to reach air-bath temperature was an appreciable fraction of each heating period. Nonetheless, both indium chelated tracers showed rapid decomposition with rate constants greater than $1.8\ d^{-1}$.

From the experimental results it was concluded that the organic ligands EDTA and NTA form stable (time persistent) complexes with indium at room temperature.

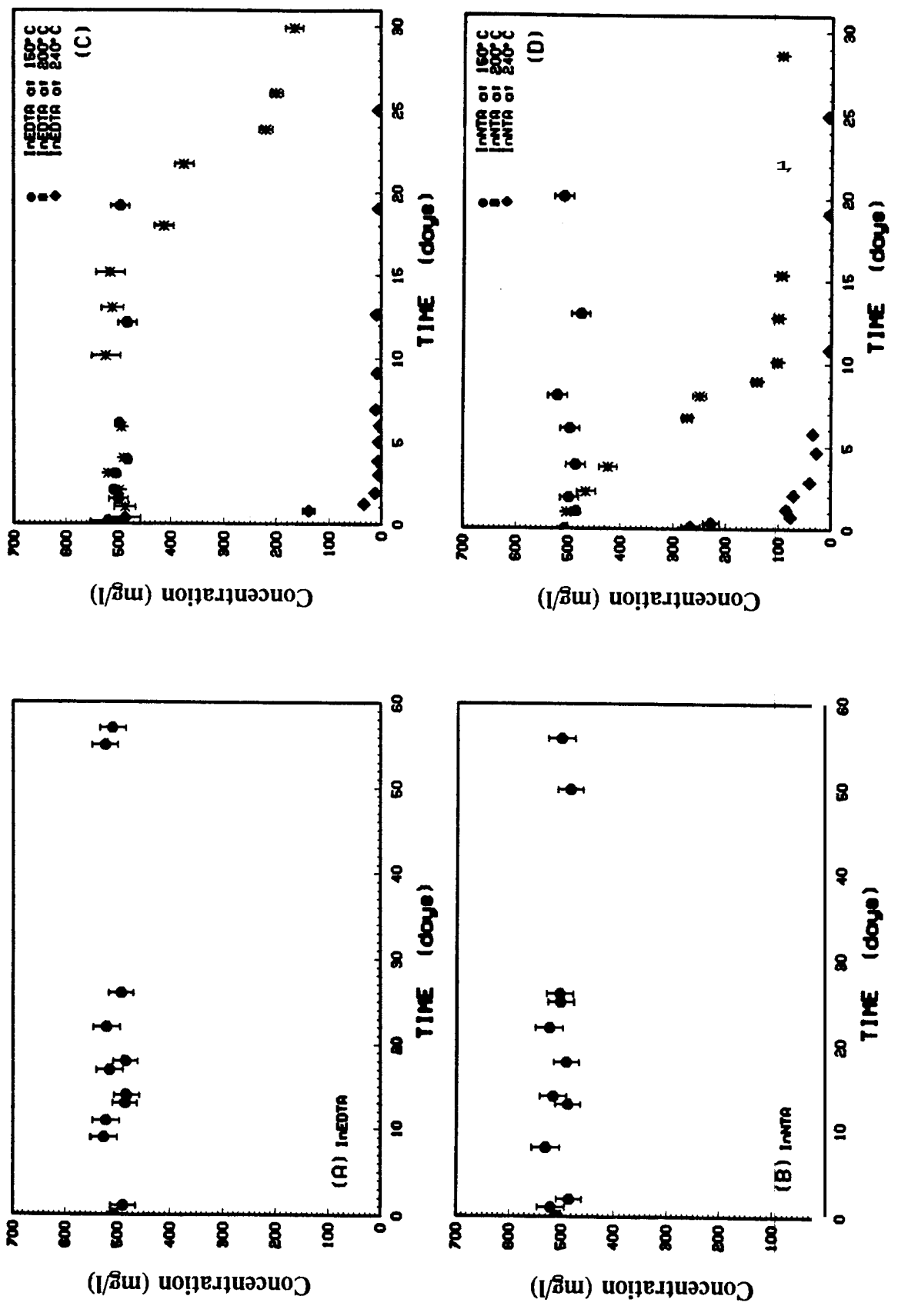

Figure 2.4: Indium chelated time stability (A,B), and thermal stability (C,D) behavior.

The results from the thermal stability measurements showed that indium chelated tracers can be used effectively in geothermal reservoirs with temperatures up to about 200°C for transit times of at least 20 days.

Experiments are underway to investigate the effects of temperature and organic complexing ligands on the adsorption of indium on geothermal rock types, such as graywacke. Initial experiments are being run to determine adsorption and precipitation phenomena of In^{+3} at room temperature.

SECTION 2.4 - THERMAL STABILITY OF FLUORESCENT DYES

This project was performed under the direction of program manager, Prof. Jon Steinar Gudmundsson, and research assistant Yathrib Al-Riyami.

Testing a geothermal field by means of tracer testing has become a common practice, because the information derived from these tests is very useful in the design of reinjection schemes. However there have been some difficulties involved in conducting the tracer tests in geothermal environments. some of the tracer materials used are radioactive and hence difficult to handle, while other chemical tracers (such as Iodide) require analysis techniques that can be both costly and laborious. Anticipating this development, this project set out to investigate the usefulness of some dyes as alternatives to the radioactive and chemical tracers currently in use. In particular we chose the fluorescent dyes rhodamine WT and fluorescein that had earlier found some use in the petroleum industry. Neither of these dyes is radioactive, and in the quantities used are not toxic to either animal (human) or plant life. However, little was known about their stability at high temperatures such as those likely to be encountered in geothermal fields. The dyes are easily identified by their fluorescent activity that can be simply and easily measured by a fluorimeter. However, it was not known how this fluorescent activity changes with temperature, nor what is the minimum temperature at which the dyes could be used. Since data obtained from a tracer test is used to model the tested formation, it is imperative to be able to account for any loss of the tracer in the format tion. This work was undertaken to answer some of these questions. Due to experimental constraints, the results were limited to providing qualitative guidelines only.

In conjunction with the US Geological Survey, the project carried out several batch experiments on solutions of Rhodamine WT and fluorescein of various strengths. Stock solutions of these dyes were prepared, and because of their sensitivity to light were contained in dark brown bottles which were kept in a dark drawer. From these, we prepared working solutions of known strength at the time of the experiments]

Each working solution was calibrated as a control just before it was used. A Turner Fluorimeter Model 112 was used to measure the fluorescence of these solutions. Two measured amounts of a working solution were put in duplicate test cells that were sealed in air. These were then put in a preheated air bath at the desired temperature, and removed at various time intervals. The contents were then measured for their fluorescent activity.

Some experimental difficulties were experienced with the test cells in which the dye solutions were heated in the air baths. Initially we planned to raise the temperature to up to 600 C. The USGS at Menlo Park offered us the use of one of their laboratories, and the containers that can be sealed under pressure to accommodate a temperature rise of 600 C. These containers are lined with gold, an inert substance that was thought, wrongly, to be ideal to use with the dye solutions. After some runs it was found that the fluorescence of these dyes was affected by the presence of gold, With some experimentation it was found that using teflon cups in aluminum cylinders gave better results. The cups were drilled from pieces of teflon rods at our laboratory. However, the teflon cups could be used only for two or three runs as the teflon deformed under the sealing pressure. We then obtained stainless steel cylinders whose insides were specially coated with teflon. Because we had to use teflon in our experiment, the highest temperature was set at 250 C, 300 C being approximately the melting point of teflon.

During the Klamath Falls tracer test conducted in the summer of 1984, the return concentration of rhodamine WT was measured to be in the region of a few parts per billion. On the basis of this it was decided to test the stability of rhodamine WT solution at 50 ppb, and that of fluorescein at 50 ppm. Later on we also tested solutions of fluorescein at 5000, 2500, 1250, and 625 ppm for twenty four hour periods at 150, 200 and 250 C.

Figure 2.5 shows the results obtained using Rhodamine WT solutian of 50 ppb at the three temperatures. This dye is least stable at 200 C, at which temperature it loses its fluorescence rapidly to about 60% of its original strength in the first two hours, and becomes inactive after three days. At 100 C it is stable at about 90% strength for more than a month. At 150 C its fluorescent activity is maintained at about 70% for a period of more than a month.

Figure 2.6 shows the result obtained using a fluorescein solution of 50 ppm at 150 C. At a temperature of 200 C, fluorescein loses its fluorescent activity completely within less than an hour (in teflon medium). At 150 C, it under goes rapid deterioration in its fluorescent activity within two hours to about less than 40% strength. This level is maintained for more than three hours.

Figure 2.7 shows the results obtained using fluorescein solutions of,strengths 625, 1250, 2500 and 5000 ppm for 24 hours at temperatures of 150, 200 and 250 C. A dependence of fluorescent activity on concentration is clear, but even at 5000 ppm this activity has fallen to about 70% of its original value after only 24 hours. As noted above, a 50 ppm solution at 150 C reduces to about 40%, and loses its activity at 200 C. This point is also plotted in the figure.

Difficulties encountered with the teflon bombs limited the temperature range to 250 C. With a temperature increment of 50 C, the data is essentially limited to three temperatures only. No analysis of reaction rates and activation energy was performed! as this is almost impossible with the type of data collected. As far as the fluorescent activity of these dyes is concerned, it is clear that it diminishes with temperature, and in the case of fluorescein, is dependent on concentration.

Rhodamine WT is more stable than fluorescein. Neither is to be used at temperatures of 200 C and above, even though rhodamine WT takes almost three days to lose its fluorescent activity at 200 C. However, at 150 C and less, rhodamine WT is by far the better choice. At worst it loses only about 25% of its original fluorescent strength

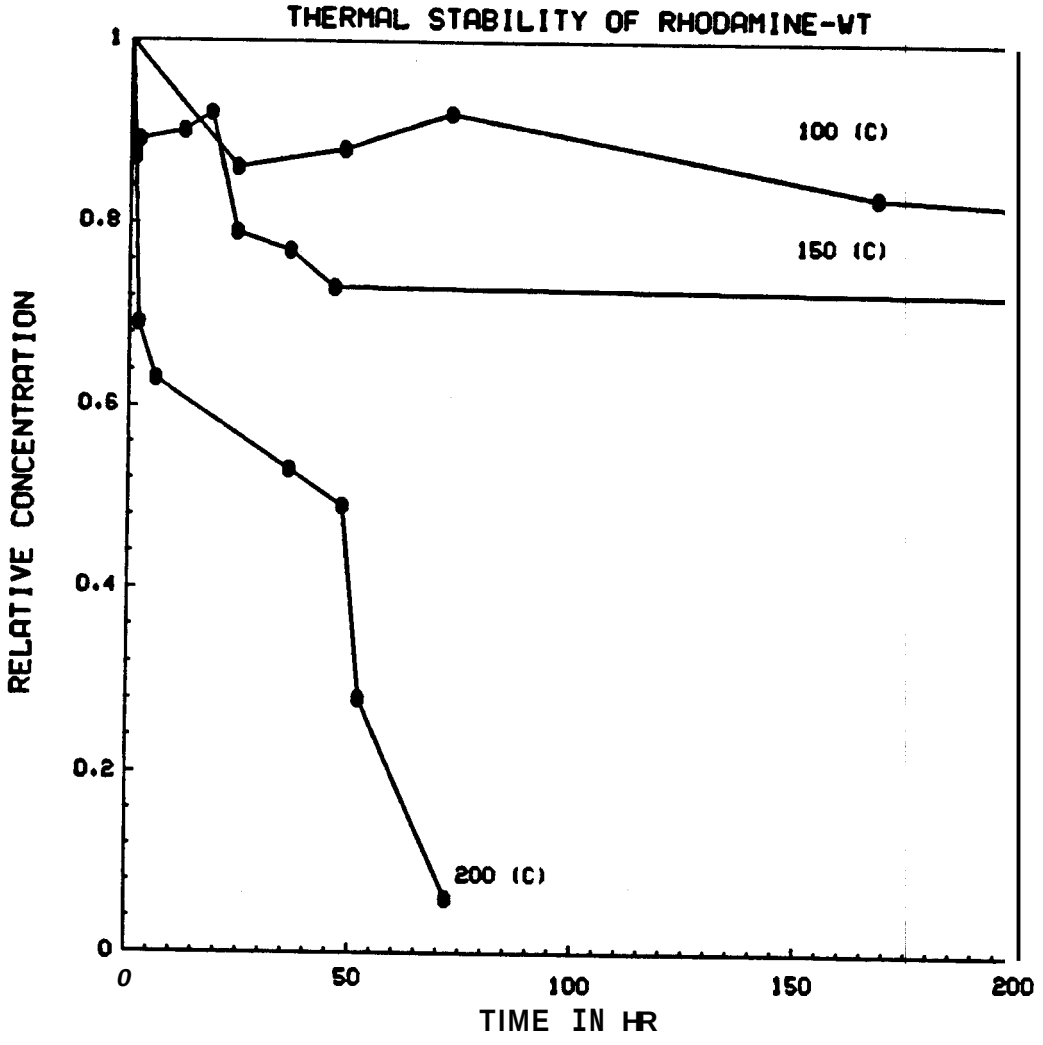

Figure 2.5: Thermal stability of Rhodamine-WT

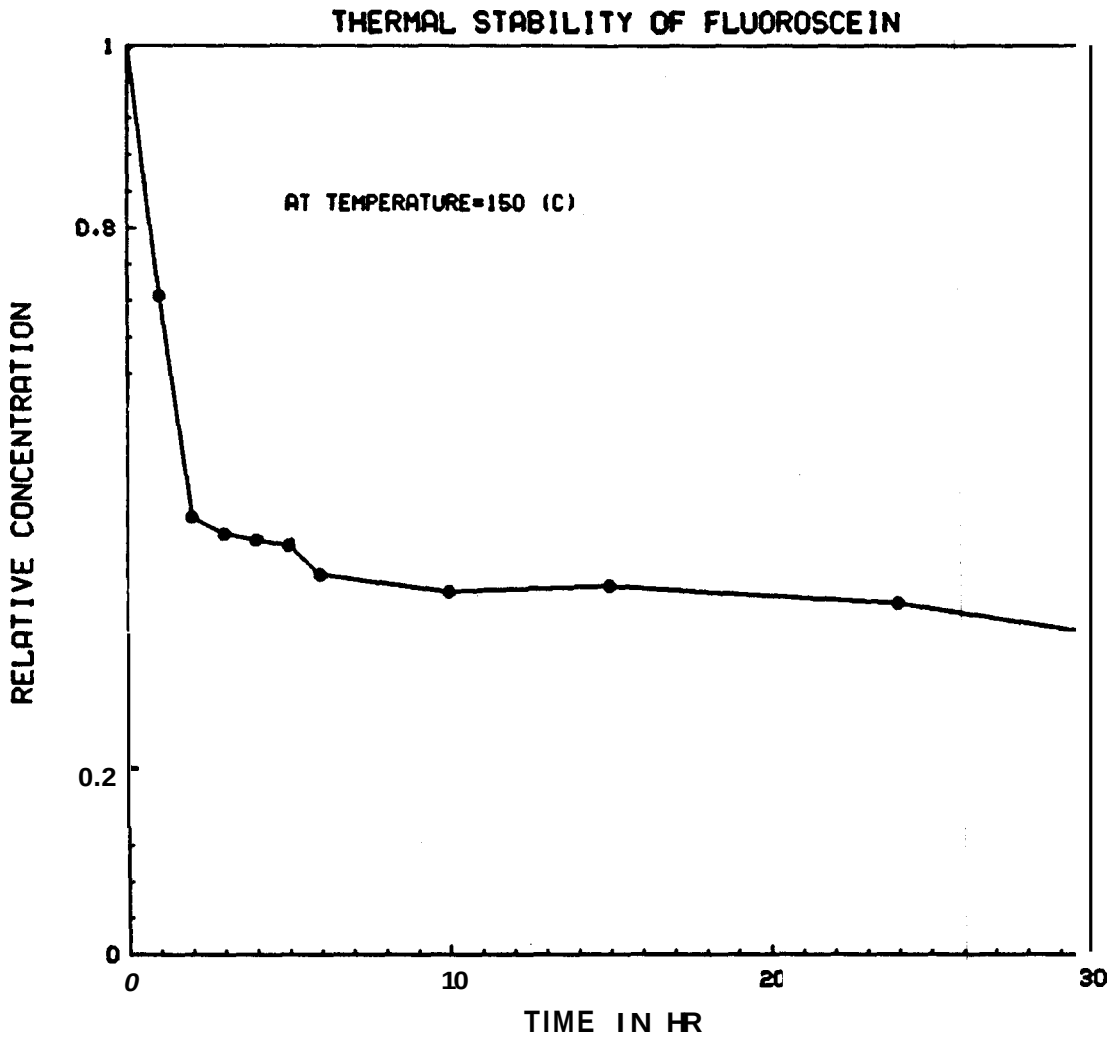

Figure 2.6: Thermal stability of Fluoroscein

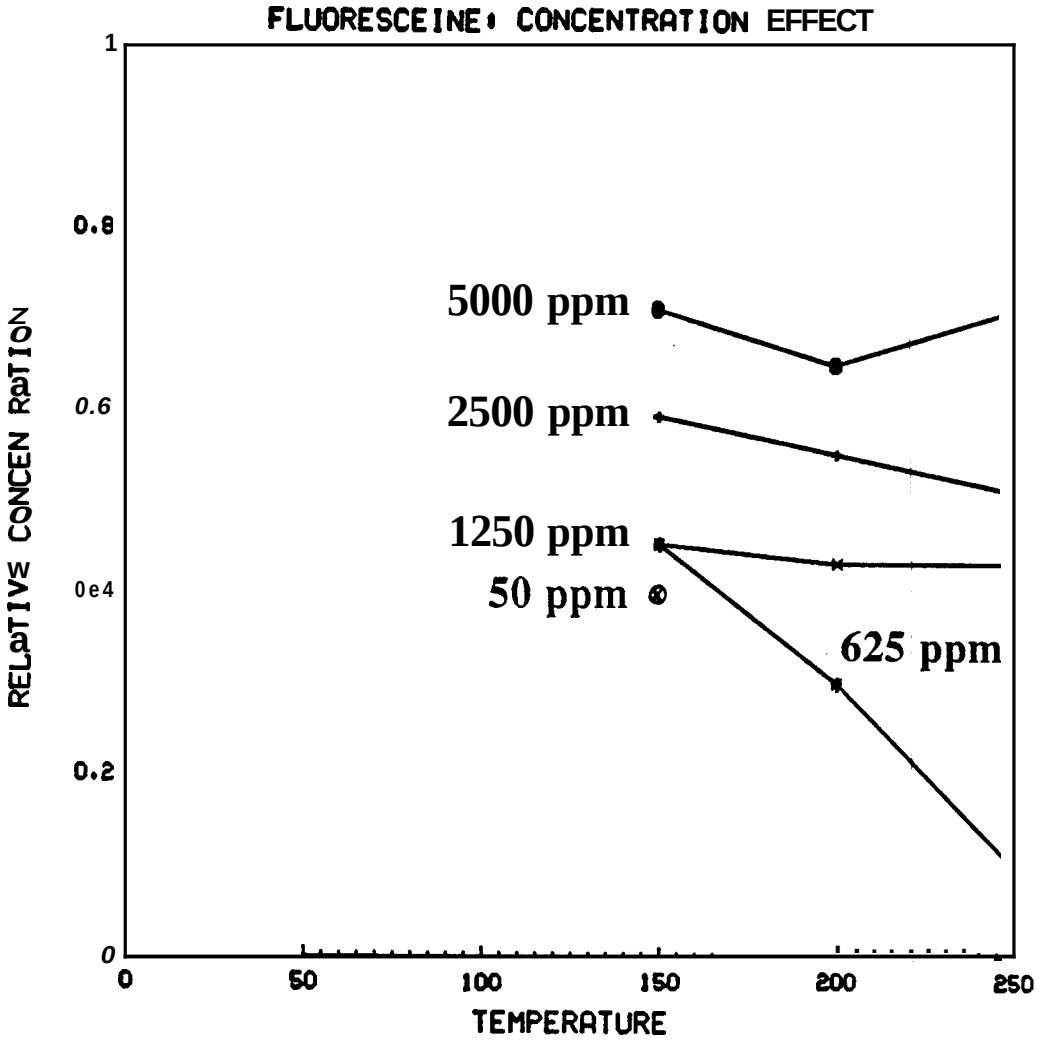

Figure 2.7: Thermal stability of Fluoroscein-concentration effect

even after a month. Fluorescein, in the same period at 150 C, loses about 60%.

In conclusion, it has been found that for quantitative work at about 150 C rhodamine WT should be used, for qualitative work both dyes might be used in temperatures less than 200 C.

3. TECHNOLOGY TRANSFER

The Tenth Workshop on Geothermal Reservoir Engineering was held at Stanford University on January 22-24, 1985. The attendance was up from previous years with about 140 registered participants. This was the first time the Workshop was held in January. Seven foreign countries were represented: France, Iceland, Indonesia, Italy, Japan, Mexico, and New Zealand.

The purposes of the Workshop are to bring together researchers, engineers, and managers involved in geothermal reservoir studies and development, and to provide for prompt and open reporting of progress and the exchange of ideas. There were 41 technical presentations at the Workshop. All of these were published in the Workshop Proceedings. Five technical papers not presented were also published.

Weekly Seminars were held during the academic year on geothermal energy topics. In autumn quarter the seminars were given by Stanford faculty, in winter quarter by representatives of industry, and spring quarter by student research assistants working of geothermal projects. These Seminars are attended by Stanford researchers and personnel of the U.S. Geological Survey and geothermal companies in the San Francisco area. The Seminars are also attended by representatives of geothermal companies in Santa Rosa.

The results of geothermal research at Stanford University were presented at several professional meetings during the year and published in the literature. Several technical reports were issued. Information on these technology transfer activities are given in appendices. The contents of the Proceedings of the Tenth Workshop on Geothermal Reservoir Engineering, and the Seminar Schedules for the 1984-1985 academic year, are also shown in appendices.

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Venezky, D. L. and Moniz, W. B. (1969), "Nuclear Magnetic Resonande Study of the Thermal Decomposition of Ethylenedinitrilotetraacetic Acid and Its Salts in Aqueous solutions," *Anal. Chem.*, 41 , pp. 11-16.

APPENDIX A: Seminar Schedules

STANFORD GEOTHERMAL PROGRAM
STANFORD UNIVERSITY
STANFORD. CALIFORNIA 94301

Son S. Gudmundsson
Petroleum Eng. Dept.
Mitchell Building, Rm. 360
(415) 497-1218 or 497-4744

SEMINAR SCHEDULE

Autumn Quarter 1984 — Room 124, Noble Building — Thursdays, 1:15-2:30 p.m.

Date	Title	Speaker
Sept. 27	Organizational Meeting	SGP Faculty
Oct. 4	Discharge Analysis of Well 9 in Reykjanes Field: The World's Largest Well?	Jon Gudmundsson Pet. Eng. Dept.
11	Preliminary Beat Sveep Analysis at the Western Boundary of Cerro Prieto	Paul Kruger Civil Eng. Dept.
18	Alteration Mineralogy and Isotope Studies of Los Azufres	Pat Dobson Geology Dept.
25	Formation of Natural Fracture Systems in Geothermal Reservoirs	Dave Pollard AES Dept.
Nov. 1	Multiphase Compressibility in Geothermal Reservoirs	Luis Macias-Chapa Pet. Eng. Dept.
8	Self Potential in Geothermal Exploration	Dale Morgan Geophysics Dept.
15	Monitoring the Hydrothermal System in Long Valley Caldera	Hike Sorey USGS
22	No Meeting (Thanksgiving)	
29	Mineralogical Record of Geothermal Fluid Circulation at the Skaergaard Intrusion	Dennis Bird Geology Dept.
Dec. 6	No Meeting (Dead Week)	

STANFORD GEOTHERMAL PROGRAM
STANFORD UNIVERSITY

STANFORD.CALIFORNIA 94401

Jon Gudmundsson
Petroleum Eng. Dept.
Mitchell Bldg., Room 360
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SEMINAR SCHEDULE

Winter Quarter 1985 — Room 124, Noble Building — Thurrday, 1:15-2:30 p.m.

Date	Title	Speaker
Jan. 31	Practical Aspects of Well Testing Using Quartz Crystal Transducers	**Roger Harrison** BGI
Feb. 7	Modeling the Olkaria Geothermal Field, Kenya	**Bo Bodvarsson** LBL
Feb. 14	Development Strategy at Coso Geothermal Field	**Jim Moor** CEC
Feb. 21	Temperature-Pressure Spinner Surveys in Well at The Geysers	**Andy Drenick** GEO
Feb. 28	Origin of Reservoir Fluids at Baca Geothermal Field	**Al Truesdell** WSGS
Mar. 7	Permits for Exploration and Development of Geothermal Power in California	Doug Stockton CDOG

STANFORD GEOTHERMAL PROGRAM
STANFORD UNIVERSITY

STANFORD.CALIFORNIA 94305

Jon Gudmundrson
Petroleum Eng. Dept.
Mitchell Bldg., Room 360
(415) 497-1218 or 497-4744

S E M I N A R S C H E D U L E

Spring Quarter 1985 — Room 124, Noble Building — Thursday, 1:15-2:30 p.m.

Date	Title	Speaker
April 11	Completion Terting and Diecharge Measurements of Mokai 6 in New Zealand	Jonathan Leaver Petroleum Engineering
April 18	No Seminar (Affiliates Meeting)	
April 25	Direct Uses of Geothermal Energy Worldwide	Jon Gudmundsson Petroleum Engineering
May 2	Evolution and Natural State of Vapor-Dominated Systems	Steve Ingebritsen Applied Earth Sciences
May 9	Interpretation of Injection-Backflov Tracer Tests	Ibrahim Kocabas Petroleum Engineering
May 16	Thermal Stability of Dye Tracers	Yathrib Al-Riyami Petroleum Engineering
May 23	Optimizing Field Development Strategy	John Marcou Petroleum Engineering
May 30	Discharge Analysis of Two-Phare Geothermal Wells	Carlos Tavares Petroleum Engineering
June 6	Dead Week	

APPENDIX B: Table of Contents Proceedings Tenth Workshop

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APPENDIX C: Participants in the Stanford Geothermal Program

Faculty	Research Assistants
Roland N. Home	Lawrence Bouett
Jon S. Gudmundsson	Costas Chrysikopoulos
Paul Kruger	Ibrahim Kocabas
	James Lovekin
	Flint Pulskamp
	Yathrib Al-Riyami

APPENDIX D: Chemical Aspects of Injection Workshop Program

Chemical Aspects of Injection Workshop - January 24, 1986 LGI Room, CERAS Building Stanford University Conveners: Tom Box and Roland N. Horne

Program

Morning: Tracers

8:30 Registration and Coffee

9:00 Roland N. Home, Stanford University, "Introduction" and "Tracer Retention/Dispersion Studies"

9:30 Larry Hull, EG&G Idaho, "Transport of Tracers in Fractures"

10:00 Bruce Robinson, Los Alamos Scientific Lab, "Temperature Sensitive Tracers"

10:30 *Mike* Adams, UURI, "Fluorinated Hydrocarbons as Geothermal Tracers"

11:00 Paul Kruger, Stanford University, "Activable Tracers"

11:30 Sally Benson, LBL, "Pressure Methods for Thermal Front Tracking"

12:15 Lunch

Afternoon: Reservoir Chemistry

1:00 Robert Fournier, USGS, "Reservoir Scaling at Cerro Prieto"

1:30 Tom Heinrichs, Magma Imperial, "Magmas Operating Experience, Imperial Valley, CA"

2:00 Karsten Pruess, LBL, "A Discussion of the Physical Effects of Reinjection on Geothermal Reservoirs"

2:30 Break

3:00 Cecil Kindle, PNL, "Chemical Agents of Spent Brines - Treatment and Instrumentation"

3:30 Mason Tomson, Rice University, "Scale Inhibition in Geopressured Wells"

Chemical Aspects of Injection

Attendence Roster

Mike Adams	UURI
Greg Andersen	Unocal
Paul Atkinson	Unocal
Jim Bantine	Union Oil
Mike Barnes	Unocal
Brian Barnett	GENZL
Tony Batchelor	Geoth. Resources
Phil Beilin	USGS
Sally Benson	LBL
Paul Bixley	MWD
Tom Box	Geysers Geo. Co.
Kenneth Chen	Bureau of Land Mngt.
Tom Clemo	INEL
Jim Combs	Geoth. Resources
John Counsil	Stanford
Charlene Crockett	Geysers Geo. Co.
Bill Dailey	LBL
Dick Dondanville	Unocal
Andy Drenick	GRI Operator Corp.
Kathy Enedy	Geysers Geo. Co.
Steve Enedy	Union Oil
Jim Ferguson	MIT
Robert Fournier	USGS
Barbara Gallinatti	LBL
David Gambill	Unocal
Jill Haizlip	Geo. Operator
Tom Heinrichs	Magma Imperial
Bill Holman	DOE
Roland Horne	Stanford
Evan Hughes	EPRI
Larry Hull	EG&G
Atsushi Ibusuki	JAPEX
Cecil Kindle	PNL
Chris Klein	Geothermax
Brian Koenig	Unocal
Paul Kruger	Stanford
Jon Leaver	Stanford
Marcello Lippmann	LBL
Steven Maione	Unocal
Sully Marsden	Stanford
Hideo Minowa	JAPEX
Marty Molloy	DOE
Carolyn Moore	PG&G
Mary McClearn	EPRI
Kaneo Okazala	JAPEX
Ender Okandan	METU
Lynn Pittinger	Unocal
Richard Pittinger	Thermal Power Co.
Susan Prestwich	DOE
Karsten Pruess	LBL

Maurice Richard'	Thermal Power Co.
Bruce Robinson	Los Alamos Sci. Lab
Alex Schriener	Unocal
Hiroshi Shigeno	
Sue Stiger	DOE
Gene Suemnicht	Union Geothermal
Stanley Sun	Bureau of Land Mgnt.
David Sussman	Unocal
Mason Tomson	Rice University
John Vickerstaffe	Gibbs & Hill
Ken Williamson	Union Oil
Rodger Witham	Bureau of Land Mgnt.

APPENDIX E: Papers Presented and Published 1984-85

1. Home, R. N.: "Tracer Flow in Fractures", Proceedings of the Geothermal Program Review III, October 16-19, 1984, El Centro, California, p. 305-318.

2. Home, R. N.: "Fluid Transport in Fractures", invited seminar at Los Alam Scientific Lab", September 1985.

3. Horne, R. N.: "Reservoir Engineering Aspects of Reinjection", Geothermics 1 1985, 449-458.

4. Home, R. N., Gilardi, J. and Bouett, L.: "Tracer Dispersion Experiments", Proceedings of the 1985 New Zealand Geothermal Workshop, Auckland New Zealand, November, 1985.

5. Ohno, K., Nanba, T. and Home, R. N.: "Analysis of Interwell Tracer Test in a Depleted Heavy Oil Reservoir", paper SPE 13672, Proceedings , 1985 SPE California Regional Meeting, Bakersfield, CA, March 27-29, 1985, p. 843-856.

6. Walkup, G. W., and Horne, R. N.: "Characterization of Tracer Retention Processes and Their Effect on Tracer Transport in Fractured Geothermal Reservoirs", paper SPE 13610 Proceedings , 1985 SPE California Regional Meeting, Bakersfield, CA, March 27-29, 1985, 229-240.

7. Walkup, G. W., Jr., and Home, R. N.: "Forecasting Thermal Breakthrough of Reinjected Water Using A Dispersion-Retention Model for Tracer Test Interpretation", GRC Transactions , 9 , part 11, August 1985, p. 369-374.