GL03100 -1 of 4

COOPERATIVE RESEARCH PROGRAM

WITH

CHEVRON

AT

HEBER

BY

UNIVERSITY OF UTAH RESEARCH INSTITUTE

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INTRODUCTION

The Heber geothermal system has many characteristics that make it an appropriate place to develop and test research ideas. Its geologic setting is similar to other Imperial and Mexicali Valley hydrothermal systems; the contribution of fracture permeability to fluid flow is unknown but probably amenable to deformation; it has a history of data collection, drilling and development that encompasses the last fourteen years, during which time much pertinent data have been collected and are available; and it presumably has subsurface rock samples available.

UURI is proposing cooperative research with Chevron and with the other DOE contractors. We propose to:

	Item	Cost
1.	Develop a subsurface geologic model of the Heber reservoir and surroundings;	$62K
2.	Perform cross-well tracer experiments coupled with long-term monitoring of the reservoir fluid chemistry;	$48K (first year) $34K (subsequent years)
3.	Study of fluid-mineral equilibria	
4.	Test tracers using an injection-backflow experiment;	$25K
5.	Perform a self-potential geophysical survey around wells undergoing production and injection;	$28K
6.	Perform a tensor CSAMT survey to (1) evaluate the method and (2) add to our knowledge of resistivity structure and the geologic model in the 0-10,000 ft depth range.	$ 64K
		$207K

RESEARCH PLAN

Task 1: Geologic Model of Heber Reservoir

Description: A reliable conceptual geologic model of the Heber reservoir and its surroundings is necessary for the interpretation of geochemical, geophysical and reservoir engineering data. A significant amount of geologic data have been collected and appear to need only compilation and interpretation. There are cuttings and some core samples from approximately 20 wells that could be made available for the study. Geophysical well logs are also available. In addition, there are geophysical data for the system, including heat flow, gravity, seismic and electrical resistivity.

We propose to review and compile the existing data. We will augment the geologic data where necessary, through lithologic logging, thin section microscopy, fluid inclusion thermometry and X-ray studies of cores and cuttings. Particular emphasis will be placed on the distribution of hydrothermal minerals and their relationship to the physical properties of the reservoir as deduced from well logs and geophysical studies. We will also obtain and interpret the available geophysical data. We will work closely in this effort with LBL, who will interpret the geophysical well logs. The objective of all of this work will be to refine the geologic model of the reservoir, with particular emphasis on location of faults and fractures, reservoir geometry and the location of and controls on permeability. Emphasis will also be placed on determination of zoning of hydrothermal minerals.

Deliverable: Report on the reservoir model developed, including maps and cross-sections.

Schedule: This will be a two-year project. These lithologic logging, X-ray studies and most of the geophysical interpretation can be completed the first year. Fluid inclusion and isotope work will be started the first year and completed the second year. The final data compilation, interpretation and development of the conceptual geologic model will be completed by the end of the second year.

Cost: $50,000 per year for two years

Support Needed: We will require from Chevron access to the chips and core samples from their wells and any lithologic, geologic, geochemical and geophysical data pertinent to this task.

Task 2: Cross-Well Tracer Experiments and Long-Term Monitoring of Reservoir Fluid Chemistry

Description: Chevron has expressed an interest in application of tracers to the Heber system. Since 1982, UURI has been working on the development of chemical tracers for use in geothermal applications. Available tracers have had a number of serious problems. First, there have been no data on the possible interaction of tracers with fluids and rocks in the reservoir. It is desirable, of course, to use tracers that do not react with reservoir rocks or fluid, i.e. are conservative. Second, available tracers are not detectable in sufficiently low concentrations for use in many cross-well tests, where tracer dilution factors of 10^8 or more may occur. Only in the case where a short, direct path exists between wells are the detection limits of available tracers such that detection of fluid communication could be expected.

UURI has been working on a group of chemical tracers never before applied to the geothermal environment -- the fluorinated and sulphonated hydrocarbons. They appear to have several advantages over current tracers:

1. They are expected to be conserved;

2. They are detectable in the parts per billion range and this range can very probably be extended to parts per trillion;

3. They do not occur naturally, so the background noise is extremely low; and,

4. They appear to be environmentally safe.

We would like to perform a series of cross-well experiments using two or more of these organic tracers. The tracers would be selected from a suite of potential tracers we are testing at geothermal temperatures and pressures in autoclaves in our laboratory. We would inject a slug containing the hydrocarbon tracers in concentrations having a known ratio along with bromine, an ion tracer known to be conservative at East Mesa, which is a geothermal system similar to Heber in temperature and geologic occurrence. Tracer injection would take place during on-going injection in a one or more wells and we would then monitor selected production wells to detect appearance of the tracers. Detection of tracers in any production well would prove fluid communication (not simply pressure communication) between the injection and production wells. In addition, the ratio of the abundances of the organic tracers compared to this ratio in the injected slug would indicate whether or not they are conservative. We envisage that this experiment will be long-term unless a pair of wells can be found that have relatively direct communication.

At the same time, other studies become possible through long-term sampling of produced fluids. Chemical analyses of geothermal brines have proven to be a useful and very sensitive means of monitoring the effects of production and injection in geothermal reservoirs. Monitoring programs utilizing chemical data in the New Zealand fields, for example, have detected the formation of two-phase zones in the reservoir and the infiltration of cold water. Long-term monitoring at Cerro Prieto has led to hypotheses about recharge of this reservoir from cold waters of the Colorado river system.

In order to detect changes in the reservoir and to interpret these changes, data are needed on the chemical and isotopic compositions of the discharged fluids and gases, and on separator and wellbore temperatures and pressures over a period of time. Samples of injected fluids may also be useful. We propose to analyze the produced and injected geothermal fluids (liquids and gases) at Heber in order to detect and evaluate any changes that may be occurring.

The same samples can be used for the cross-borehole tracer tests and the chemical monitoring. We will want samples of the produced and injected geothermal fluids initially twice each month for the first six months. Chevron will be asked to obtain the samples, so there will not be a need for a UURI person to travel to Heber except possibly for initial set-up for the sampling program. After 6 months of sample collection, the frequency of sample collection will be reviewed and modified as necessary. We believe that an ultimate frequency of once per month will be adequate.

We are currently involved in research on the distribution and composition of light hydrocarbon gases in active geothermal systems. We have so far been approaching this problem by studying the gas contents of fluid inclusions contained within secondary minerals formed during hydrothermal alteration of reservoir rocks in the Salton Sea field. We have detected variable amounts of methane through pentane in fluid inclusions, and these hydrocarbons appear to exhibit zoning with depth. Gas samples collected at Heber would be analyzed for these light hydrocarbons to help develop a better understanding of their behavior. We would also analyze for these gases in fluid inclusions from Heber cuttings samples.

Liquid and gas samples will be sent to UURI for analysis. The ongoing tracer analyses will be performed by Hydrogeochem of Tucson, Arizona through a purchase order from UURI. The other analyses will incorporate our standard geothermal brine analysis by ICP as well as measurement of chloride and total dissolved solids (TDS). Electrical conductivity and pH will be measured on samples as they are collected in the field. The gas composition of selected samples will be determined at a commercial laboratory.

Deliverables: Report on chemical analyses and their interpretation. We envisage a brief report the first year and thereafter status reports yearly until such time as enough data are generated to interpret the tracer analyses in terms of fluid breakthrough and the other chemical data in terms of long-term trends.

Schedule: This must be viewed as a multi-year project, but the cost per year is rather low. The project would continue at least 5 years.

Costs: First Year: $52,000
Subsequent Years: $36,000 per year

Support Needed: Chevron would need to do the sample collection, estimated to be 2 man-hrs per well per sample. For first six months, this would require about 40 hours per month, and thereafter, the time required would be about 20 hours per month.

Task 3: Study of Fluid-Mineral Equilibria

Description: The injection of supersaturated cooled fluids into a geothermal reservoir can affect the porosity and permeability of the rocks through mineral deposition or dissolution. These effects can occur through reactions between the injected and reservoir fluids and between the mixed brines and reservoir rocks.

Several different equilibrium models are currently available for calculating fluid-fluid and fluid-rock interactions. We propose to utilize selected codes to determine which minerals will become saturated in the fluid and are thus likely to precipitate as a result of reinjection.

The initial data used for the modeling will be obtained from analyses of the reservoir and injected fluids and from mineralogic and alteration studies of the reservoir rocks.

Deliverable: Status report on expected effects of mineral precipitation or dissolution in injection zone.

Schedule: This is viewed as a two-year effort.

Cost: First Year - $64,000

Task 4: Testing of Tracers using an Injection-Backflow Experiment

Description: Our laboratory experiments with the fluorinated and sulphonated hydrocarbons as well as reasoning from thermodynamic considerations have shown that a number of the fluorinated and sulphonated hydrocarbons should be thermally stable at temperatures beyond 150°C and that they should not undergo reaction with reservoir rocks or fluids, i.e. that they should be conservative. We would like to test the stability and conservation of selected tracers from this family of tracers in the field.

The injection-backflow method offers the only means we know of to demonstrate stability and conservation of a tracer in the field. An injection-backflow experiment could easily be coupled with a transient-test injection experiment in which there is injection under controlled conditions followed by a cessation of injection and a period of monitoring the temperature and pressure recovery of the well. During injection, a slug of tracer could be introduced along with the injected fluid. The transient recovery period would furnish a quiescent interval in which the tracer rests in the reservoir and has the opportunity to react with reservoir rock and fluids or to thermally degrade. All that would remain would be to backflow the well to recover the tracer slug. This could be done at a low incremental cost over and above the cost of the injection transient test.

In order to make the tracer test meaningful, several conditions would be desirable. First, the injection interval should be typical in nature to reservoir rocks. Second, if the temperature of the injection interval is below 100°C, the experiment may not be worth doing. Whether or not we ultimately recommend proceeding with such an experiment will depend upon finding an injection well with suitable subsurface conditions. We plan to evaluate the potential of doing this tracer test when we have a more complete data package from Chevron, and to make a recommendation at that time.

Deliverable: Report on tracer conservation

Schedule: The experiment would be completed and analyzed within 6 months of the beginning of field work.

Cost: $25,000

Support Needed:

We would require Chevron to backflow the injection well for about 3 days and to furnish fluid sampling support.

Task 5: Self-Potential Experiment at Heber

Description: The self-potential geophysical method has proven to be useful in certain geothermal areas as an exploration tool. For example, a large SP anomaly that is associated with a known hydrothermal system has been documented in the Puna area on the East Rift Zone on the island of Hawaii.

Research work at UURI has cast new light on the mechanisms that create self potentials in the earth. We have developed and published theoretical work that quantifies the generation of voltages in the earth as a result both of natural and man-induced flow of thermal energy or of fluids, i.e. we have developed models of the so-called "thermoelectric" and "electrokinetic" effects. We have computer programs to model these processes for inhomogeneous earth structure and are able to use these programs to help design surveys and interpret data.

During injection-backflow tests on Republic wells at East Mesa in 1983, UURI did SP monitoring in an attempt to detect fluid movement. Modeling had shown us that an SP effect may or may not be detectable because the magnitude of the expected effect would be within or perhaps only slightly above ambient electrical noise level. Our analysis of the results indicates that no certain SP effect was detected. The most serious limitations in that study were the rather high electrical conductivity of the upper 5000 feet of stratigraphic section and the depth to the injection zone, which was roughly 5000 feet.

We would like to perform an experiment to try to measure the SP effects of injection on Chevron's property. We understand that in 2 wells the injection zone is only 2500 feet deep, and so the occurrence of a detectable surface SP anomaly is much more likely than in our previous work at East Mesa. The hope is that if an SP anomaly can definitely be shown to be associated with the movement of injected fluid, the surface SP anomaly would contain information on the predominant flow directions. This information would be of obvious interest.

For the field work, we would need to measure the natural self-potential field around a selected well both during periods of injection and during periods when there is no injection. For logistical reasons as well as for our concern with minimizing long-term noise effects in the data, we would prefer to do surveys both during injection and during quiescence that are close together in time. This may be possible if injection-transient testing of a suitable well is carried out at Heber by one of the national laboratories.

Deliverables: Report on SP effects of injection.

Schedule: Work would be complete within 3 months of initiation of field work.

Cost: $28,000

Support Needed: No support from Chevron is visualized other than access to the site.

Task 6: Evaluation of the Tensor Controlled-Source Audiomagnetotelluric Geophysical Method

Description: Electrical geophysical techniques have the potential for being able to locate faults which may divide a hydrothermal system into discrete blocks and for yielding information on the preferred orientation of fracturing at small to large scales, which would be useful in siting production and injection wells. There are good geologic and geophysical reasons why virtually all hydrothermal systems should have an associated low resistivity anomaly, and we consider electrical techniques to be perhaps the most useful of all geophysical techniques. Of all of the electrical techniques that could be used, we believe that tensor controlled-source audiomagnetotelluric (CSAMT) surveys have the best chance of proving useful for targets in the depth range 1500 to 10,000 feet.

At the present time, there is no wholly satisfactory electrical method for exploration for concealed geothermal resources. Galvanic resistivity surveys, while relatively easy to run and for which interpretation methods are reasonably well worked out, lack depth penetration. Scalar AMT, which is easy to run and for which highly portable equipment is available, does not provide enough data to resolve inhomogenous subsurface resistivity structure adequately. The MT method is able to resolve complex structure better, but uses very sophisticated processing and marginally portable equipment and requires a highly trained crew and complex, sophisticated interpretation. It is expensive. The CSEM methods are relatively easy to run but equipment is only marginally portable and adequate interpretation is only now becoming available. SP surveys are easy and cheap but interpretation is difficult and ambiguous. In view of the relevance of electrical methods to geothermal exploration, development of electrical equipment and techniques specifically for the geothermal environment would seem like a wise research investment.

Little application of tensor CSAMT surveys to geothermal research has been made. Simple, scalar natural-field AMT surveys have been run over a great many geothermal systems for research purposes, mainly by the U.S. Geological Survey. These surveys have largely failed to contribute to delineation of the hydrothermal system or to selection of drill sites for two primary reasons:

1. Scalar AMT surveys do not contain enough information to allow an interpretation that is detailed and unique enough to be of real use. In scalar surveys, only one of three magnetic components and one of two

electric components are measured. By failing to measure the other components, a great deal of information is lost which is obtainable with relatively modest additional effort in a tensor setup.

2. Scalar AMT surveys have, for the most part, been interpreted using one-dimensional models. This is a generally incorrect approach, since the geologic and electrical structure of the earth in geothermal areas is complex enough to require two- or often three-dimensional models. Tensor data is necessary in these complex environments and multi-dimensional modeling capability at UURI is second to none.

On the basis of the above discussion, we conclude that:

1. Methods that measure electrical resistivity (or its reciprocal, conductivity) have application to a broad range of geothermal problems, from reconnaissance, to delineation of the boundaries of a system to siting drill holes.
2. The tensor CSAMT method is perhaps optimum for the scale of detail, depth penetration and relative cost in geothermal application; and,
3. The tensor CSAMT method has not been tested for use in geothermal application.

We would survey the south portion of the East Mesa hydrothermal system at a density averaging 16 stations per square mile. Approximately 80 stations would be occupied to cover several geologic environments from points outside the system to points in the center of the system. Particular coverage would be given to areas of suspected faults. The data would be interpreted using UURI's two- and three-dimensional modeling capability.

Deliverables: A report evaluating the CSAMT method in this application and integrating the data into the geologic model of East Mesa.

Schedule: The work would be finished within one year of funding.

Cost: $64,000

Support Needed: No support other than access to land and to existing data would be needed.