DOE's EGS Program Review

EVALUATING PERMEABILITY ENHANCEMENT USING ELECTRICAL TECHNIQUES

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Project Objectives

1. To gain fundamental understanding of the mechanisms by which hydrofracturing operations can cause electrical signals to propagate outward into an EGS geothermal reservoir and be detected by instrumentation located in nearby shut-in observation wells,
2. To establish the quantitative relationships among *(a)* reservoir rock and fluid properties, *(b)* fracture characteristics, *(c)* well characteristics, and *(d)* the amplitudes, propagation rates, and spatial distributions of the resulting electrical signals,
3. To estimate the important reservoir mechanical, hydraulic and electrical properties that affect electrical signal characteristics in the laboratory, using rock samples gathered from candidate EGS field sites,
4. To identify and recommend preferred techniques for carrying out monitoring operations in the field to *(a)* detect and characterize the electrical signals caused by hydrofracturing and *(b)* gather other supporting information needed to interpret these signals, and
5. To devise procedures for subsequently analyzing the electrical signals obtained in combination with additional supporting information that will provide the best possible estimates of the spatial distribution of reservoir permeability created by the hydrofracturing operation.

EGS Problem

"Determining the location and geometry of the fractured volume during stimulation is also problematic despite significant research. Microseismic monitoring is the best available technique, but the relationship between the microearthquake cloud and the fractures is not understood. New and improved real-time methods are needed to monitor fracture progress and to indicate when and how to modify the stimulation program."

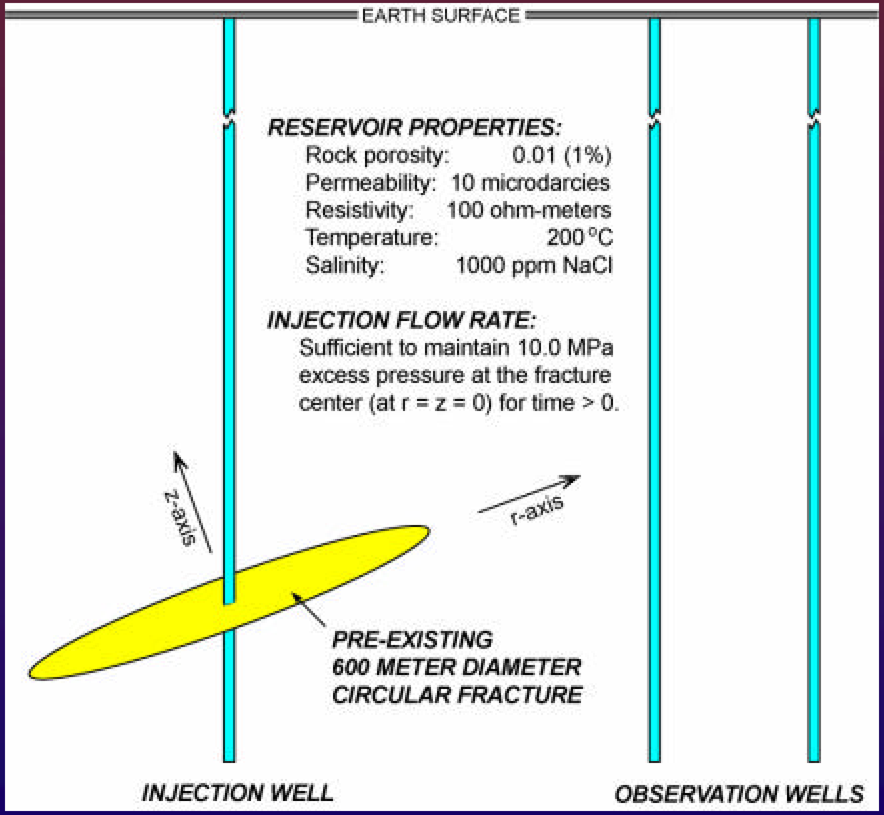
--- DOE Geothermal Technology Program Multi-Year Program Plan 2006-2011, Section 3.1.1.4.2, p. 30-31.

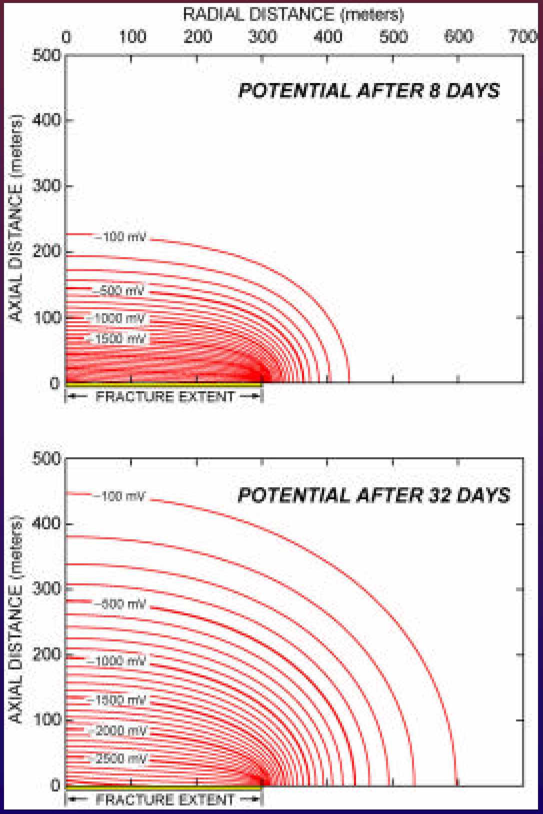
Background/Approach

- ***Task 1:*** Perform parametric theoretical calculations to characterize *free-field SP signals* caused by hydrofracturing operations. *Status: completed.*
- ***Task 2:*** Appraise *near-borehole effects* upon the free-field signals. *Status: completed.*
- ***Task 3:*** Obtain rock samples from candidate EGS sites and perform *laboratory measurements* in Japan to quantitatively appraise key properties needed for SP interpretation. *Status: initial results being evaluated.*
- ***Task 4:*** Identify optimum *field techniques and operational procedures* to obtain the downhole SP measurements along with other essential supporting field data. *Status: in progress.*
- ***Task 5:*** Develop computational tools for performing *joint interpretation* of downhole SP data sets with other survey data (*i.e.* MEQ) to estimate fracture characteristics. *Status: to be done next year.*

Results – Task 1

Base Case:

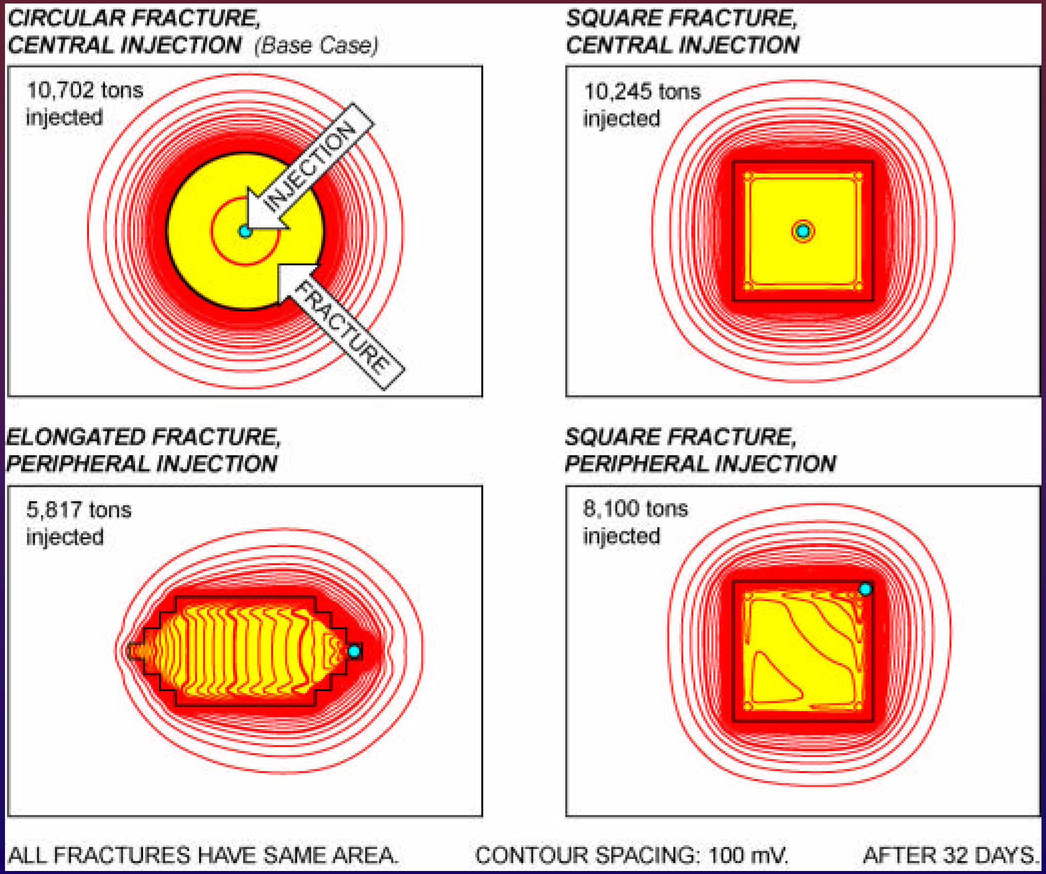




Results – Task 1

89 calculations were carried out to examine the influence of various key parameters on the free-field SP signals.

Most were parameter variations of the axisymmetric Base Case, but several fully three-dimensional calculations were also performed.



Results – Task 1

Parameters Examined:

- *Formation properties:* porosity and permeability.
- *Reservoir properties:* initial pressure, temperature, salinity, steam saturation, and electrical resistivity.
- *Injection parameters:* pressure, temperature, salinity, and duration.
- *Fracture properties:* transmissivity, storativity, spatial extent (diameter), geometric shape, injection point location, and degree of permanent stimulation achieved by fracture pressurization.

Results – Task 2

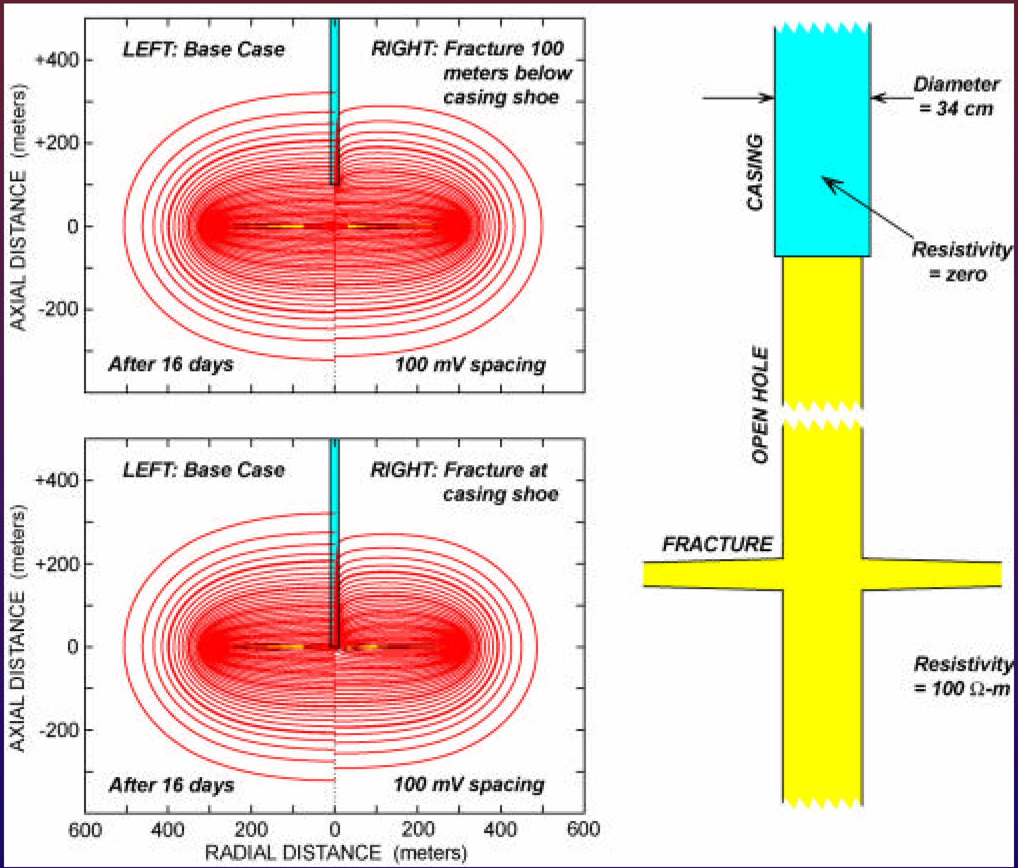
Both fracture pressurization and SP observations will be done using wells. These wells will perturb the free-field SP response to some degree.

An additional 29 calculations were performed to examine these issues:

- *What is the effect of a conductive metallic casing in the injection well?*
- *Does a cemented liner in the observation well influence results?*
- *What is the effect of a resistivity mismatch between the observation well and the surrounding reservoir formations?*
- *How long must the nonmetallic section in the observation well be?*

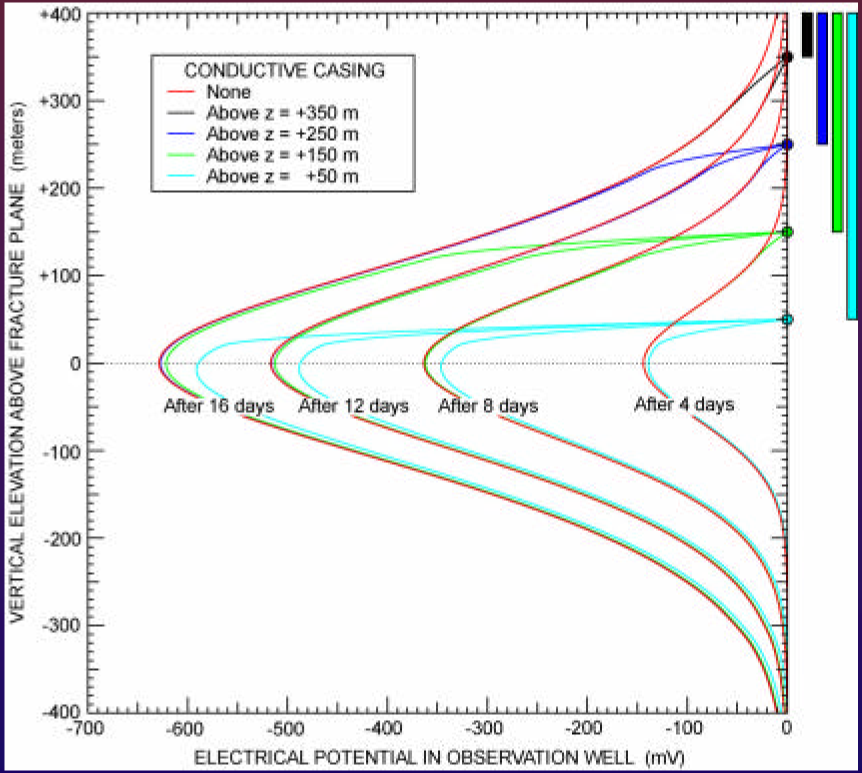
Results – Task 2

Effects of metallic injection well casing on free-field SP signal

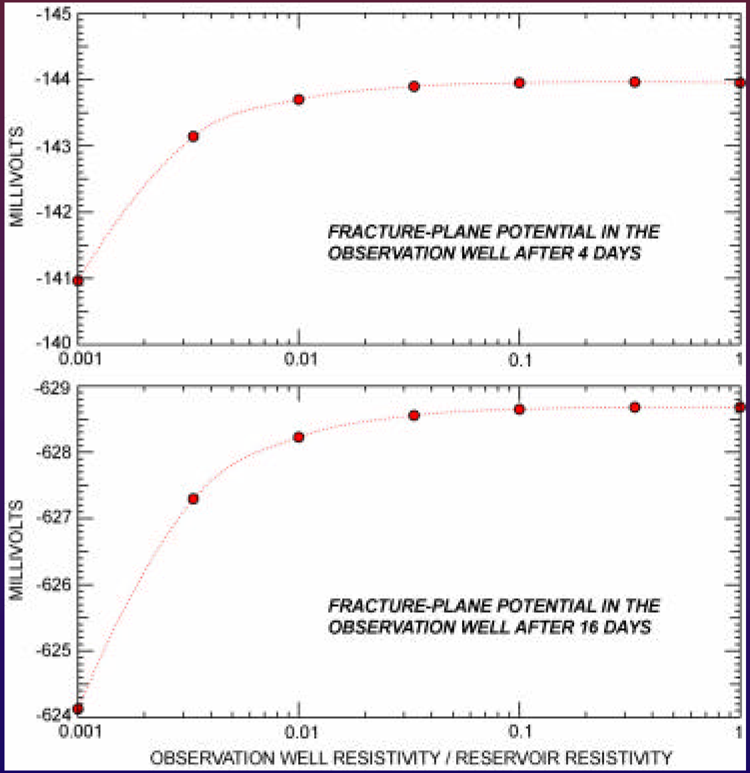


Results – Task 2

Observation well steel casing effects



Resistivity mismatch effects



Early Results – Task 3

Two small core sample fragments were obtained from Coso well 34-9RD2, from depths of 2430 (upper) and 2432 meters (lower).

Coso diorite sample from 2430 m depth

Coso granite / granodiorite sample from 2432 m depth

Early Results – Task 3

- Two Coso samples tested with one Inada Granite sample. Analysis in progress.
- Zeta-potential of intact samples only 30% - 50% of granular sample values. *Why?*
- Zeta-potential increases with temperature, but not always monotonically. *Why?*
- Decrease in zeta-potential with salinity greater for Inada Granite sample than for Coso samples. *"Surface conductivity" more important for Coso samples?*
- Zeta-potential results from each of the two Coso samples are closer to Inada Granite results than to each other. Coso samples came from locations two meters apart. Inada Granite sample came from site 9,000 kilometers away.
- Lab measurements useful for characterizing trends and important parameters, but *in-situ* determinations of streaming potential needed for field data interpretation. *Methodology?*

Early Results – Task 4

Observation Well Characteristics

- Slim holes should suffice as observation wells.
- Observation wells must be cased and cemented in the test interval (several hundred meters long) using non-conductive casing materials such as fiberglass.
- Drilling fluids must not leave an electrically conductive coating on the wall of the hole or inject conductive material into the formation.
- A good cement job is essential to avoid flow behind the casing and resulting SP interference.

Early Results – Task 4

Observation Well Measurements

- An array of permanent electrodes will be deployed down the wall of the observation well (intervals between 10 and 50 meters).
- Electrode array will permit continuous monitoring of SP simultaneously at multiple locations.
- Array can also be used for pre-fracture “downhole DC resistivity” surveying to establish average electrical resistivity and distribution of resistivity with depth.
- Seismic sensors can be deployed in the same observation well if temperature-tolerant seismic sensors are available.

Early Results – Task 4

Injection Well Measurements

- Time-history of fluid pressure at the fracture depth must be recorded both during pressurization and during post-fracture falloff period.
- Fluid flow rate must be monitored, both during the injection and subsequent backflow period.
- These measurements are essential both for interpretation of SP transient signals and for appraisal of permeability using pressure-transient analysis techniques.

Plans for Task 5

- Task 1 and 2 calculations were carried out using the general-purpose STAR reservoir simulator with a general-purpose SP postprocessor.
- Axisymmetric calculations took 1-2 hours apiece on a modern Unix workstation. 3-D calculations took 8-15 hours each.
- Substantial physical and mathematical simplifications are permissible based on results obtained during Tasks 1 and 2.
- Next year, special-purpose software will be developed to carry out simulations of this general kind using far less computer time on portable “PC” computers.
- The new software will be suitable for routine interpretation of SP signals from hydrofracturing operations.

Conclusion

Project is proceeding as planned and will be completed by the end of CY2007 as scheduled.

The next step will presumably be field deployment, but specific plans along these lines cannot be finalized until the present work is completed.