FINAL REPORT

INTERPRETATION OF SELF-POTENTIAL MEASUREMENTS
DURING INJECTION TESTS AT RAFT RIVER, IDAHO

by

William R. Sill

September 1983

Work performed under Contract Number: DE-AC07-80ID12079

Prepared for
U.S. Department of Energy
Division of Geothermal Energy

MASTER

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**EARTH SCIENCE LABORATORY
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ABSTRACT

Self-potential measurements before and during injection tests at Raft River KGRA, Idaho indicate a small negative change. The magnitude of the change (5 to 10 mV) is near the noise level (5 mV) but they extend over a fairly broad area. The presence of a cathodic protection system clouds the issue of the validity of the changes, however the form of the observed changes cannot be explained by any simple change in the current strength of the protection system. Furthermore, similar changes are observed for two separate tests, months apart.

Modeling of the changes indicate that they are likely caused by a fracture extending from the reservoir (1400 m) to close to the surface.

INTRODUCTION

Self-potential (SP) measurements were made prior to, and during several injection tests at Raft River KGRA, Idaho. The objectives of these measurements are to determine if measurable changes in the SP could be observed and whether they could be used to infer the direction of fluid flow. The SP changes are expected to be caused by electrokinetic effects (streaming potentials) generated by a new flow regime induced by the injection. For most geological materials, the streaming potential coefficient produces a positive potential in the direction of flow and the injection of fluid should produce a negative anomaly in the vicinity of the well (Sill, 1983). The form of the anomaly should provide some information about the direction of fluid movement in the system.

SP measurements were made before and during two injection tests (Test 2 and Test 5). Because of the short injection period during Test 2, the second set of measurements were made after only 24 hours and only a limited amount of data could be gathered. The injection phase of Test 5 was of a longer duration (376 hours) permitting a more extensive survey. The injection phase of these tests consisted of the injection of water from Well RRGP-3 into well RRGP-5 at a rate of 9.5 L/S (150 gpm) at a wellhead pressure of about 0.6 MPa (90 psi). The water from RRGP-3 is slightly more conductive ($1.25 \Omega\text{m}$) than the water produced from RRGP-5 ($4.0 \Omega\text{m}$) and the temperature of the injected water is close to the reservoir temperature at RRGP-5 (Downs et al., 1982).

Figure 1 shows a geological cross-section at the Raft River test site (Blackett, pers. comm.). The upper section is dominated by the conductive sediments of the Salt Lake Formation. Below these sediments are possible reservoirs in the quartzite and fractured crystalline basement. Injection

into the reservoir at RRGP-5 takes place at the bottom of the hole at a depth of about 1400 m. The total amount of injected fluid in Test 5 was 1.5×10^4 m³ and spherical spreading into a medium with 10 percent porosity would displace the native fluid out to a radius of only 35 m. If the fluid spreads out laterally along fractures or fault zones the distance traveled can be larger. For example, if the fluid moves out radially within a 1 cm thick fault zone with 50 percent porosity, the radius of the disc containing the injectate is about 1 km. However, tracer studies indicate that the injectate did not reach Well RRGE-1 which is at a horizontal distance of 750 m (Downs, 1982).

Changes in the fluid flow are not necessarily restricted to such distances since the injectate will displace an equal volume of native fluid. The changes in flow propagate outward with the pressure pulse and pressure communication between RRGP-5 and RRGE-1 has been observed.

SELF-POTENTIAL DATA

Figure 2 shows two sets of data along the same line prior to Test 2 (9/20/82) and prior to Test 5 (11/2/83). This figure illustrates the typical repeatability and for the data shown the standard deviation is about 6 mV. The self-potential map for the Raft River test site is shown in Figure 3, for the quiescent condition prior to the injection Test 5. The map is dominated by two features, the first is a small negative anomaly near RRGP-5 and the second is a strong dipolar anomaly associated with a buried cathodic protection system. Unfortunately, the true nature of this second feature was not discovered until well into the injection phase of Test 5.

Toward the end of the injection phase of Test 5 (350 hours) a second survey was conducted and the changes in the data (injection minus quiescent) are contoured in Figure 4. The major large scale change is a zone of negative potential trending to the northeast from RRGP-5. There is also a small scale dipolar change, indicated by the +10 mV contour and the single station change of -300 mV, near the cathodic protection system. This change could be explained by a reduction in the strength of the cathodic protection dipole. However, this type of a change does not offer a ready explanation for the other observed changes especially the large negative region (-10 mv contour) just to the north of the cathodic protection dipole. This can be illustrated by considering Figure 3 which shows the nature and extent of the dipolar anomaly associated with the cathodic protection system. If the strength of this dipole is decreased, then the change produced is also dipolar in form but with negative changes over the positive portion and positive changes over the negative portion. Except for the small scale dipolar change close to the cathodic protection system, the changes in Figure 4 do not fit this pattern.

Figure 5 shows the changes produced during Test 2. The data are sparse compared to Figure 4 but the anomaly pattern and magnitude are similar where the data overlap.

In evaluating these data, we note first that the large scale anomaly is near the estimated noise level. Second, the presence of the cathodic protection system raises the problem of cultural noise. However, a large portion of the anomaly does not fit the pattern for an anomaly caused by a reduction in the strength of the cathodic protection dipole and separate sets of data from two tests give similar results.

SELF-POTENTIAL MODELS

Figure 6 shows a cross-section of Model 1 perpendicular to strike. The region from 0 to 100 m represents a resistive surface layer and the region from 100 m to 200 m represents the more conductive Salt Lake Formation. From 1200 m to 1400 m is a more permeable (fractured) reservoir and below 1400 is a relatively unfractured and resistive basement. The thin vertical feature (media 5) represents a permeable fracture connected to the reservoir and the hatchured region (media 4) on either side of the fracture represents the source region for the self-potential. The self-potential modeling requires three sets of model parameters (Sill, 1983). These are the permeability (k), the electrical resistivity (ρ) and the voltage crosscoupling coefficient (c). The values for the various media and models are given in Table 1.

In addition to the model parameters, the flow source location and strength must be specified. The flow source is located at a depth of 1400 m corresponding to the bottom of the casing. With a source strength of $0.95 \times 10^{-2} \text{ m}^3/\text{s}$ (150 gpm) and a reservoir permeability of 15 millidarcy, the pressure in excess of hydrostatic at the point of injection is 0.5 MPa (75 psi) which is close to the wellhead injection pressure (90 psi).

The calculated self-potential for Model 1 at the surface is shown in Figure 7 along with the -5 mV contour from the observed anomaly in Figure 4. The negative anomaly is produced by the outward flow from the fracture into media 4. The fit is fairly good with the calculated anomaly being somewhat broader perpendicular to the strike of the fracture. The width of the anomaly is partly determined by the depth extent of media 4 and partly by its width. In the early stages of the modeling it was determined that the width of media 4 had to be restricted or the anomaly would be much too broad. The width of

TABLE 1
Model Properties

	<u>Model 1</u>					
	media					
	1	2	3	4	5	6
k(Darcy)	1.510^{-3}	10^{-8}	1.510^{-4}	1.510^{-4}	1.510^{-2}	1.510^{-5}
$\rho(\Omega m)$	50	10	10	10	100	100
c(mV/bar)	0	0	0	29	0	0

	<u>Model 2</u>							
	media							
	1	2	3	4	5	6	7	8
k(Darcy)	1.510^{-3}	1.510^{-3}	1.510^{-4}	1.510^{-4}	1.510^{-1}	10^8	1.510^{-2}	1.510^{-5}
$\rho(\Omega m)$	50	50	10	10	10	10	100	100
c(mV/bar)	0	28	0	28	0	0	0	0

$$\text{Darcy} = 10^{-12} \text{ m}^2$$

$$\frac{\text{mV}}{\text{bar}} = 10^{-8} \frac{\text{V}}{\text{Pa}}$$

the anomaly can be reduced further by restricting the outward flow at depth. This has been accomplished in Model 2 (Figure 8) by imposing a low permeability zone (media 6) just above the reservoir. The outflow from the fracture is then mostly in the depth interval from 100 m to 800 m. The resulting SP anomaly (Figure 9) is narrower perpendicular to strike and provides a better match to the observed -5 mV contour. Given the magnitude of the anomaly, the quality of the data, and the limitations of the model (2 dimensional structures), additional modeling is probably not warranted.

DISCUSSION

The modeling results indicate that most of the source region for the self-potential changes must be above the bottom of the hole and presumably above the main reservoir. The source region is restricted in its width perpendicular to strike (< 800 m). The width of this zone might be determined by a fracture system and/or alteration. The modeled fracture zone feeding the SP source region extends quite close to the surface and the width of the anomaly favors a model with most of the leakage in the depth interval from 100 m to 800 m. The required strength of the crosscoupling coefficient in the source region (30 mV/bar) is reasonable, given the typical range of values for rocks from a few to 50 mV/bar.

The interpretation of the observed changes during injection has to be tempered by the presence of the cathodic protection system. This system introduces the possibility of cultural noise contamination. However the form of the large scale anomaly is not readily explained by this source. In addition, measurements made in conjunction with two separate tests give similar results where the data overlap.

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FIGURE CAPTIONS

- Figure 1. Geological cross-section at the Raft River KGRA, Idaho (Blackett, pers. comm.).
- Figure 2. Repeat measurements of self-potential during the quiescent periods prior to Tests 2 and 5. These data show the typical repeatability with a standard deviation of 6 mV.
- Figure 3. Contour map of the self-potential prior to Test 5. The t,- symbols show the location of a cathodic protection system.
- Figure 4. Contour map of the change in self-potential during Test 5. The period of injection was 350 hours.
- Figure 5. Contour map of the change in self-potential during Test 2. The period of injection was 24 hours. Although the data are sparse, the changes are similar to those in Figure 4.
- Figure 6. Cross-section of Model 1 showing the location of the point of injection, the vertical fracture and the SP source region (hatched region). Model parameters in Table 1.
- Figure 7. Contour map of the self-potential produced by Model 1. Dashed lines are the -5 mV contours from the observed self-potential change of Figure 4.
- Figure 8. Cross-section of Model 2 with a shallower SP source region (hatched) compared to Model 1. Model parameters in Table 1.
- Figure 9. Contour map of the self-potential produced by Model 2. Dashed lines are the -5 mV contours from the observed self-potential change of Figure 4.

Figure 1.

SELF - POTENTIAL REPEAT MEASUREMENTS RAFT RIVER

Figure 2.

Figure 3.

SELF-POTENTIAL RAFT RIVER

⊖⊕ LOCATION OF CATHODIC PROTECTION DIPOLE

--- SP LINES

— CONTOUR INTERVAL 25 MILLIVOLTS

• WELLS

0 SCALE 500M

14

Figure 4.

SELF - POTENTIAL CHANGE RAFT RIVER TEST 5

$V(\text{injection}) - V(\text{before})$

SELF-POTENTIAL CHANGE RAFT RIVER TEST 2

$V(\text{injection}) - V(\text{before})$

Figure 5.

MODEL 1

CROSS - SECTION [2D]

Figure 6.

SELF - POTENTIAL MODEL 1

Figure 7.

MODEL 2 **CROSS - SECTION [2D]**

Figure 8.

Figure 9.

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SELF - POTENTIAL MODEL 2