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MAPPING THE ACID STIMULATION IN THE BEOWAWE GEOTHERMAL FIELD USING SURFACE ELECTRICAL POTENTIALS

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ABSTRACT

A surface electrical potential system was fielded during the chemical stimulation of the Rossi 21-19 well in the Beowawe Geothermal Field. The technique, which measures variations in resistivity resulting from the flow of conductive fluid into the reservoir, was not only shown to be highly sensitive, not only to the chemical treatment, but also to the in situ conductive zones before any acid injection. A review of the experiment and a preliminary interpretation of the data are presented. The data provide convincing evidence that it should be possible to map the treated zone as well as the primary pre-treatment in situ conductive zones.

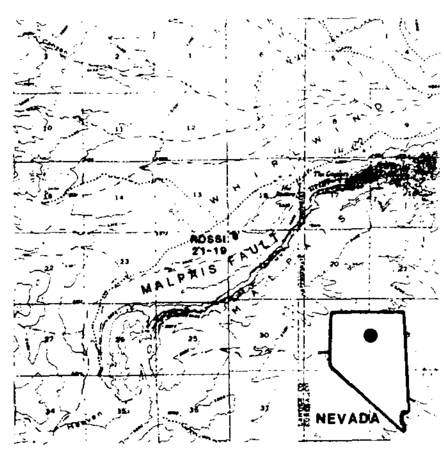
INTRODUCTION

Chevron has drilled a total of five deep wells in the Beowawe Geothermal Field in north-central Nevada. One of these wells, Rossi 21-19, has been subcommercial, even though it does intersect a high-temperature zone. Pressure interference tests have shown that all of the Chevron wells are hydraulically connected. Thus, it has been assumed that Rossi 21-19 was completed in a limited zone of restricted permeability and/or was damaged during drilling (Republic Geothermal, 1983 and Hanold, 1983).

As a part of DOE's comprehensive 8-well geothermal reservoir well stimulation program, Republic Geothermal, Inc. and its contractors performed a 60,000 gallon two-stage chemical stimulation treatment intended to remove the near-wellbore restriction suspected to exist in Rossi 21-19. Sandia National Laboratories participated in the acid stimulation experiment by fielding a surface electrical potential system that has been developed to map fracture treatments. This diagnostic technique has been used in the evaluation of hydraulic fracture treatments of oil and gas reservoirs, but had never been applied in a geothermal well or during an acid stimulation treatment. The objectives of its use at the Beowawe site were to determine whether or not the technique is sensitive to chemical treatments of geothermal wells and, if so, to map the directional nature of the treated zone.

SITE DESCRIPTION

The Beowawe Geothermal Field is located on an ENE striking Basin and Range normal fault which marks the southwest boundary of Whirlwind Valley, a few miles southwest of the town of Beowawe in north-central Nevada (see Figure 1). The complicated geology of this field has been the subject of many geologic studies, including Smith (1983), Struhsacker (1980), Zoback (1979), and Garside and Schilling (1979). The reservoir is thought to be in the lower Paleozoic carbonates at depths approaching 20,000 to 30,000 feet. The low salinity brine of the reservoir (1200 ppm TDS) flows upward from the carbonates by way of a complicated series of faults (Epperson, 1982). The east-northeast trending Malpais fault system is one of two major fault sets in the area. As shown in Figure 1, Rossi 21-19 lies along the Malpais fault zone at the base of the Malpais rim.



each square - 1 square mile

Figure 1. Map of the Beowawe Area Showing Rossi 21-19.

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ROSSI 21-19

The stimulation well, Rossi 21-19, was drilled by Chevron Resources Company in 1979 to a depth of 7212 feet. A slotted liner is hung at the producing zone (4178 ft - 7213 ft). The actual production interval(s) in the well may lie anywhere in a range between 130 and 1000 ft. Interpretations of electric log data suggest possible productive intervals at 4400-4600 ft, 5000 ft and near 6100 ft. Downhole static temperature is near 386°F at 5100 ft (Republic Geothermal, 1983).

THE SURFACE ELECTRICAL POTENTIAL SYSTEM

The surface electrical potential system (SEPS) measures variations in resis- tivity contrasts resulting from the flow of a conductive fluid into the earth. This system, essentially a "misse a la masse" technique (Parasnis, 1973), utilizes the stimulation well as a current source electrode and an outlying well as the current sink. Hole-to-surface resistivity measurements are made by injecting bipolar pulses of current into the stimulation well and measuring the resultant distribution of electrical poten- tial on the earth's surface. A rigorous analysis of potential distributions resulting from a penetrating electrode has been pre- sented by Muskat (1932).

The surface distribution of equipotential lines surrounding the pole source buried in a laterally isotropic earth (a homogeneous halfspace) is in the form of concentric circles with the stimulation well as their center, as shown in Figure 2. During stimulation, the well casing, along with the associated reservoir matrix, when filled with a conducting fluid, acts as a changing current injection electrode. As the stimulation treatment progresses, the electrode geometry changes and the electrical potentials measured at the surface reflect this changing shape.

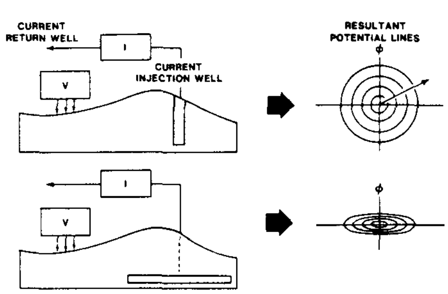

Figure 2. Surface Electrical Potential Distribution.

The SEPS da.a are taken by periodically recording the induced potential differences at the earth's surface between an infinite reference probe and the data probes placed every 15° circumferentially around the stimulation well. Background data are taken to establish the induced potential levels around the well prior to the stimulation treatment. These data then become the reference data for detecting the changes produced when the conductive fluid alters the electrical geometry. If the electrical potentials before, during and after the stimulation are compared, diagnostic information about the directional nature of the treatment is obtained.

SEPS INSTRUMENTATION CONFIGURATION

The surface electrical potential data were taken by measuring potentials at 65 probe locations placed circumferentially around Rossi 21-19 at distances of 750 ft, 2000 ft and 4000 ft. A schematic of the probe array is presented in Figure 3. The probes were stainless steel rods measuring 18 inches in length and 1/2 inches in diameter and were driven approximately 6 inches into the ground. A wire from each probe was fed to an associated potential measurement box (PMB) located adjacent to the inner potential probe. The output from the PMB's was frequency multiplexed into cables which carried power from an instrumentation van (B-59) to the PMB's and transmitted data from each PMB to the instrumentation van.

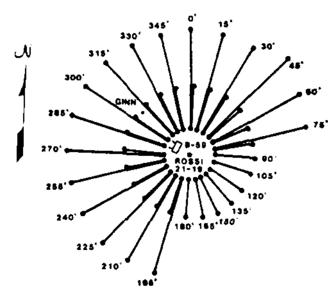

Figure 3. Surface Electrical Potential Array for Rossi 21-19 Acid Stimulation.

The potential field was created by injecting electrical current flow into Rossi 21-19. Bipolar current pulses from a series of solid gel batteries was injected at the Rossi 21-19 wellhead, and the current was returned via two current return (sink) wells. The first sink well, the Batz well, was approximately two miles NE of Rossi 21-19. Interference tests had previously suggested that Batz was hydrologically coupled to Rossi 21-19. Thus, this current return path was a part of the current injection electrode. The second current return well was a windmill that was located approximately three miles SW of the injection well. This well was drilled in a shallow fresh water reservoir and had no hydraulic communication with Rossi 21-19.

The directional reversal of the injected current during each measurement was necessary to prevent polarization effects. The potential for each probe location was taken as the difference between the sampled positive and negative pulse referenced to infinity and normalized with respect to the current used to induce the field. The injected current and the data collection were controlled from the instrumentation van by a PDP 11/34 minicom- puter.

STIMULATION EXPERIMENT

The stimulation design for Rossi 21-19 was a two-stage chemical treatment confined to the slotted liner interval below 4369 ft. An abbreviated test schedule is given in Table 1. The first acid treatment included 500 bbl of 14.5 percent hydraulic acid (HCl)) dis- placed by 2400 bbl of water and the second treatment consisted of 982 bbl of 12 percent HCl and 3 percent hydro-floryl (HF) acid solution followed by 4000 bbl of water (Smith, M. C., 1983). Injectivity tests performed before and after stimulation indi- cated a 2.3 fold increase in injectivity by the end of the second treatment.

TABLE 1. TEST SCHEDULE

Date	Activity	Fluid Pumped
8/16-8/17	SEPS Background Data	None
8/20	Injectivity Test	Water
8/21	Acid Injection 1, Injectivity Test	Water & HCl Water
8/22	Acid Injection 2, Injectivity Test	Water,HCl,HF Water
8/23	SEPS Post-Test Data	None

Since the success of this diagnostic tech- nique relies on changes in resistivity resulting from the flow of a conductive fluid into the formation, quantitative estimates of expected resistivity contrasts were made before SEP was fielded. Resistivity of the in situ brine was measured at 80 ohm-m. The effect of adding various concentrations of HCl to the sampled in situ water is shown in Figure 4. The reduction in resistivity by an order of magnitude is due almost entirely to the HCl. The addition of HF to the solu- tions has an insignificant effect due to the high acidity of HCl and the low ionization constant for HF. Thus, it was concluded that SEPS should easily detect the presence of HCl at the levels to be injected.

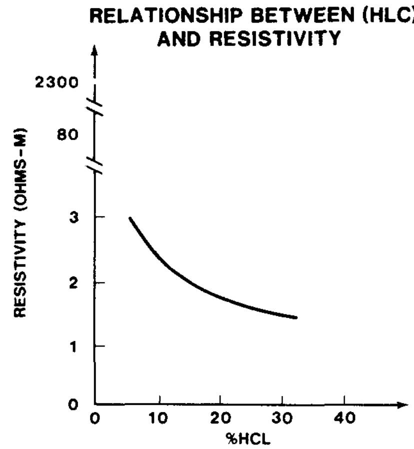

Figure 4. Resistivity vs (HCl).

PRELIMINARY DATA INTERPRETATION

SEPS data from both current return wells were collected during all of the experimental stages outlined in Table 1. A different set of data was acquired approximately every five minutes. The data was displayed in the field during real-time, so some indication of the directional nature of the treatment zone was available on site. Since that time, data from discrete times that are representative of the various experimental stages (back- ground, injectivity tests, acid injections and post-test) have been more thoroughly examined. Analysis of these "snapshots" along with the real-time observations pro- vide a preliminary interpretation of the subsurface activity during the chemical stimulation.

Polar plots of the background data collected around Rossi 21-19, using the Batz well for current return, are shown in Figure 5. The

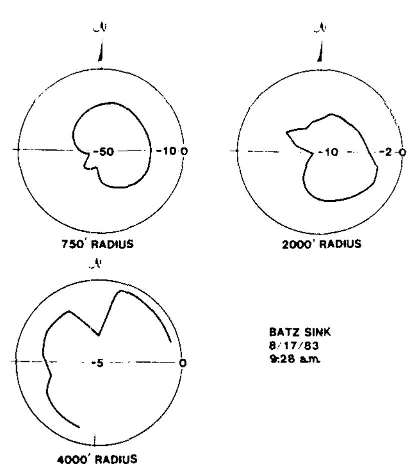

Figure 5. Polar Plot of Pre-Stimulation Potentials (mV/A) around Rossi 21-19.

windmill current return data provided similar plots. These data remained stable over a two day period. Because of the resistivity contrast between the in situ brine and the surrounding earth, the Malpais fault (60°/255°) is seen in the background data from all three radii. Also apparent in the data are a near surface conductive body at the 195°, 750 ft probe and a near surface anomaly at the 4000 ft radius in the vicinity of the 0° and 345° probes. A neighboring well, Ginn 1-13, is depicted by the protrusion in the 2000' radius, 315° probe. This probe location was within 100 ft of the 9000+ ft well. Notice that the magnitude of the potential measurement decreased because the current was sinking in this deep well.

No observations were made during the injectivity tests. This is not surprising because the water was being pumped from and reinjected to the same reservoir, thereby creating no resistivity contrast.

Some activity was observed along the known predominant fracture direction and toward the Ginn well during the hydrochloric acid stage, but the data did not indicate any significant movement during this stage. The HCl was not expected to produce any measurable stimulation effect, but was necessary to prevent formation of insoluble calcium fluoride precipitate in the formation during the second stage (Hanold, 1983).

Data from the second acid injection portray definite acid flow patterns as exemplified in Figure 6. Major acid flow paths were along the Malpais fault line (60°/255°) and along a 15°/195° path. Although not obvious from the "snapshot" displayed in Figure 6, some movement of the treatment fluids was seen along an east-west path approximately 2000 ft north of Rossi 21-19 with activity centered at Ginn 1-13. The conductive paths observed during the HCl/HF treatment are illustrated in Figure 7.

Post-stimulation data (Figure 8), when compared to the background data of Figure 5, indicate that the chemical treatments altered the in situ flow patterns. The predominant 60°/255° fracture is still present but the flow appears to be enhanced along the 60° azimuth. This is most obvious in Figure 8 from the 4000 ft radius data. The stimulation also appears to have increased permeability between Rossi 21-19 and Ginn 1-13.

Although data from the windmill sink was not presented in this paper, the response was consistent with that of the Batz well.

SUMMARY

The surface electrical potential system was fielded during the chemical treatment of

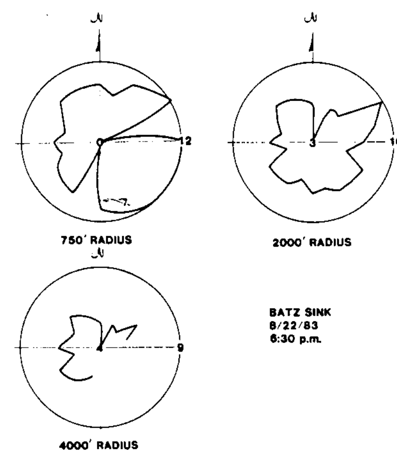

Figure 6. Polar Plot of Acid Injection 2 Potentials (mV/A) around Rossi 21-19.

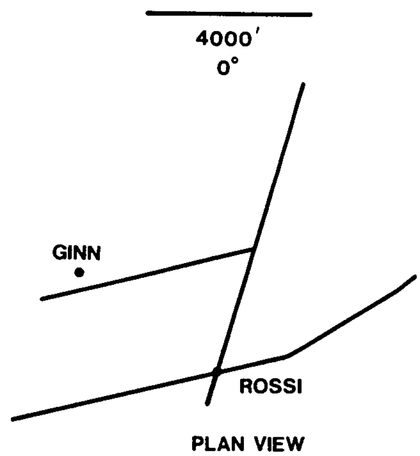

Figure 7. Plan View of Conductive Paths During Acid Injection 2.

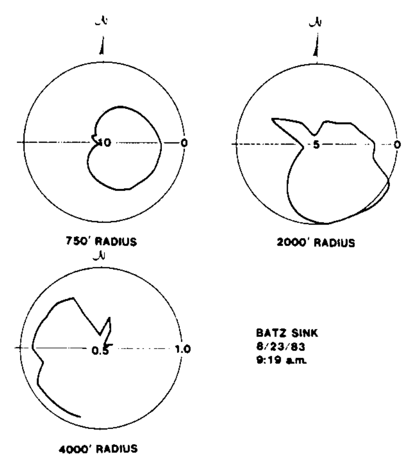

Figure 8. Polar Plot of Post-Stimulation Potentials (mV/A) around Rossi 21-19.

Rossi 21-19 in the Beowawe Geothermal Field in north-central Nevada. The objectives of its use at the Beowawe site were to determine the sensitivity of the technique to chemical treatments of geothermal wells and to map the directional nature of the treated zone.

Post-test data indicate that the stimulation indeed altered flow patterns. Moreover, the SEPS was, in fact, sensitive to the chemical treatment and there appears to be substantive data relative to the directionality of the treatment.

Because of the high conductivity of the in situ fluid, the system was able to detect a major conductive path extending along azimuths ENE and WSW from Rossi 21-19 before any acid injection. This path of flow was enhanced during the stimulation treatment and a second major flow path appeared to the NNE. Some activity was also evident in the vicinity of an adjacent well (Ginn 1-13).

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