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# SIXTH WORKSHOP
# GEOTHERMAL RESERVOIR ENGINEERING

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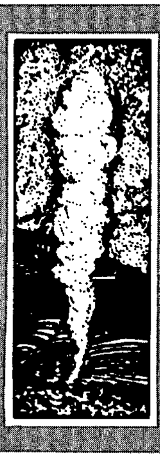

Henry J. Ramey, Jr. and Paul Kruger, Editors
William E. Brigham, Ian G. Donaldson, Roland N. Horne,
and Frank G. Miller, Co-Principal Investigators
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# LOG INTERPRETATION TECHNIQUES TO IDENTIFY PRODUCTION ZONES IN GEOTHERMAL WELLS

Mark Mathews

Geosciences Division

Los Alamos Scientific Laboratory

Los Alamos, New Mexico 87545

## Abstract

Identification of production zones in a fractured or faulted geothermal well is quantitatively difficult. Temperature and spinner surveys along with flow tests are the techniques generally used to identify and describe these fractured zones during production testing. These techniques generally do not describe the production zones in any detail and they miss or bypass potential zones of production when fractures have been closed or plugged during the drilling process. These latter zones could possibly be stimulated (hydraulic fracturing, acidizing, explosive fracturing) and brought into production if all the fracture zones could be identified and described. Interpretation techniques using wireline logs show promise in identifying and describing fractured (open and closed) zones in geothermal wells. The strategy described in this paper on two different geothermal wells (the hot dry rock well and the Surprise Valley well) used a trial and error basis to outline and define the interpretation techniques that work best in each case. Fracture zones are identified that are both open and closed and this type of information gives a better estimation of reservoir size, flow control and reservoir life (production potential) from geothermal wells.

## Introduction

Isolation of potential production zones by perforating a cemented casing is a common and routine practice in reservoir engineering for oil and gas production. Open hole and slotted casing completion techniques are used occasionally in competent formations, but lack the control and definition of the production zones. In geothermal well completions and usual geothermal reservoir engineering practice, open hole and slotted casing completions are routine. The definition of the actual production zone or zones is generally not known very well, if at all.

Isolation of potential geothermal production zones in fractured igneous rock is difficult. Detection of fractures with a single reliable logging or interpretation technique has not yet been developed. In an article, "Current Status on the Study of Naturally Fractured Reservoirs," the authors, R. Aguilers and H. H. Poolen, list eight different techniques for resolving the fracture identification problems in oil and gas reservoirs. These eight techniques of fracture identification are supported by 214 references, and 32 of these references are related to log-analysis techniques. The interpretation techniques that are useful for a specific hydrocarbon well and field are found on a trial and error basis. This is also the strategy that has been used in geothermal wells and fields.

Fracture Zone Identification

In the Geothermal Well Log Interpretation State-of-the-Art Report (LA-8211-MS) 11 logs or log interpretation techniques are discussed that might be used for the location of fractures. These logs or log interpretation techniques are:

(1) Borehole geometry (caliper logs)
(2) Temperature surveys
(3) Acoustic logs (full wave sonic, amplitude waves, cycle skipping, etc.
(4) Porosity comparisons (sonic vs neutron vs density)
(5) Borehole televiewer
(6) Spontaneous potential - SP (streaming potential)
(7) Resistivity logs
(8) Compensated density log (correction curve)
(9) Multiarm microresistivity logs (dipmeter)
(10) Spectral gamma log (potassium, uranium, thorium content)
(11) Rock strength (bulk modulus computed from sonic and density logs).

An example of the use of some of these techniques for evaluation of fractures in a hot dry well at Fenton Hill, New Mexico will be presented. Five techniques were used to define and quantify the variable termed "Frac." The techniques used were:

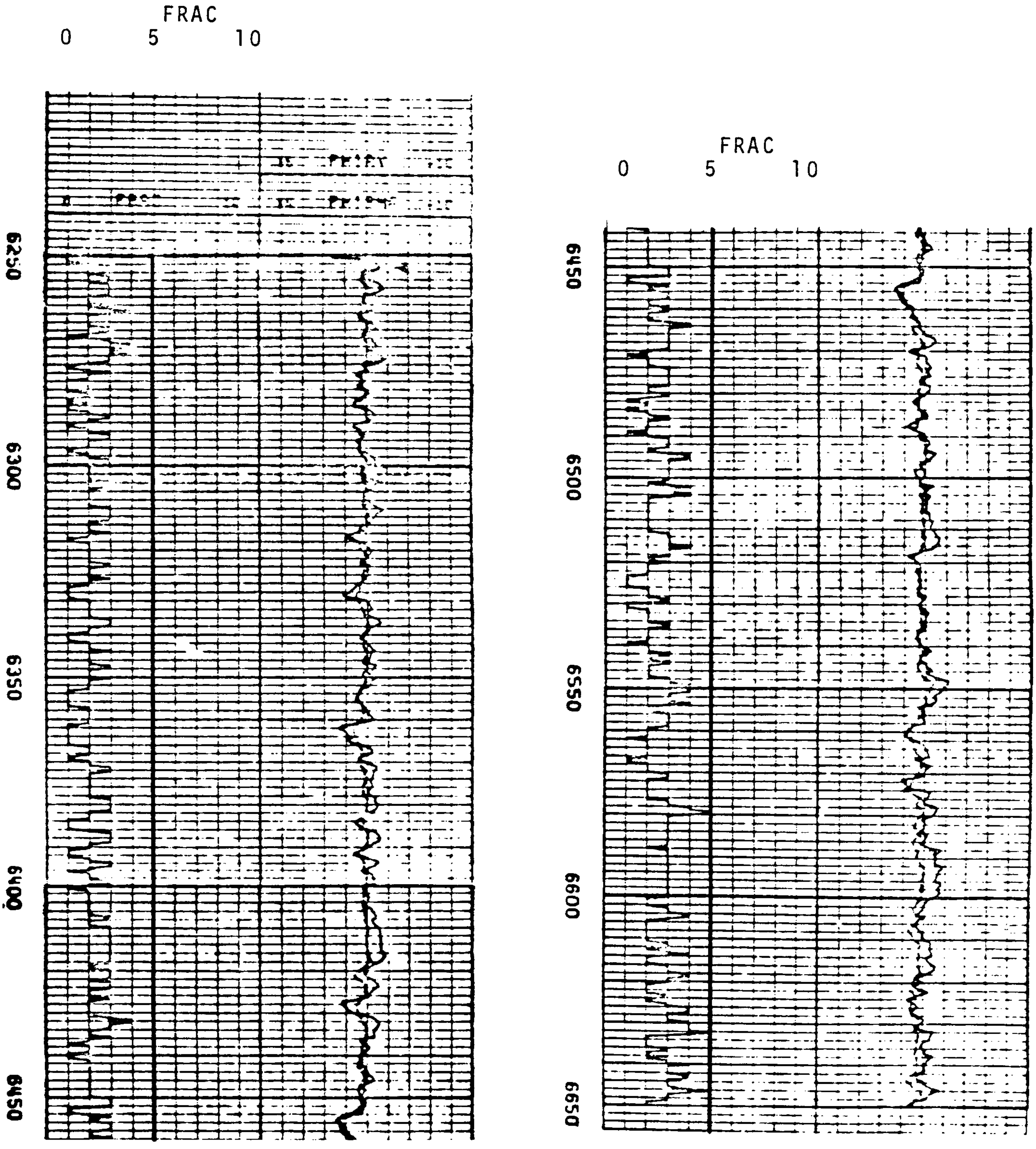



Figure 1: Fracture Detection Technique for Well GT-2.

(1) Resistivity
(2) Caliper (hole washout)
(3) Correction curve for density log when borehole is in gauge (excessive correction)
(4) Comparisons of porosity (sonic vs density vs neutron)
(5) Rock strength (mechanical properties using sonic and density logs).

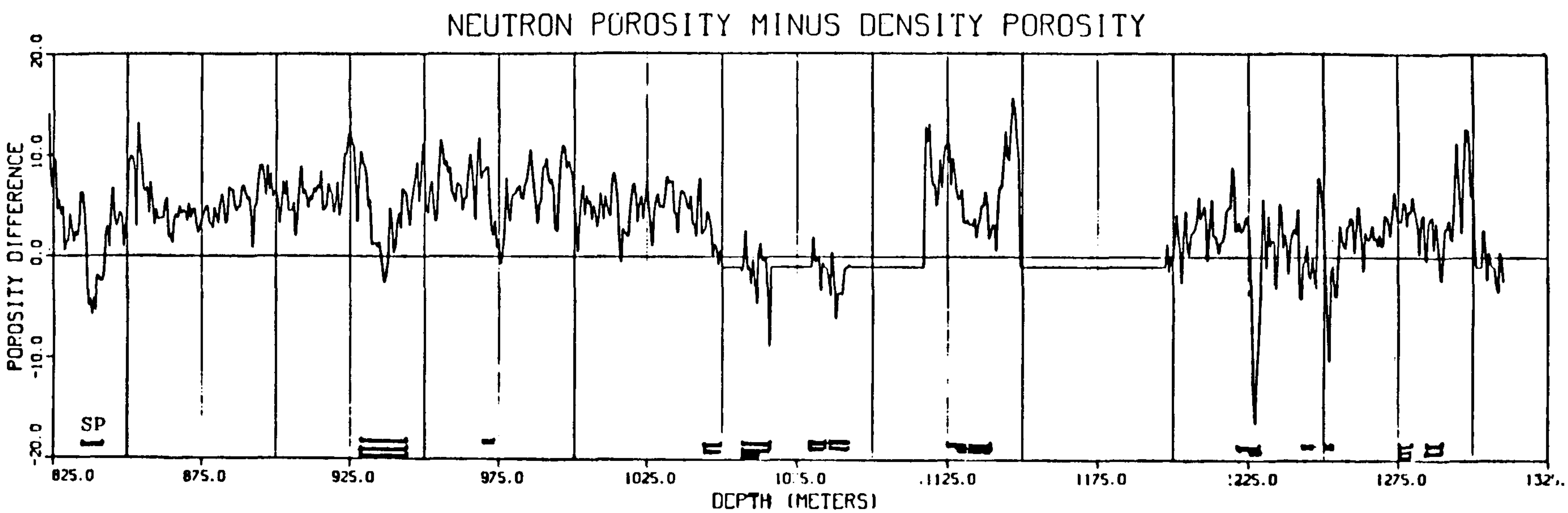
A list of each technique that indicated a fracture at a given depth was added a value of 1 to Frac. With a range of 0 to 5, the larger the value of Frac, the possibility of the existence of fractures increases. This result of the application of this method is displayed in Figure 1.

The description of the rock in the interval from 1905-2027 m (6250-6650 ft) is given by Pettitt, 1975, and Kintzinger and others, 1977, as predominantly light pink granite. The zones from Figure 1 that have values of 5 for Frac are at depths of 2006.1 m (6580 ft), 2022 m (6632 ft). These zones are fractured as described by Kintzinger (1977). We note that no estimates of permeability were made, but it is estimated that values were very low.

Another example of fracture detection is presented in the case history report on Surprise Valley, California for the Phipps No. 2 geothermal well. This well was drilled through a complex igneous lithology sequence consisting of basalt, breccia, agglomerate, volcanic ash, and welded tuff. The detailed description of the lithologic column was accomplished through the use of well cuttings and various wireline logs. The potential open and closed fractures were identified by log interpretation techniques. These are:

(1) Spontaneous potential (SP) combined with the resistivity logs
(2) Density response
(3) Neutron response.

The SP deflections on the order of 10 to 15 millivolts indicated an open fracture in this well. Also the difference in the neutron porosity ($\phi_N$) and the calculated density porosity [$\phi_D = (\rho m - \rho)/(\rho m - 1)$], where $\rho m$




Difference in porosity value from the neutron log and porosity calculated from the density log. Washed out intervals are set to -1 to render them easily identifiable. The position of SP deflection is shown by bars along the bottom of the plot. One bar corresponds to a deflection greater than 5 mV; two bars, greater than 10 mV; and three, greater than 15 mV. Below 1200 meters location of the SP deflections depends on correlation of the electric logs from the original hole and the redrill and is somewhat less precise.

Figure 2. Fracture Detection Techniques for Well Phipps No. 2.

is the matrix density and $\rho$ is the density log value, indicated open and closed fractures. The washed out intervals were determined from the caliper log and are set to -1 to render them easily identifiable. Where the porosity difference becomes negative (see Figure 2) and corresponds to a SP deflection, these indications denote zones of open fracturing. These zones should be isolated and tested for hot water production. Note that no estimates of permeability of the zones can be made from the log data.

## Conclusions

Production zones of geothermal wells that are related to fractures can be identified by the use of drill cuttings and wireline logs. Each geothermal field or area has local conditions that suggest the various interpretation techniques for detecting and evaluating fracture systems. No single reliable interpretation technique for detecting and evaluating fracture systems has been developed. A trial and error approach with various logging and interpretation techniques to locate and evaluate fractures has been shown in two different geothermal fields in this paper. Production testing of the zones indicated as fractures will verify these results. If the results are positive, this type of information will yield better reservoir size definition, flow control, and estimation of production from geothermal wells.

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