Geothermal Resources Council, TRANSACTIONS Vol. 7, October 1983

A PRELIMINARY REPORT ON FRACTURED IGNEOUS ROCK ENVIRONMENT TEST PITS

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ABSTRACT

Geophysical well logs can now be calibrated for the measurement of physical properties of some igneous and metamorphic lithologies and for the determination of fracture porosity. These geologic conditions are routinely encountered in geothermal reservoirs and geothermal fields.

Three large calibration models or test pits were completed on May 1, 1981, at the United States Geological Survey (USGS) Denver Federal Center Calibration Facility. Each calibration model was constructed of large stone blocks that have a cored borehole and wire-sawn simulated fractures. Details of the test pit sizes, simulated fracture locations, rock type of each test pit, and location and access of these pits are discussed herein.

Geophysical well logs were obtained from these test pits and these data are shown and discussed.

INTRODUCTION

Geothermal well logging and log interpretation are currently being developed. The proper interpretation of geophysical logs can increase (or promote) user confidence in estimates of geothermal reservoir size and quality.

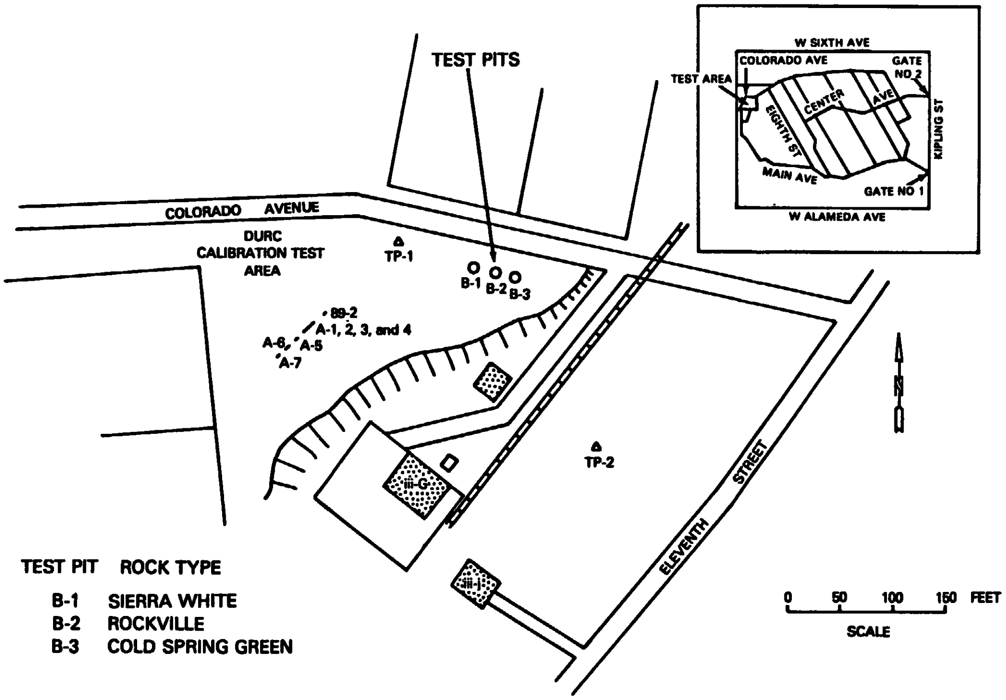
Crucial to reservoir evaluation is the development of techniques for the interpretation of geophysical logs run in both exploration and production wells. Certain parameters are essential for evaluation of a particular geothermal resource, and the priority of a parameter determination varies with resource type. A list of parameters for needed development of log measurements and interpretation techniques was developed for geothermal exploration under the categories of formation evaluation and production management (Mathews, 1980). The parameters of lithology, permeability (intergranular and fracture), porosity (intergranular and fracture), and fracture systems were listed under "Formation evaluation." Calibration of logging equipment for igneous and metamorphic lithology and for fracture location and porosity could not be done at that time. Because of the importance of these parameters, calibration models or test pits constructed of large stone blocks with simulated fractures were constructed for calibrating geophysical borehole logging equipment.

BOREHOLE MODEL REQUIREMENTS AND CONSTRUCTION

Three models or test pits were built as primary standards and are located at the USGS Denver Federal Center Calibration Test Area in Denver, Colorado, as shown in Figure 1. These test pits are available for public use at no charge and reservations can be made with the USGS Water Resources Division (303/234-2617) for scheduling the use of these test pits. The dimensions of each test pit are shown in Figure 2 and the rock block geometries and fracture orientation directions for each test pit are given in Figure 3.

Construction began in the summer of 1980 with the drilling of three holes, each with a diameter slightly greater than 10 ft and a depth greater than 25 ft. A Fiberglas cylinder 10 ft in diameter was inserted in each hole. Each pit has a concrete base that was poured into and under the Fiberglas cylinder, and this base is strong enough to support the weight of the rock in each pit. There is no reinforcing metal in the concrete base of any of the test pits, and each pit has a plastic pipe 9 in. in diameter that extends 30 ft below the concrete base and acts as a runpipe or rat hole. Each Fiberglas cylinder, cement base, and plastic run pipe form a container that holds the rock and water of each test pit. The container is built so that it is watertight. Covers made of Fiberglas are placed over the container and bolted with Fiberglas bolts and nuts to the top, completing these test pit containers as shown in Figure 4.

Each test pit contains a different type of rock as listed in Figure 1. Test pit B-1 has Sierra white granite, a fine-grained granite quarried near Raymond, California. Test pit B-2 has Rockville granite, a coarse-grained granite quarried near Rockville, Minnesota. Test pit B-3 has Cold Spring green blocks, a medium-grained, low-grade metamorphic granodiorite quarried near Au Sable Forks, New York.



TEST PIT	ROCK TYPE
B-1	SIERRA WHITE
B-2	ROCKVILLE
B-3	COLD SPRING GREEN

Figure 1. Location of calibration test area at the Denver Federal Center.

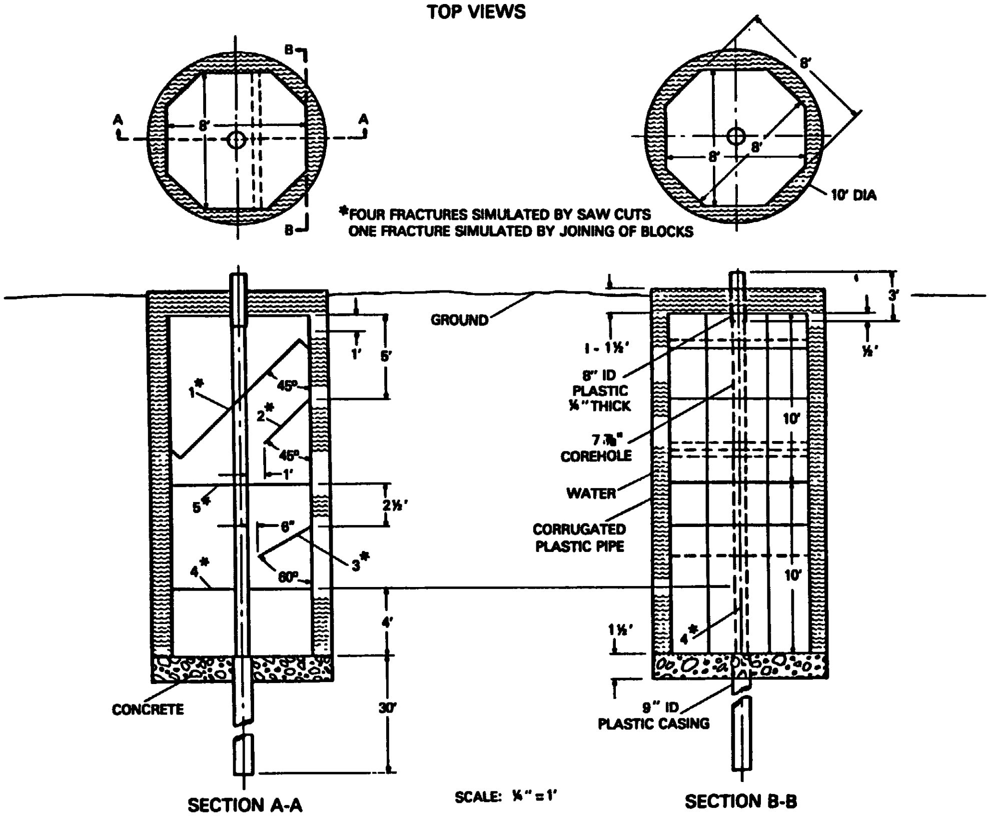
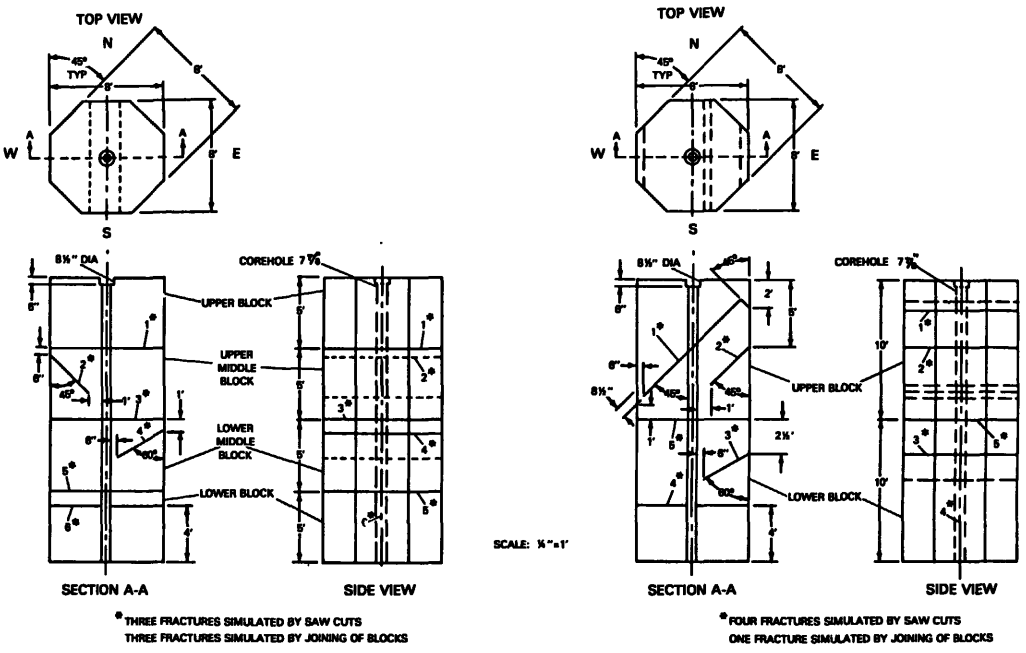


Figure 2. Test pit design.



COLD SPRING GREEN (LOW GRADE METAMORPHIC GRANODIORITE) GEOMETRY

SIERRA WHITE AND ROCKVILLE GRANITE GEOMETRY

Figure 3. Rock block geometries for test pits.

The finished rock was delivered, checked for dimensions, and placed in the test pits as shown in Figure 5. The cored borehole and the eight sides of each block were aligned to give the block geometry shown in Figure 3. Each borehole was also aligned with the run pipe in each model so a continuous borehole of 50 ft was achieved. An 8-in. plastic pipe was inserted 6 in. into the hole at the top of the rock in each model and acts as a guide between the Fiberglas lid and the rock. The depths from the flanges of the Fiberglas covers (with lids removed) to the tops of the rock blocks are: 41.9 in. (3.49 ft) for the B-1 test pit, 42.8 in. (3.56 ft) for the B-2 test pit, and 27.8 in. (2.31 ft) for the B-3 test pit.

The cores from the cored boreholes were analyzed by G. R. Olhoeft and others of the USGS Laboratories for their petrophysical properties, and the average values are given in Table 1. A more detailed analysis of these core results is underway.

TABLE 1. AVERAGE PETROPHYSICAL PROPERTY VALUES

		Natural State		
Pit	Rock Unit	Density (g/cm^3)	Porosity (%)	Velocity (ft/s)
B-1	Sierra white granite	2.64	0.24	18,700
B-2	Rockville granite	2.69	0.22	20,600
B-3	Cold Spring green	2.77	0.71	22,500

These calibration pits are saturated with fresh water at shallow ambient ground temperatures. The log environment obtained from these pits matches the conditions that are routinely found in logging most sections of geothermal wells. High temperatures and hot water are anomalous conditions that can be regulated and adjusted through calibration/test wells, core analysis, and cross plots. Different water salinities can also be analyzed in this manner. The fixed primary standard calibration pit provides a base line or starting point in log response, and other geologic conditions can be analyzed with reference to this starting point.

LOGGING RESULTS

The top of the flange of each test pit with the lid removed is the zero reference point on all log depths discussed in this section. The logs acquired from these test plots are: natural gamma, neutron-thermal neutron, density (long- and short-spaced detector), caliper, induced polarization, self potential, magnetic susceptibility, sonic (Δt, velocity, amplitude), and Wenner resistivity (8- and 16-in. array).

The results of the neutron-thermal neutron, density-short spaced detector, sonic-Δt, and natural gamma logs from these test pits are shown in Figures 6-9. The neutron-thermal neutron log (Figure 6) and the natural gamma log (Figure 7) results show different rock or matrix properties

Figure 4. Test pits with Fiberglas covers.

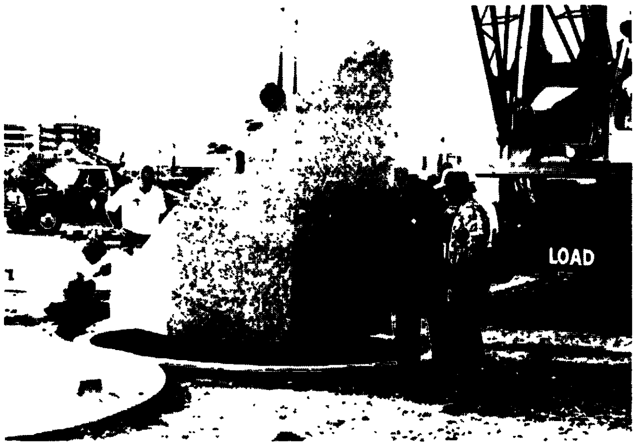


Figure 5. Careful attention was paid to orientation of blocks as they were placed in the pits.

of these models. The results are summarized in Table 2. The neutron-thermal neutron response is reduced to approximately 200 API units at the bottom of the test pits by the high-porosity rock below the pits and by the simulated vertical fracture.

The density log results from these test pits for the short (8.15 in.) source to detector spacing yields approximate densities of 2.5 g/cm^3 for B-1, 2.5 g/cm^3 for B-2, and 2.6 g/cm^3 for B-3, as shown in Figure 8. Density decreases seen on these log results correlate with the location of the horizontal or 45° fractures that intersect the borehole. This is seen at A (decrease to 2.2 g/cm^3) on B-1, at A (decrease to 2.2 g/cm^3) and H (decrease to 2.0) on B-2, and at H_2 (decrease to 2.5 g/cm^3) on B-3. A slight enlargement of the borehole or misalignment of the two adjacent rock blocks at these locations could also partially account for some of the decrease seen in the density logs from these test pits.

The sonic log results for the P-wave transit time from these test pits is shown in Figure 9. This sonic log has a transmitter and two receivers with a 3-ft spacing between the transmitter and one receiver, a 4-ft spacing between the transmitter and the other receiver, and a 1-ft spacing between the two receivers. The arrival times of the P-wave are subtracted from the two receivers and this result is divided by their separation of 1 ft. The general results are summarized in Table 3.

Transit time increases are seen on the log results at all locations where fractures intersect the borehole (A and H on B-1 and B-2 test pits and H_1, H_2, and H_3 on B-3 test pit. A dramatic increase in transit time is seen at the location of the vertical fracture that intersects the B-2 test pit borehole, but the other two test pits (B-1 and B-3) do not exhibit this feature. This phenomenon probably is caused by

TABLE 2. MATRIX PROPERTIES OF NEUTRON-THERMAL NEUTRON AND NATURAL GAMMA LOG RESULTS

Test Pit / Log	B-1	B-2	B-3
Neutron-Thermal Neutron	Approximately 1500 API units average for upper half (upper rock block, 10 ft); approximately 2100 API units average for lower half (lower rock block, 10 ft); slight decrease in API units at A, which correlates to 45° fracture.	Approximately 2000 API units average for entire model, a very slight decrease in API units at A and H, which may be indications of these fractures.	Approximately 2200 API units average for upper block (5 ft); approximately 2400 API units average for two middle blocks (10 ft); approximately 2100 API units average for lower block (5 ft).
Natural Gamma	Approximately 55 API units average for entire test pit.	Approximately 180 API units average for entire test pit.	Approximately 20 API units average for entire test pit with slight variations for each individual rock block.

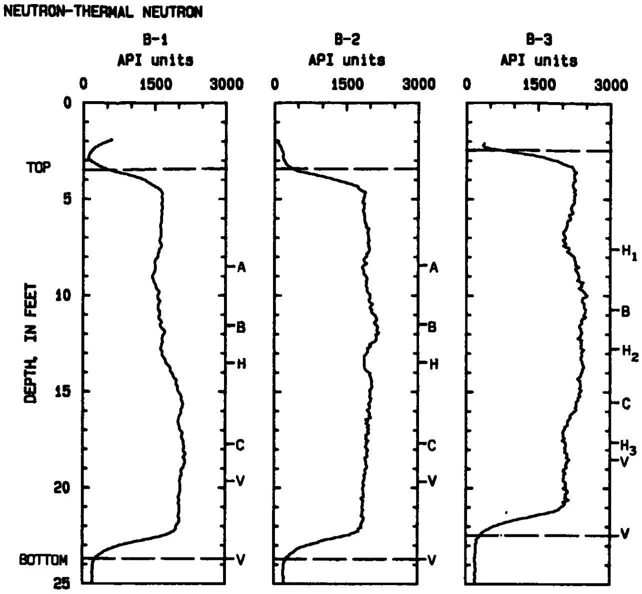


Figure 6. Neutron-thermal neutron. API units are defined by the American Petroleum Institute, 1974.

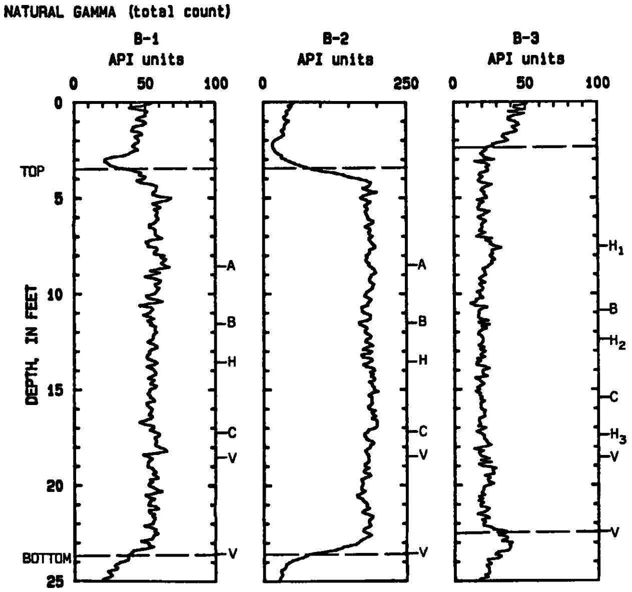


Figure 7. Natural gamma (total count). API units are defined by the American Petroleum Institute, 1974.

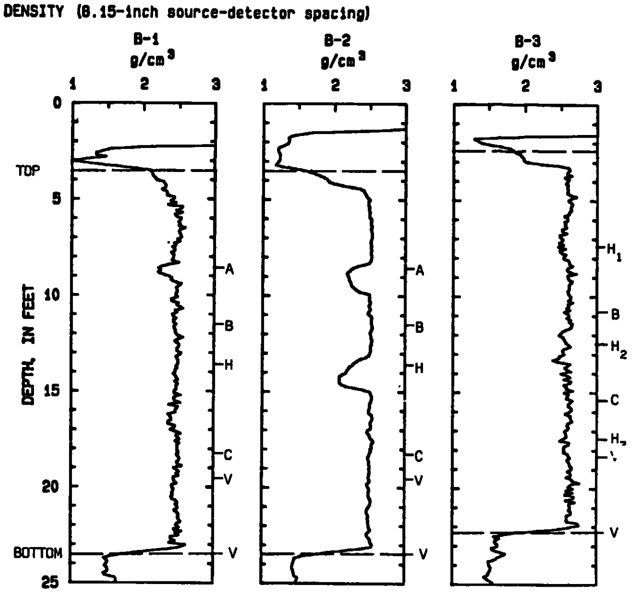


Figure 8. Density (8.15-in. source-detector spacing).

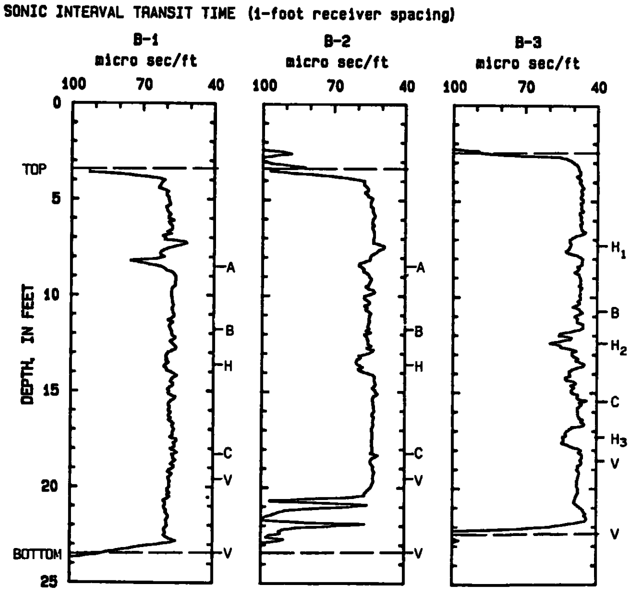


Figure 9. Sonic interval transit time.

Legend for Figures 6-9:

____ ____ ____ Top and bottom of rock blocks.

Angle of fracture that intersects borehole: A - 45°; H - Horizontal; V-V - Vertical.

Angle of fracture that does not intersect borehole and distance from borehole: B - 45° and 1.0 ft; C - 60° and 0.5 ft.

TABLE 3. SONIC LOG RESULTS FOR P-WAVE TRANSIT

Log \ Test Pit	B-1	B-2	B-3
Sonic	Approximately 59 μs/ft (16,950 ft/s) average for entire test pit.	Approximately 54 μs/ft (18,520 ft/s) average for entire test pit.	Approximately 47 μs/ft (21,275 ft/s) average for entire test pit.

either a malfunction of this sonic tool or a rough borehole for this interval. Slight fluctuations in the recorded transit time (this could be noise) are also observed for locations in these test pits where the fractures do not intersect the borehole (locations B and C). More data from different sonic logging tools and caliper tools are needed to verify this association.

CONCLUSIONS

The average petrophysical properties obtained from the core, along with the known location and fixed geometry of the simulated fractures of these calibration test pits, provide primary standards for calibrating logging equipment in igneous and metamorphic lithology with fracture porosity. The logging results presented in this paper show the different log responses to the dissimilar matrix properties and simulated fractures of these test pits. This calibration capability increases the interpretation reliability of geophysical logs obtained from igneous and metamorphic environments. It hopefully will also stimulate the development of the economic potential of geothermal prospects. These calibration test pits and their standardization capability are designed to improve geophysical logging and log interpretation in fractured competent rock environments.

ACKNOWLEDGMENT

The authors appreciate the efforts of Ed Karls of Cold Spring Granite Company; Scott Keys, Gary Olhoeft, Gordon Johnson, and Frank Stead of USGS; Joe Walker and Tom Clark of Fenix and Scisson; all the people who were on the Geothermal Log Interpretation Steering Committee; and other firms and individuals that supported the construction of this calibration facility.

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