HYDRAULIC FRACTURE INITIATION SITES IN OPEN BOREHOLES IDENTIFIED BY GEOPHYSICAL LOGS

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Smith et al (1975) have proposed the creation of man-made geothermal energy reservoirs by drilling into relatively impermeable rock to a depth where the temperature is high enough to be useful; creating a reservoir by hydraulic fracturing; and then completing the circulation loop by drilling a second hole to intersect the hydraulically fractured region.

The initiation of hydraulically created fluid reservoirs in highly impermeable hot dry rock must by definition take place in a wellbore. The nature of these initiation sites will provide the initial resistance to flow into the reservoir and therefore will strongly influence the rate of energy withdrawal. The nature of the interception site in a second wellbore which has been directed to intersect the reservoir will have a similar effect.

The program to create and study such artificial geothermal reservoirs in hot dry rock is being pursued by the Los Alamos Scientific Laboratory and has been presented to these workshops by Murphy (1975) and Murphy et al (1976). In parallel with the drilling of the two boreholes rather complete suites of wellbore geophysical logs were run followed by further diagnostic logging both during and after fracturing operations. This paper discusses some aspects of what has been learned about the entrances and exits of some of the hydraulic fractures created in both the GT-2 and EE-1 wellbores. Table 1 gives the location of the more important fractures and the types of logs used to both identify the location of these fractures and to measure some of their properties.

The Caliper Log

This important and quite dependable logging technique has proved to be the most useful method for detecting both potential sites for fracturing and the actual fractures. Pressure-volume records taken during the fracturing process show that the great majority of fracture initiations show no breakdown; this observation is consistent with the opening of incompletely cemented natural fractures occurring along the open borehole. Also the cemented zone in these natural fractures appears to have widths great enough after erosion by the drilling process for the caliper arm to register. Figure 1 is a 4-arm caliper log taken in EE-1 at the end of the drilling and prior to fracturing. The strong response of one set of arms is consistent with a set of highly vertical slots. This region was subsequently determined by means of temperature and tracer logs to be the entrance to the main EE-1 fracture. This fracture has a very low impedance and exhibits the desirable property of self-propping. The caliper log has revealed other regions in the two boreholes with similar caliper signatures that may be other cemented fractures with desirable features. A series of such fractures when hydraulically stimulated may provide the nucleus of a three-dimensional geothermal reservoir.

The Spinner Log

The measurement of the flow of fluid into a fracture opening provides the most conclusive proof of fracture location. Figure 2 shows the response of the spinner tool during a flow of $\sim$170 gpm into two open hole fractures. By averaging the results from 8 spinner runs a detailed analysis of the locations of the two fractures was made. This analysis was later confirmed by televiewer pictures. The relative flow fraction and the flow distribution into each fracture can be derived from this log. This log would have been used more often but its temperature capability to date has limited its use to upper regions of the boreholes.

The Borehole Televiewer

The conditions existing in the two boreholes are ideal for the use of this logging technique except for high temperature. Scott Keyes of the United States Geologic Survey in cooperation with G. C. Summers* has recently developed a high temperature televiewer which has been used successfully in EE-1 at a depth of 10,000 ft and a temperature of 205°C. Figure 3 is a televiewer composite of the region in GT-2 that was shown in Figure 2. A fracture with a dip of 87° relative to the borehole and a strike of N4°E is identified between 6526 and 6540 ft. The vertical range of the fracture is identical with that derived from the spinner surveys.

The Spontaneous Potential Log

Significant changes in the potential field measured in an open wellbore are caused by hydraulic fracturing and the subsequent flow of fluid into the fracture. Figure 4 shows both the reversible and irreversible changes accompanying such fracturing. A background log from casing to TD in the open borehole is followed by a second log taken after fracturing. Two permanent large anomalies mark accurately the position of two fractures. Later SP logs taken both during pumping and venting show that the widest anomaly accepts most of the flow and is therefore designated the main fracture. SP logs taken under both static and dynamic conditions are proving to be extremely valuable in understanding the total fracture process in open boreholes.

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The Impression Packer

The impression packer has been used to record the nature and orientation of fractures created from open wellbores. Figure 5 shows a tracing of the outer surface of an impression packer taken in GT-2 over the region covered both by the spinner log and the televiewer. Table 2 gives the parameters of the two fractures obtained from the various logs. As with some of the other logging techniques, higher temperatures have prevented its further use.

Oriented Cores

Numerous oriented cores have been obtained during the drilling of both GT-2 and EE-1 and the geologic information that they contain has aided greatly in the understanding of the total system. Figure 6 shows a map of a core taken under rather unique circumstances. Recent redrilling of the GT-2 wellbore was directed towards the interception of the main EE-1 fracture (origin at $\sim$9060 ft) which was kept pressurized. The drilling of GT-2 was halted at the time when a major drop in pressure in EE-1 was noticed. The core taken at this point shows the bottom portion (marked A in the Figure) of the intercepted pressurized fracture. The initial success of this operation suggests that further attempts may produce cores that will contain extremely valuable samples of actual fracture surfaces.

The Tracer Log

This type of log can yield important information concerning the flow of fluid through the borehole system and its subsequent movement into any accompanying fracture or porosity. Figure 7 shows the history of a released I^{131} sample as it was pumped down the EE-1 casing and then returned up behind the casing through an uncemented annulus to a hydraulically created fracture centered at 9060 ft. Almost 80% of the injected flow appears to be following this flow path. This fracture opening would have been difficult to detect and accurately locate with any other logging technique.

This powerful method will be used extensively in the analysis of complex flow systems that will arise from multiple fracturing from open wellbores.

The Temperature Log

This standard wellbore logging technique has proved invaluable in locating both fracture origins and zones of porous rock. Temperature logs have been taken during the pumping of fluid into the fracture system, subsequent venting and the following temperature recovery phase. Figure 8 shows the temperature history measured in the EE-1 wellbore. The numbered positions have generally been related to various features noted in other wellbore logging surveys. This logging technique will have great value in understanding the heat removal process especially if they can be run throughout the long-term heat extraction experiments.

REFERENCES

1. Murphy, H. D., Dec. 15-17, 1975; "Hydraulic-Fracture Geothermal Reservoir Engineering," First Workshop on Geothermal Reservoir Engineering and Well Stimulation, Stanford University, Stanford, CA (sponsored by NSF).

2. Murphy, H. D., Lawton, R. G., Tester, J. W., Potter, R. M., Brown, D. W., and Aamodt, R. L, Dec. 1-3, 1976; "Preliminary Assessment of a Hot Dry Rock Geothermal Energy Reservoir Formed By Hydraulic Fracturing," Second Workshop on Geothermal Reservoir Engineering, Stanford University, Stanford, CA.

3. Smith, M. C., Aamodt, R. L., Potter, R. M., and Brown, D. W., May 19-29, 1975; "Man-Made Geothermal Reservoirs," Second United Nations Geothermal Energy Symposium, San Francisco, CA.

TABLE 1

Logging Techniques Used to Define Fracture Positions

Log	Fracture (Borehole, Approx. Depth (ft)) GT-2, 6530; 6560	GT-2B, 8740;	EE-1, 6420;	EE-1, 9060;	EE-1, 9670
Caliper (4-arm)	x	x	x	x	x
Spinner	x	-	-	-	-
Televiewer	x	-	-	-	x
Spontaneous Potential	-	x	x	-	-
Impression Packer	x	-	-	-	-
Oriented Core	-	x	-	-	-
Tracer	-	-	-	x	x
Temperature	-	x	-	x	x

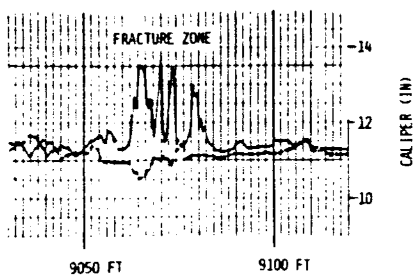
TABLE 2

Fracture Measurements in GT-2 at 6525-6570 ft.

Log	Upper Fracture Orientation	Vertical Range (ft)	Lower Fracture Orientation	Vertical Range (ft)
Spinner	--	6526-40	--	6554-6568
Televiewer	N3°E	6526-40	N12°E	6555-6569
Impression Packer	N25°E	--	N25°E	--

FIGURE 1

DRESSER ATLAS 4-ARM CALIPER
LOG IN EE-1



SPONTANEOUS-POTENTIAL LOGS
IN EE-1 AUG 27, 1975

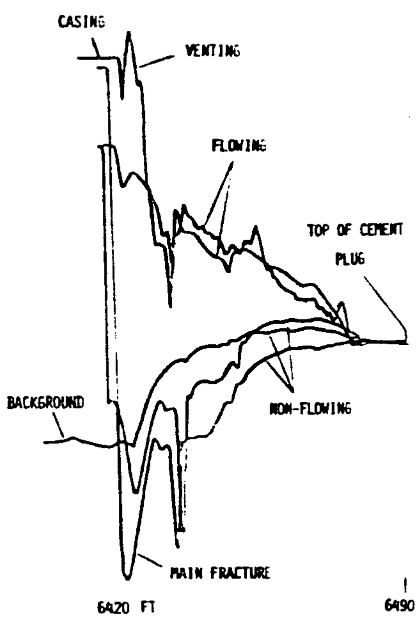


FIGURE 2

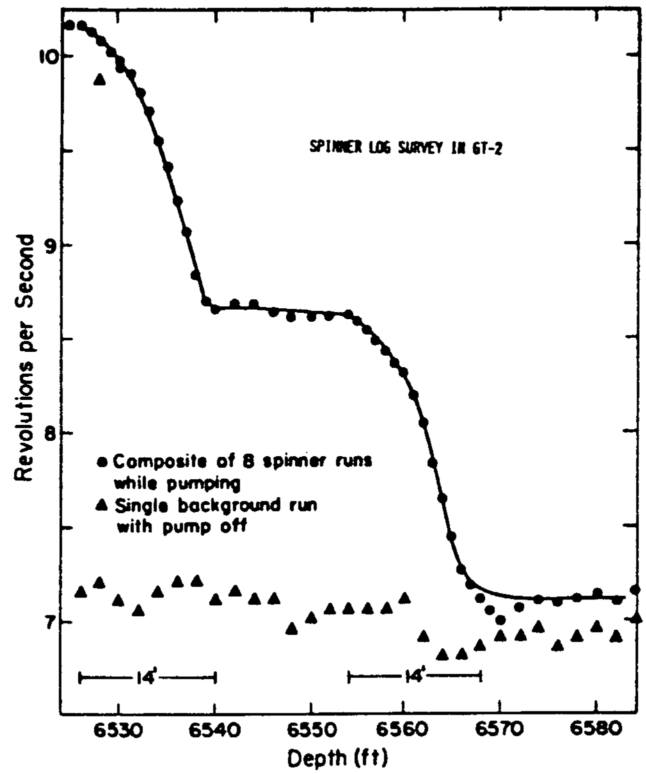


FIGURE 3

FIGURE 4

TELEVIEWER PICTURES
FROM GT-2

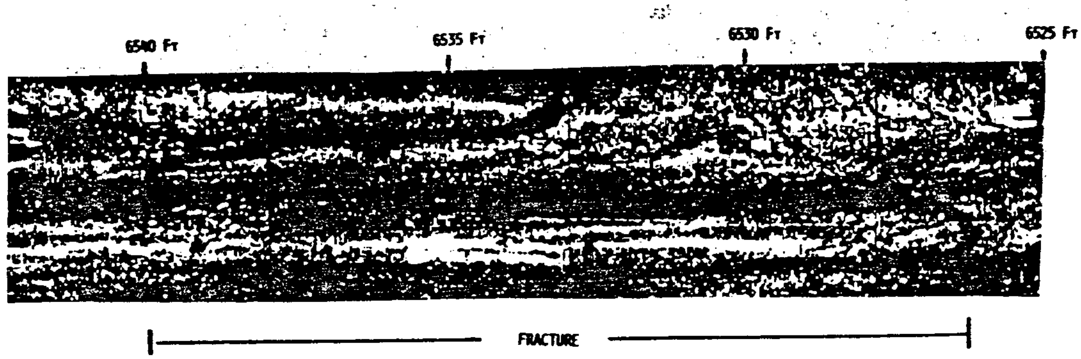


Figure 5

TRACING OF IMPRESSION FROM
UPPER PACKER IN GT-2

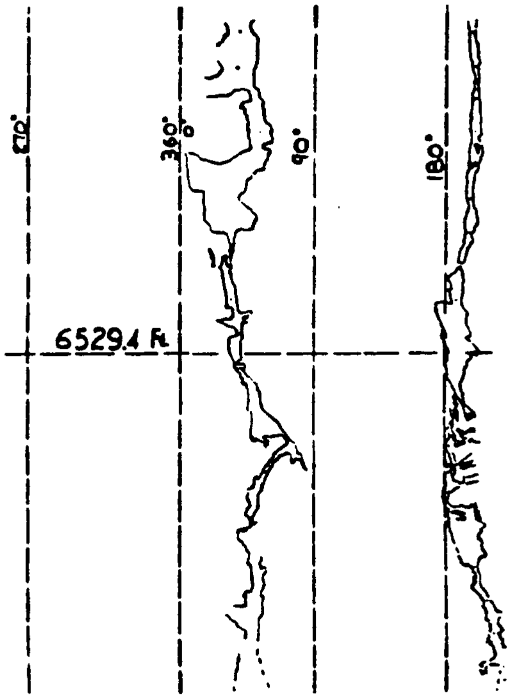


Figure 6

MAP OF CORE TAKEN IN
GT-2B AT 8742 FT

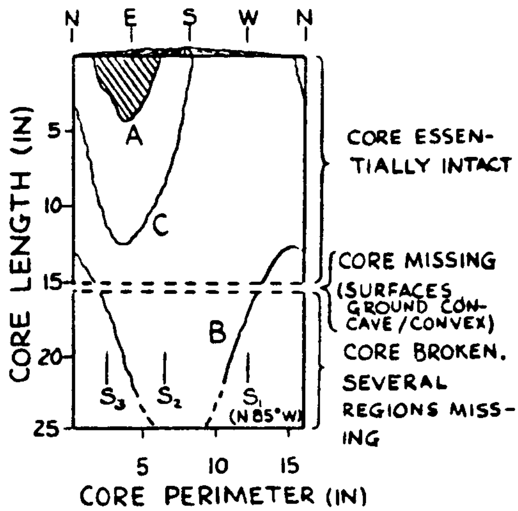


Figure 7

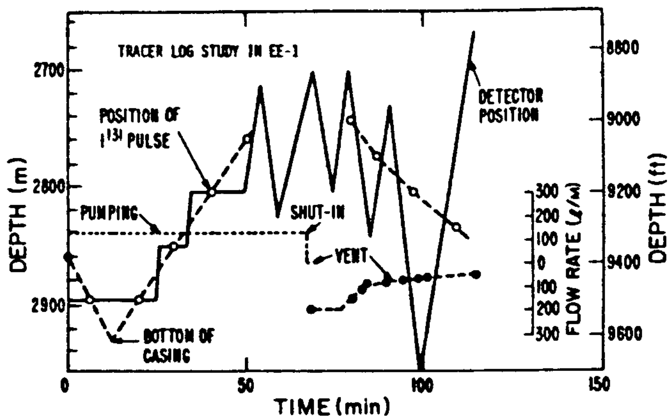


Figure 8