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FEASIBILITY OF A BOREHOLE VHF RADAR TECHNIQUE FOR FRACTURE MAPPING *

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ABSTRACT

Experiments were conducted to establish the feasibility of a downhole high-frequency electromagnetic technique for location of fractures in the vicinity of boreholes. An existing flame-cut slot in granite was filled with salt water to simulate a brine-filled fracture. A transmitter consisting of a phased dual-dipole array arranged to provide a directional signal toward the fracture was installed in a borehole opposite the fracture. A receiver operated at 30 to 300 MHz was also located in the same borehole. The radar returns from the simulated fracture were detectable in boreholes located at distances of up to 12 meters from the fracture. These results indicate for the first time the feasibility of a downhole VHF radar for use in a single borehole for detection of fractures located away from the borehole.

INTRODUCTION

The conduction of hot fluids into geothermal wells is, at least, partially dependent upon the presence of natural or artifically induced fractures in the geothermally active rock matrix. Because of the very high cost of drilling and fracturing in geothermal areas, it is economically critical that techniques for detecting natural or induced fractures be developed. A very desirable technique for detecting and locating such fractures is one which employs a borehole probe operating from a single hole. According to Hartenbaum and Rawson (1980), wet granite of a geothermal site can act as a low-loss dielectric for the electromagnetic (EM) waves at VHF frequency ranges (30--300 MHz). EM waves might be able to propogate tens of meters into such a formation.

In order to confirm the radar fracture detection concept, an experiment was carried out in a granite quarry site to determine whether a brine-filled fracture will provide sufficient contrast to reflect the EM waves. A pulse-echo probe developed by Southwest Research Institute (1982) was used in performing the test. S. A. Suhler and T. E. Owen of the institute were also involved in the initial planning and execution of the experiment as a Sandia contractor.

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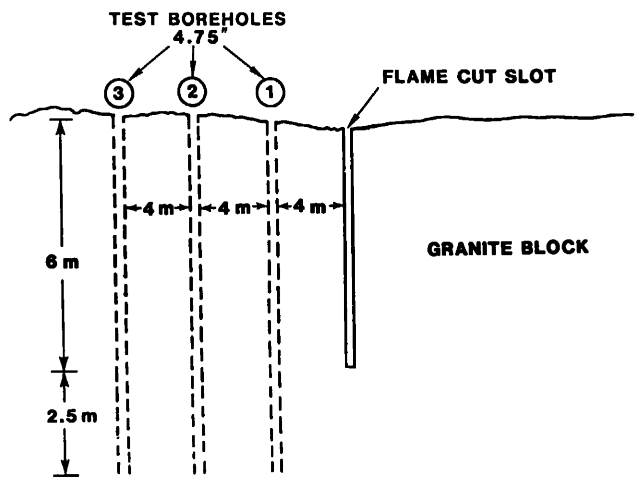
TEST SITE

The test site is a granite quarry operated by the Texas Granite Corporation in Marble Falls, Texas. The test site had an existing flame-cut slot which was filled with salt water to simulate a brine-filled fracture in a geothermal well. Three holes were located broadside to the target slot as shown in Figure 1. The holes were drilled to 8.5 meters depth, approximately 2.5 meters deeper than the target slot.



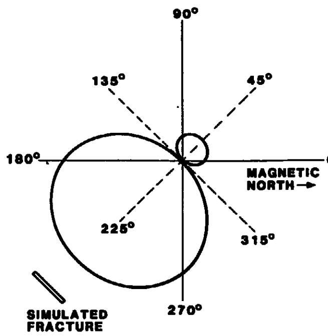
Granite Quarry Test Site
Figure 1

A barrier was installed in the slot at 3.1 meters from the closed end extending from the surface to the bottom of the slot. The purpose of the barrier was to contain fluid in the closed end of the slot. This closed off section of the slot, when filled with conductive fluid, provided a rectangular (3.1 x 6m) planar interface which is a reasonable simulation of an open fracture filled with brine.

An important goal of the tests was to determine the effects of fracture-fluid conductivity on the electromagnetic reflection signals. To perform these experiments, the slot was initially filled with fresh water. Later, the slot was filled with salt water having a concentration of approximately 10 parts per 100 which was diluted to lower concentrations by the addition of fresh water. Radar reflection tests were performed using different fluid conductivity levels. Samples of the fluid in the slot and in the boreholes were taken for later analysis.

RADAR SYSTEM USED IN THE TEST

The transmitting antenna is a dual-dipole array arranged in such a way that the radiation in one direction is enhanced, while the radiation in the opposite direction is reduced. Its beam-width is about 150° and the front-to-back ratio is about 18 db in laboratory testing. This ratio is reduced in the field due to the effects of borehole fluid and formation rocks. The direction of the transmitter is measured against the magnetic north. Its relative location with respect to the slot is shown in Figure 2. The receiver is a single dipole operated at 30-300 MHz bandwidth.



Dual-dipole array

Beam Width: about 150°

Peak Output Power: 1 KW

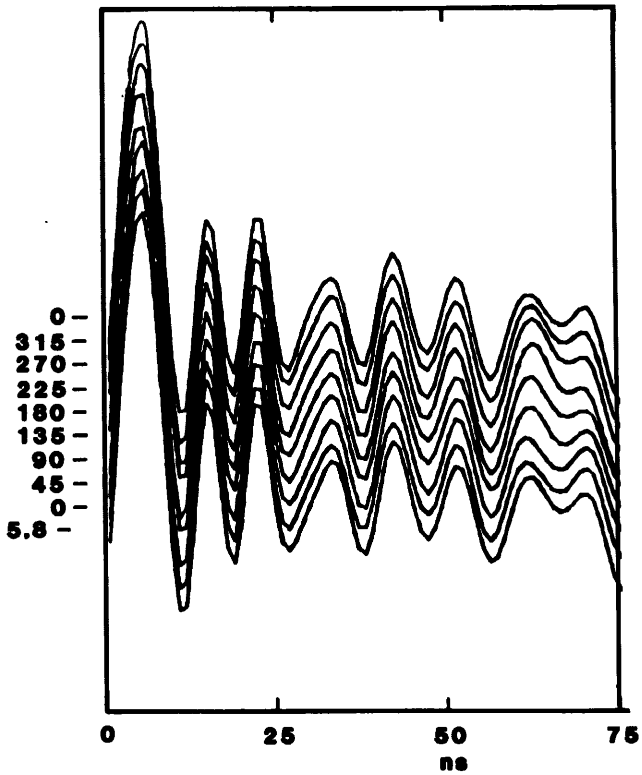
Directivity	Borehole loss
6 db	0 db
12 db	6 db

Transmitter Used in the Test
Figure 2

TEST METHOD

A metal sheet was initially inserted into the slot to represent the best condition for EM reflections. Then, the metal reflector was removed and the slot was filled with water of various conductivities to simulate brine-filled fractures.

Throughout the measurements, the probe is held stationary at each depth interval while the antenna is rotated through eight angular positions. Radar waveforms are recorded at each 45-degree increment. This procedure is repeated at each depth station until the vertical depth interval of interest is logged. This type of borehole scan assures that each of the azimuthal position recordings are made at the same level in the borehole; however, this procedure is very slow. Typical raw data is shown in Figure 3. Reflected signal from the slot is only barely visible. Further processing is necessary to enhance the desired signal.



Raw Data With Radar Probe in Borehole 1 at 5.8 Meters Depth (Salt Water in Target Slot)
Figure 3

In the signal enhancement process, video waveforms taken at complimentary angles are subtracted. The residual waveform is free of signals which are independent of antenna position such as internal feedover and vertical reflection signals from the hole collar and hole bottom. Reflection signals and noise remain in the four video waveforms with a 180-degree ambiguity as to the direction of the reflecting interface. If necessary, this ambiguity could be removed by additional processing.

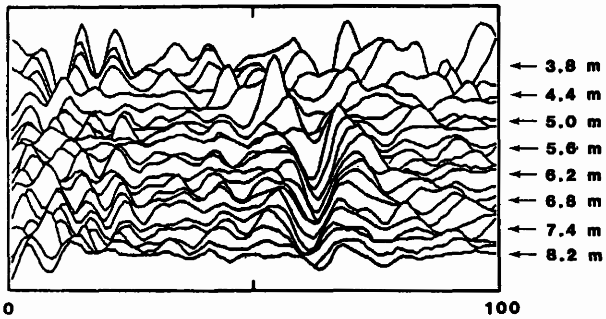
TEST RESULTS

(A) Metal Reflector Tests

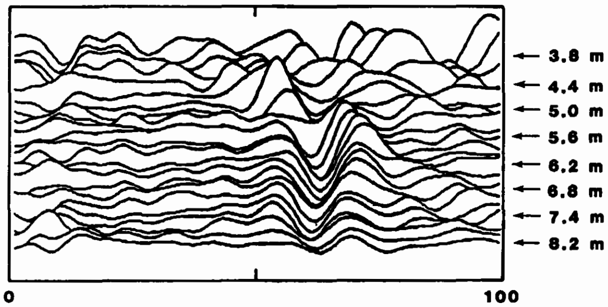
A square metal reflector eight feet on a side was fabricated using 24-gauge galvanized steel sheet attached to two 4 x 8-foot sheets of plywood. This reflector was lowered to the bottom of the slot with the metal facing borehole No. 1.

With the radar probe in Borehole No 1, constant depth-azimuthal scans from 8.2 meters to 4.0 meters depth were performed. Very little reflection signal is detectable in the raw data; however, when reverse-angle subtraction processing is applied, the large reflection signal shown in Figure 4 is obtained. In Figure 4(a) the broadband output is shown. A 100 MHz low-pass filter was applied to the data to yield the waveforms shown in Figure 4(b). The directivity of the radar antenna is demonstrated in Figure 5. Figure 5(a) shows the 90 (270) degree response and Figure 5(b) shows the 135 (315) degree response.

From the azimuthal responses shown in Figures 4 and 5, the true target direction is very near 225 degrees magnetic bearing from the borehole. Cancellation of the reflection signal is almost complete in the measurements at 135 (315) degrees.

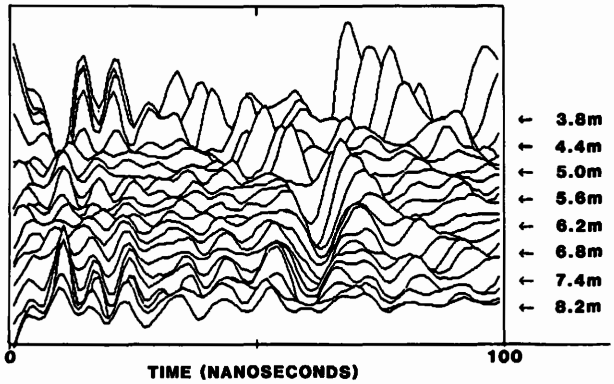


TIME (nanoseconds)
(a) BROADBAND RESPONSE, RETURNS FROM 45° and 225° SUBTRACTED

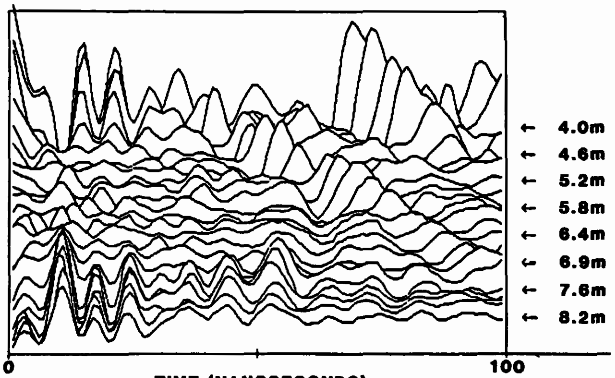


TIME (nanoseconds)
(b) 100 MHz LOW PASS FILTER RESPONSE, RETURNS FROM 45° AND 225° SUBTRACTED

Radar Signals with Probe in Borehole 1,
Metal Reflector in Target Slot
Figure 4



TIME (NANOSECONDS)
(a) Difference of Signals from 90° and 270°



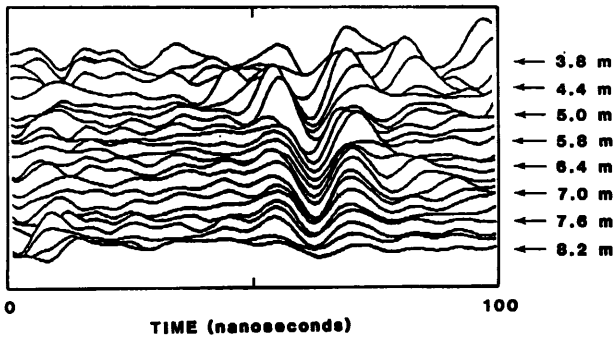
TIME (NANOSECONDS)
(b) Difference of Signals from 135° and 315°

Radar Signals With Probe in Borehole 1, Metal
Reflector in Target Slot
Figure 5

(B) Conductive Fluid Tests

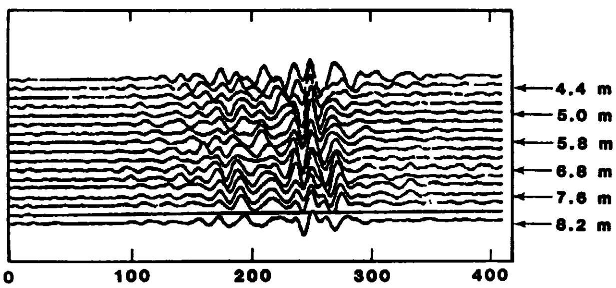
A sodium chloride brine solution was prepared by mixing rock salt with fresh water. The water was poured into the slot, allowed to stabilize in temperature, and then sampled for conductivity measurements.

Figure 6 shows the processed data when the fluid resistivity is 16 ohm-centimeters. The reflections from the slot target are not significantly different from those obtained with a metal reflector in the slot.



Radar Probe in Borehole 1, 16.0 Ohm-Centimeter Resistivity Brine in Target Slot
Figure 6

The data shown in Figure 7 were acquired employing different recording equipment. The output of the radar system was connected to a Nicolet waveform averager. An average of 128 sequential waveforms was then digitized and recorded. This process was very slow; however, the results indicate that with appropriate signal enhancement the slot is detectable by the radar at a distance of 12 meters away (Borehole 3).



Radar Probe in Borehole 3, 16.0 Ohm-Centimeter Resistivity Brine in Target Slot
(Average of 128 Waveforms)
Figure 7

CONCLUSIONS

This experiment demonstrates the feasibility of a VHF radar technique for fracture mapping. A simulated fracture 12 meters away from the borehole was clearly detected during the test. The depth of penetration into the formation can be further increased using a more sophisticated data processing technique or a higher power radar.

The transmitter used in the experiment was a dual-dipole array which provides adequate directivity with beamwidth of about 150°. Both the transmitter and receiver were packed into a 3" diameter and therefore can be operated inside a borehole. Recent study by Chang and Scott (1984) has shown the feasibility of designing a 60° beamwidth directional antenna in a 15 cm diameter housing. A high power VHF radar system is currently under design for use in a single borehole for detection of fractures located away from a borehole.

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