# FRACTURE DETECTION FROM GEOTHERMAL WELL LOGS

by

S.K. Sanyal, Stanford University,
L.E. Wells and R.E. Bickham, Scientific Software Corp.

## INTRODUCTION

Most of the geothermal systems in the world are fractured. In many systems, fractures provide the only pore spaces, serving both storage and flow capacities, while in others fractures may provide a large flow capacity but not contribute significantly to storage capacity. In either case, fracture detection becomes an indispensible step in the development of a well.

There are several ways of detecting fractures: from drilling and workover information, from well logs and flow tests of wells. This paper will discuss the state-of-the-art of fracture detection from geothermal well logs and provide a case history.

Assessment of a fractured reservoir requires not only detection of fractures in a well but also evaluation of their location (subsurface depth of occurence), orientation (whether horizontal, vertical or inclined; angle and direction of dip), aperture (width), extent of filling (open, filled, or partially filled), and habit (single fracture, set of parallel fractures, cross joints, or rubble-like geometry).

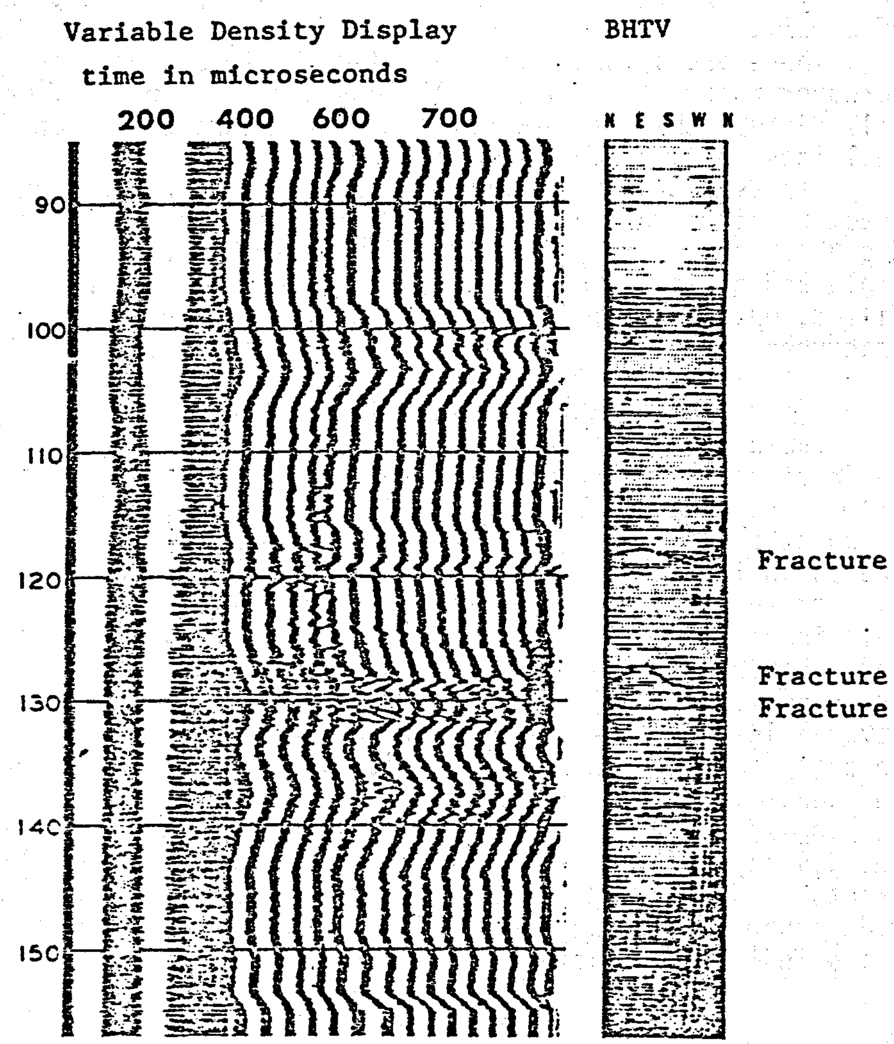
## FRACTURE EVALUATION FROM LOGS

Table 1 presents a list of various well logs and their response to fractures. During oral presentation, examples of each type of response were shown and the pitfalls in interpretation of each response was be pointed out. Only a few examples of typical fracture detection logs are shown in this paper. Figure 1 presents typical examples of a full wave train sonic log and a borehole televiewer log. On the borehole televiewer log (BHTV) one can detect two low angle fractures (wavy lines) and a horizontal fracture (horizontal lines). The corresponding full wave train sonic log (called Variable Density Display in the figure) shows several interference patterns indicating fractures. In Figure 2 is shown an example of a Fracture Identification Log (Schlumberger Trademark) through a massive unfractured carbonate section. Note the dense overlapping of the 1,2 and 3.4 resistivity profiles and overlapping of 1,3 and 2,4 caliper profiles. In Figure 3 from the same well we have shown a Fracture Identification Log through a fractured section. Note the wide separation between resistivity profile pairs and the caliper profile pairs indicating fracture.

## A CASE HISTORY

During the oral presentation, a case history of fracture detection was given. The case history is that of a well drilled by the ORE-IDA food processing company with USDOE cost sharing. The well was drilled through sediments, basaltic rocks, and tuffs. In the deeper, hotter parts of the well, fractures are the only pore spaces. Hence, fracture detection at the well site was a major effort of the drilling program. Over a dozen fracture detection criteria (see Table 1) were used to quantify the relative probability and intensity of fracturing for each zone in the well. The logs used were: SP, dual induction, guard, caliper, acoustic, density, neutron and micro-seismogram. Based on these logs, net thickness of definite, probable and possible fracture zones were estimated.

FIGURE 1. Variable density display and Borehole Televiewer (BHTV) showing fractures over a limestone section (courtesy Birdwell)



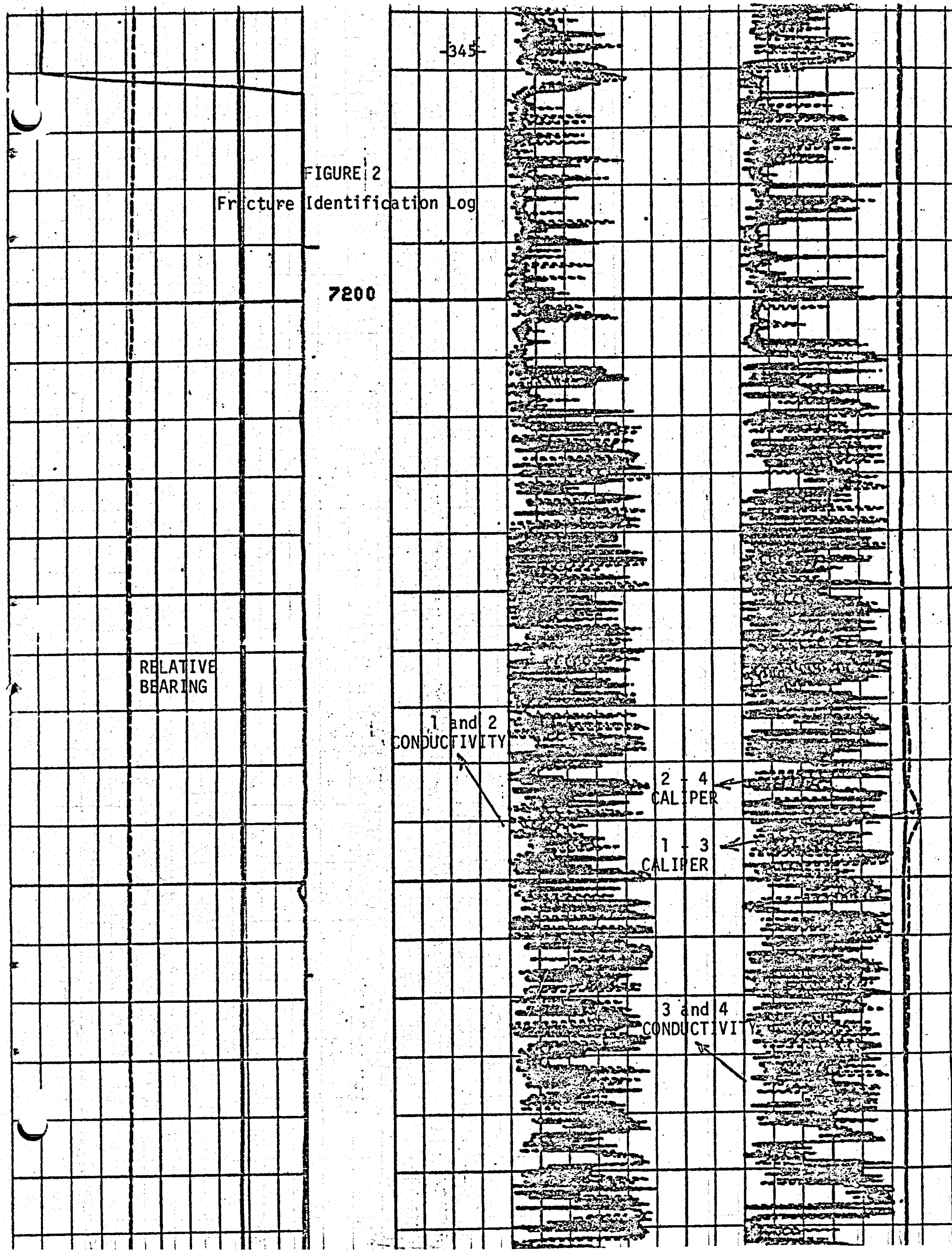



FIGURE 2
Fracture Identification Log

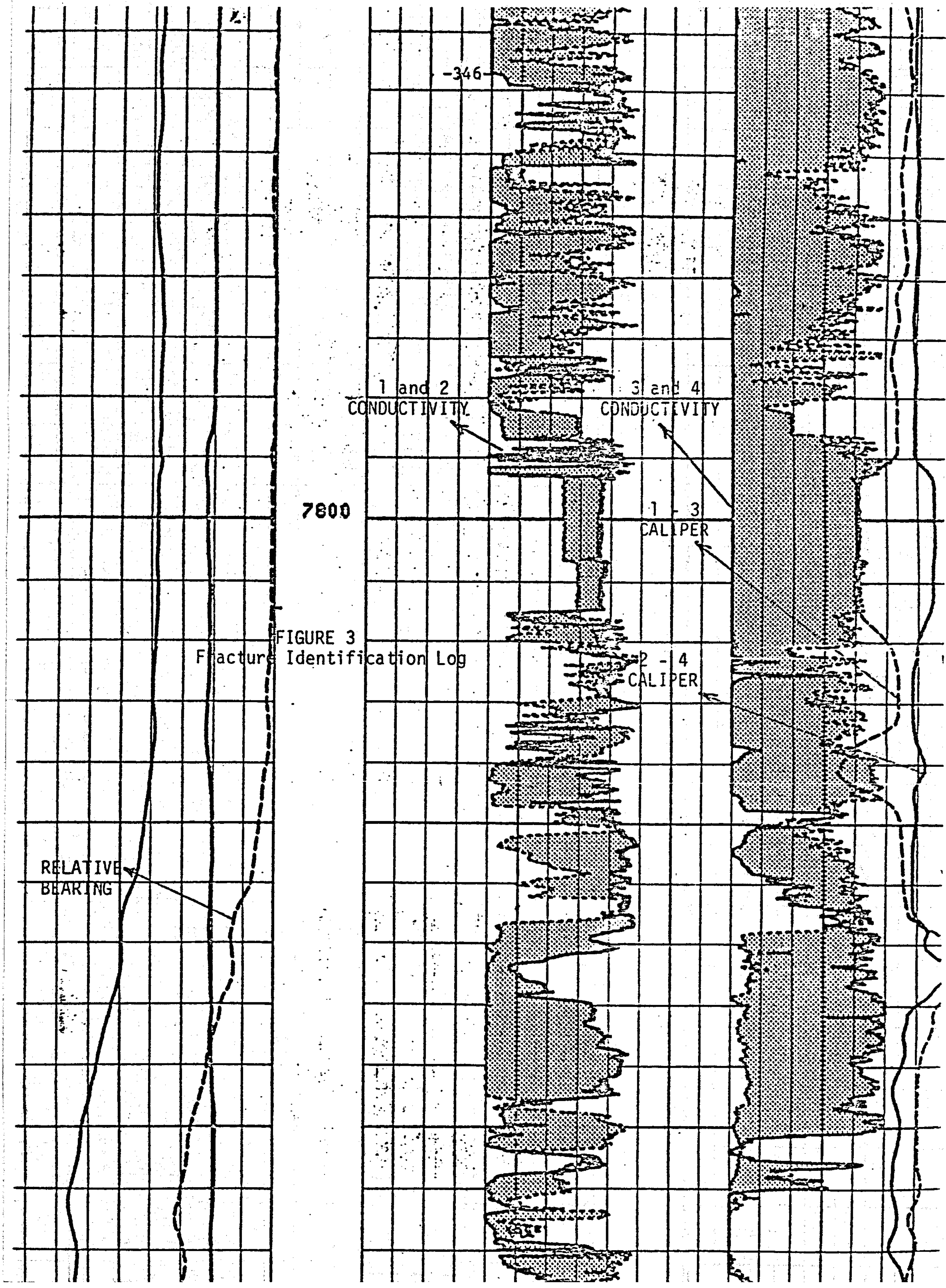



FIGURE 3
Fracture Identification Log

TABLE 1: Response of Well Logs to Fractures

| LOG TYPE | RESPONSE TO FRACTURES |
|---|---|
| 1. CALIPER | |
| 1a. 2 Arm | Hole enlargement |
| 1b. 3 Arm | Hole enlargement |
| 1c. 4 or 6 Arm | Asymmetrical hole enlargement |
| 1d. Multiarm Acoustic | Asymmetrical hole enlargement |
| 1e. Comparison of 2 & 3 Arm | Asymmetrical hole enlargement |
| 2. SPONTANEOUS POTENTIAL | Generation of streaming potential |
| 3. RESISTIVITY | |
| 3a. Comparison of tools | Different response for different tools |
| 3b. Log F vs. Log Ø | $m \approx 1$ |
| 3c. Multiarm Microresistivity (Fracture Identification Log) | Correlation of 4 resistivity profiles |
| 4. ACOUSTIC DEVICES | |
| 4a. Amplitude of Compressional Wave | Reduction, more due to high angle fracture |
| 4b. Amplitude of Shear Waves | Reduction, more due to low angle fracture |
| 4c. Full Wave Train | Attenuation and interference patterns |
| 5. COMPARISON OF POROSITY | |
| 5a. Neutron vs. Core Porosity | $\phi_N > \phi_{core}$ |
| 5b. Sonic vs. Others | $\phi_S > \phi_N, \phi_D$ |
| 6. $\Delta\rho$ CURVE | Large $\Delta\rho$ in smooth hole section |
| 7. ROCK STRENGTH EVALUATION: $\rho/(\Delta t)^2$ | Brittle fracture in strong rocks |
| 8. SPECTRAL GAMMA RAY | Increase in U concentration |
| 9. BOREHOLE TELEVIEWER | "Pictures" of fractures |

TABLE 1 (cont'd):

| LOG TYPE | RESPONSE TO FRACTURES |
|---|---|
| 10. IMPRESSION PACKER | Impression of fracture |
| 11. TEMPERATURE | |
| 11a. Production Profile | Hot anomaly |
| 11b. Injection Profile | Cold anomaly |
| 12. DRILLING | |
| 12a. Drilling rate | Increase in rate |
| 12b. Mud Circulation | Lost circulation |
| 13. DRILL CUTTINGS | Evidence of "fill" minerals |
| 14. COMPUTER INTERPRETATION | Multiple responses |