ACOUSTIC CEMENT EVALUATION - ACE

OPERATION--CALIBRATION--INTERPRETATION

H. W. KILLION
CRC WIRELINE, INC.

INTRODUCTION

The ACE log is an efficient aid in determining the quality of reservoir isolation achieved through primary or squeeze cementing.

A subject of controversy since its inception, cement bond evaluation has improved with advanced technology and with continued concern by the industry for an effective evaluation method.[1]

A better understanding of the operations principles by service company and operations personnel, meaningful calibration, and the application of logic to interpretation are some of the factors responsible for increased acceptance by the industry.

Properly run ACE logs respond to downhole conditions that are present, which may or may not correspond to the expected conditions. Unlike formation evaluation logs, there are no correlative factors extending from well to well to act as repeatability checks. Each log must stand on its own, and its interpretation must be supported with logic.

The lack of standardization of logging systems by service companies should not present an insurmountable problem to log quality or interpretation if proper basic logging principles are followed.

PRINCIPLES OF OPERATION

All acoustic cement bond evaluation systems adhere to the same basic operating principles.

A sound transmitter is positioned at a fixed distance from a receiver, Fig.1. The acoustic coupling of the transmitter-receiver housing material is poor compared with that of the surrounding media, i.e., casing fluid, steel casing, cement, and formation.

The transmitter-receiver section must be precisely centered in the casing to insure equal distribution of the transmitted signal through 360° of the surrounding media.

When a sound pulse is generated at the transmitter, the resulting acoustic waves traverse the surrounding media. Each part of this media contributes its specific data pertaining to the transit time and acoustic measurements of the total received signal. This data is transmitted to the surface and displayed on an oscilloscope as a cyclic wave form, Fig. 2. Selected portions of this cyclic wave form may be electronically isolated and measured.

Two basic ACE measurements are made from the full wave form: the signal amplitude of the first measurable casing arrival and the total transit time of the first media arrival that displays a predetermined amplitude.

The first measurable casing arrival will not vary in total transit time for a given tool diameter, casing I. D. and casing fluid. Its amplitude however will vary depending on the amount of support provided the casing by a surrounding material.

When an acoustic wave is propagated along a steel casing, the casing is set in motion. If the casing is free to move, the acoustic wave maintains its energy and the resulting casing arrival amplitude will be high.

When the casing is supported by a solid material, it is not so free to move. The acoustic wave then loses energy to a degree related to the amount of support applied to the casing. For a complete or partially bonded condition the resulting casing arrival amplitude will be low.

Positioning of the amplitude measure gate is performed by visually observing the full wave form and a bright spot or bar, representative of the measure gate position and width. Gate position, in time and width, is adjusted to span a half a cycle of the appropriate casing arrival, Fig 3a. The gate is then properly positioned in time for the duration of the log, for constant casing fluid and casing diameter conditions.

Total transit time is the lapsed time from transmitter firing until a signal is received that is equal to, or greater than a predetermined amplitude, Fig. 3b. The signal amplitude that terminates the lapsed time measurement is controlled by an adjustable discriminator circuit. The detection level of this discriminator is normally set to approximately 30% of the maximum amplitude that would be expected in unsupported casing. When casing is well supported, its acoustic signal may be sufficiently attenuated such that the discriminator is triggered by a signal other than that casing signal, Fig. 3c.

LOG PRESENTATION

All pertinent data pertaining to logging equipment, cement and casing is noted in an appropriate section of the log heading.

The ACE log consists of three sets of recorded data, Fig. 4:

Amplitude curve, scaled in millivolts, with zero at the left side of track two, and increasing amplitude to the right.

Transit time curve, scaled in micro-seconds, with increasing time from right to left of track two.

The format of acoustic data, presented in track three, is optional. It may be either interval recordings of the full wave form, or a Variable Intensity log, which is a continuous recording of the signal intensity and total transit time, of a half cycle of each arrival contained in the full wave form. Either is scaled in micro-seconds with time increasing from left to right.

CALIBRATION

The wide variation of unexpected downhole conditions involved in acoustic cement evaluation logging often creates doubt as to log validity. A lack of meaningful systems calibration, the subject of an earlier publication[1], has been a source of controversy.

Consistent transmitter signal strength and the correct positioning of the amplitude measure gate are critical factors in obtaining a valid log. Both factors may now be presented as steps in the recorded tool calibration.

Transmitter output strength is checked periodically, by centering the tool in a fluid filled, pressurized test chamber. After calibrating the received amplitude to a precise 50 millivolt pulse, this signal amplitude generated by the transmitter, is recorded, and should produce a consistent signal level for given tool and calibrator specifications, Fig 5.

The position of the amplitude measure gate is presented by recording a full wave form, with the gate positioning brightener in place, covering a half cycle of the appropriate casing arrival, Fig. 6.

The transit time circuit is calibrated to a precise oscilloscope pulse, covering a range from 200 to 1200 micro-seconds.

INTERPRETATION

ACE log interpretation begins at the well site; therefore, all data pertaining to the cement and casing program should be available to the logging operator when the log is run. This information should include:

1. Cement type and volume of each stage
2. Additives
3. Date and time pumped
4. Date and time pressure released
5. Was drill out necessary
6. Casing and well bore dimensions
7. Approximate location of stage tool, when used
8. Placement of centralizers
9. Casing preparation - coating, etc.
10. Casing - liner overlap intervals
11. Fluid type and approximate fluid level

All of the above factors may influence the response of the log and are considered in making a complete and logical interpretation.

The amplitude curve supplies the basic data used in determining the quality of zone isolation. A low, consistent amplitude indicates complete bond of cement to casing. Low amplitude values may range from 1 to 10 millivolts, depending primarily on casing dimensions and the cement compressive strength. A high amplitude, covering a range of approximately 50 millivolts or greater, will be displayed in unsupported casing.

Log intervals, displaying amplitudes in the intermediate range between complete bond and unsupported casing, require a more detailed consideration.

Indicated imtermediate bond may be the result of:

1. Micro-Annulus
2. Channeling

A micro-annulus is a break in the acoustic bond of cement to casing and may occur as a result of drilling inside casing or from maintaining pressure on the casing for an extended period after cementing. When suspected, a micro-annulus may be confirmed by applying pressure to the casing and re-logging the interval of interest. If a micro-annulus does exist, it will be reduced by the resultant casing expansion and the log will indicate improved bond. A micro-annulus normally does not provide sufficient channel to permit communication.

When possible channeling is indicated, a numerical value of "BOND INDEX", or "PERCENT BOND", may be applied to the interpretation as an indicator of the zone isolation quality that exists across specific channel lengths.[2,3]

BOND INDEX has been defined as:

$$\text{BOND INDEX} = \frac{\text{Attenuation (db/ft) in zone of interest}}{\text{Attenuation (db/ft) in 100\% bonded interval}}$$

Attenuation in db/ft may be obtained from the chart, Fig. 7, relating amplitude to attenuation rate for specific tools and casing diameters. Bond Index relates to that part of the casing circumference which is bonded; therefore, for a given value of Bond Index or Percent Bond, the quality of zone isolation will vary with varying casing circumference.

Channel length is also considered in determining the effectiveness of a hydraulic seal. Local conditions, such as pressure differentials, and formation characteristics, will dictate the degree of hydraulic seal required to affect zone isolation.

As a general rule, the following guidelines are used in the Permian Basin:

Casing Diameter	5½" or less:	
Minimum Bond Index	0.8	80% Bond
	Cumulative Hole Interval 10'	
Minimum Bond Index	0.7	70% Bond
	Cumulative Hole Interval 15'	

In hard formations the total transit time curve is used qualitatively for determining bond of cement to formation. When the formation arrival amplitude is higher than that of the casing arrival, the transit time curve responds to the later arrival and will correlate to porosity and lithology variations, indicating good bond of cement to formation. When the curve responds to the casing arrival time, as in the case of unsupported casing, poor bond of cement to formation is suspected.

Transit time through hard, low porosity formations may be faster than through steel casing. When this occurs in well bonded intervals, the recorded amplitude may be from an over-riding formation signal, and be high enough to erroneously indicate poor or intermediate bond.

The full wave form, or variable intensity, recording presents qualitatively an overall graphical picture of bonding conditions, Fig. 4. Casing arrivals are visible, showing their arrival time and any amplitude variations indicating changes of cement bond to casing. Formation arrivals are clearly visible, when a cement coupling exists between casing and formation, indicating cement bond to formation.

LOG EXAMPLES

Fig. 8. ACE-VIL on an Ector County, Texas producer. The interval shown is 5½" 15.5# casing, coated, centralized, and cemented with 150 sks. Class "C" cement with 2% Gel and 4# Salt. Proposed perforations are from 4344' to 4376'. A Bond Index of 1, or 100% bond, is noted above and below the zone of interest. A Bond Index of .76, or 76% bond, is noted through the zone of interest.

The transit time curve is responding to a strong formation arrival, indicating good bond to formation. Fast formation arrivals are seen on the VIL through the zone of interest and at several other intervals on the log. Note the strong formation signal, varying in time, over-riding the weaker consistent casing signal.

The amplitude increase recorded through these intervals is a response to the formation amplitude. This indicates that the zone of interest is actually 100% bonded, a fact that would not have been noted without the use of the VIL data.

The formation involved is a 3% to 8% porosity dolomite which has a transit time faster than the steel casing.

Note the poor bond indicated through the interval 4510' to 4540', well away from the zone of interest. This interval correlates to a segment of an injection reservoir, which is probably swept, at this well.

Fig. 9. ACE log on an Ector County, Texas injection well. The interval shown is 5½" 15.5# casing, centered and cemented initially with Class "C" cement circulated to surface. Run #1, 3/1/78, shows poor bond across zone of interest at 4312' to 4420'.

A squeeze was performed through perforations at 4415' with 40 sacks. The perforations broke down at 1100 PSI, cement was pumped at 800 PSI with a final pressure of 2000 PSI.

Run #2 ACE, 3/6/78 shows bond improved sufficient for isolation up to 4340'.

A second squeeze was performed through perforations at 4335' with 70 sacks. The perforations broke down at 1200 PSI, cement was pumped at 800 PSI with a 2000 PSI final pressure.

Run #3 ACE, 3/8/78 shows zone isolation achieved with sufficient bond up to 4290'.

Fig. 10. ACE-VIL on a Ward County, Texas producer. Centralized 5½" 15.5# casing was cemeted on 11/10/79 with 400 sacks Class "C" cement.

Approximately 700' of cement had to be drilled out.

Run #1 ACE-VIL, 11/17/79 indicates poor bond from T. D. 6200' to an apparent cement top at 5700'.

Run #2 ACE-VIL was made with casing pressured to 1500 PSI. Note the improved bond to both casing and formation, indicated by amplitude and transit time. Run #2 VIL displays strong formation arrivals.

Apparently a micro-annulus had been caused by the drilling.

CONCLUSIONS

1. Most acoustic cement evaluation logging systems adhere to the same principle of operation. The lack of equipment standardization, while not the ideal, should not present an insurmountable problem to the field engineer, when the operations principles are understood and followed.

2. Meaningful calibrations can be performed that will insure log validity.

A. Periodic transmitter output record, identified by equipment number, and presented with each log.

B. Amplitude circuit calibration to a consistent, downhole generated pulse.

C. A recording of the amplitude measure gate position.

3. Interpretation is primarily qualitative. It requires the application of logic to relate log response to downhole variables. A complete knowledge of the casing and cement program is necessary to interpretation of apparent, partially bonded intervals.

The variable intensity recording is a valuable part of the complete log interpretation. Its continuous presentation of both casing and formation signals permit fast formation arrivals to be distinguished from casing arrivals.

ACKNOWLEDGEMENTS

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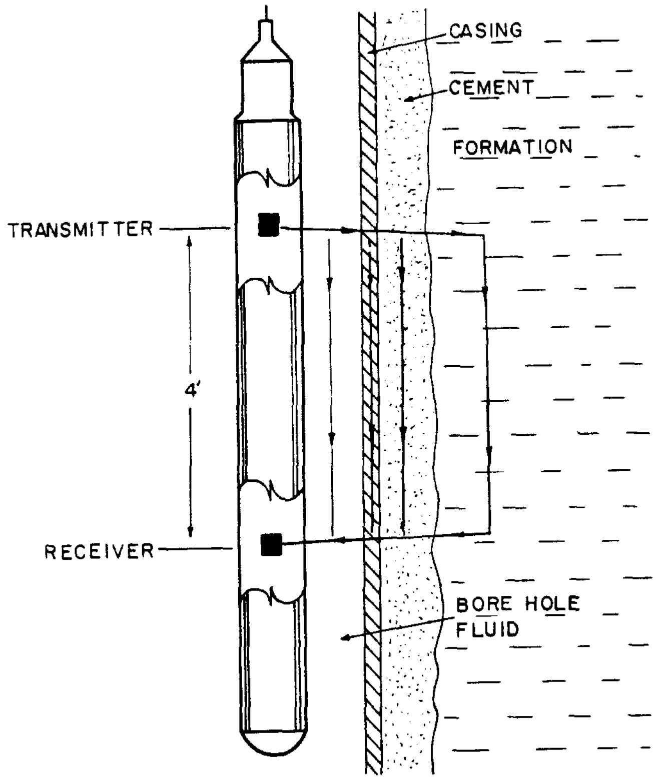

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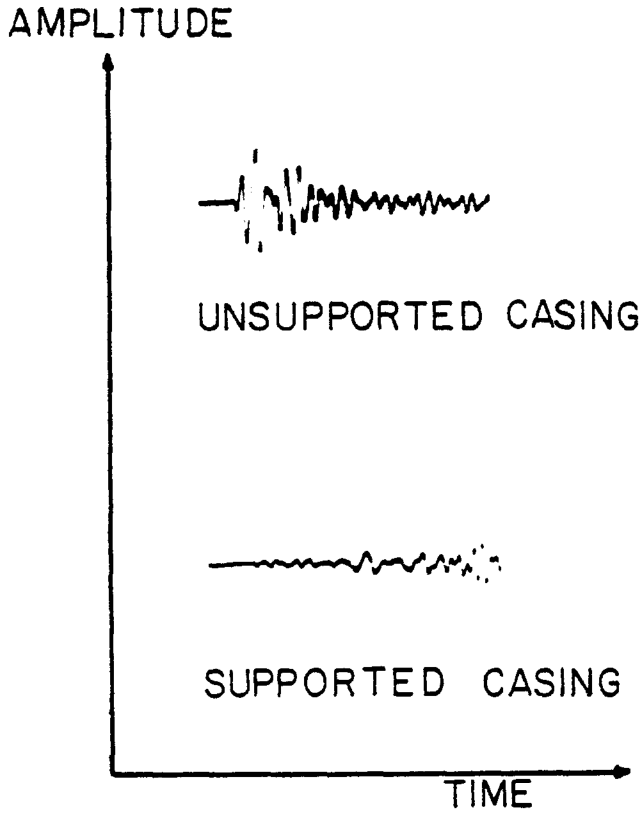

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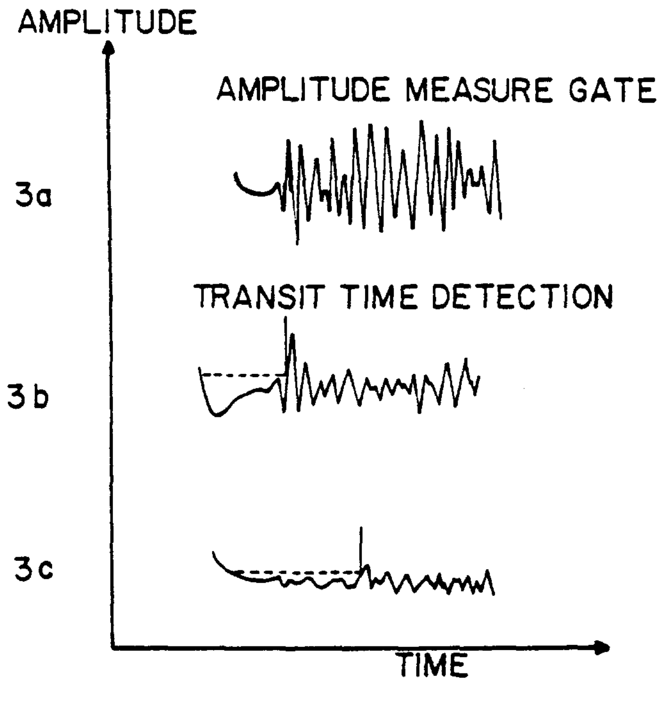

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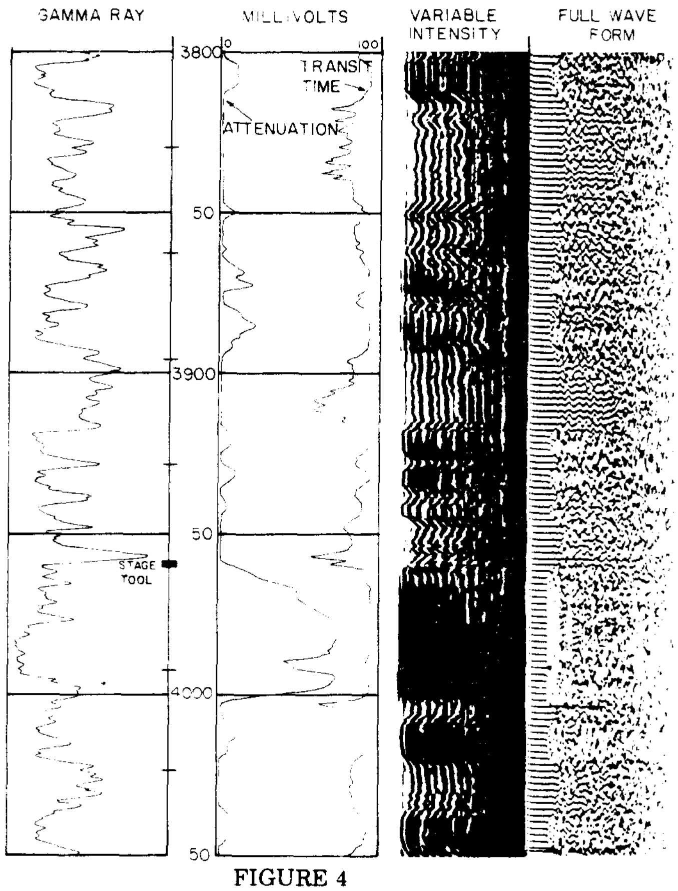

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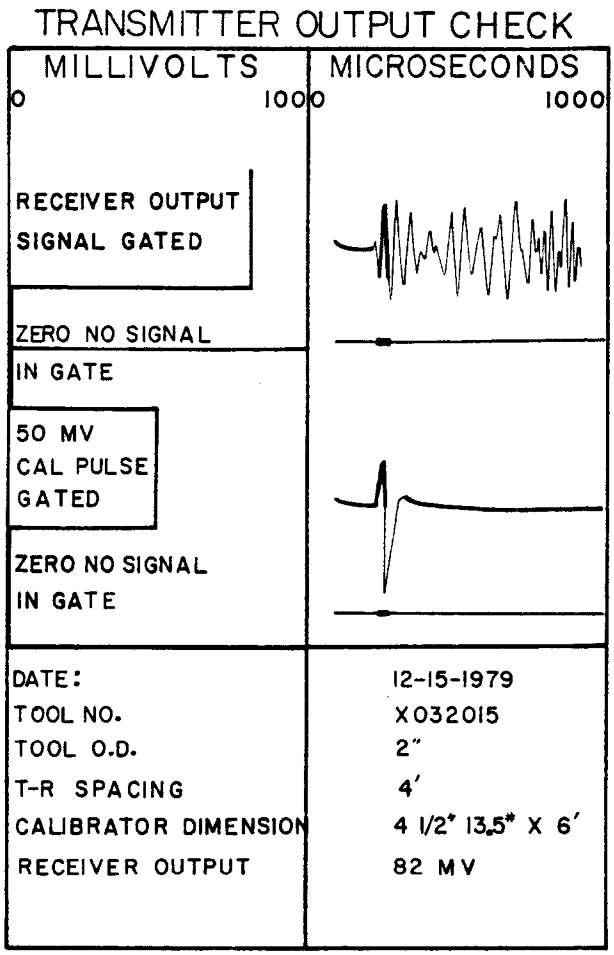

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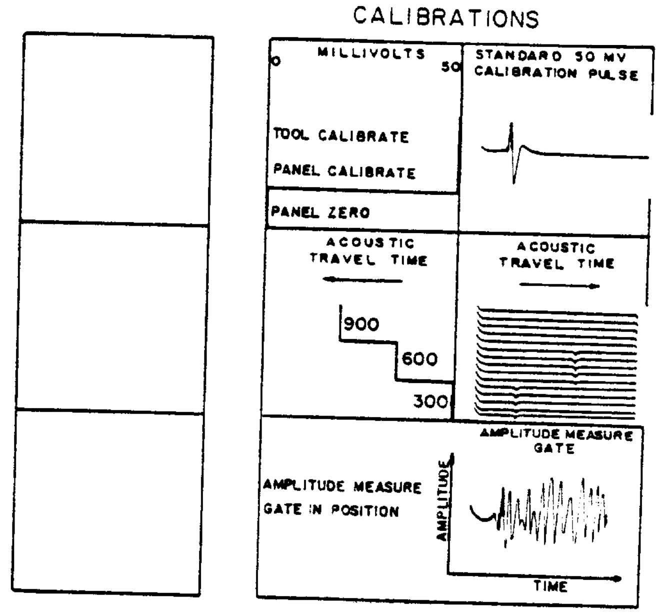

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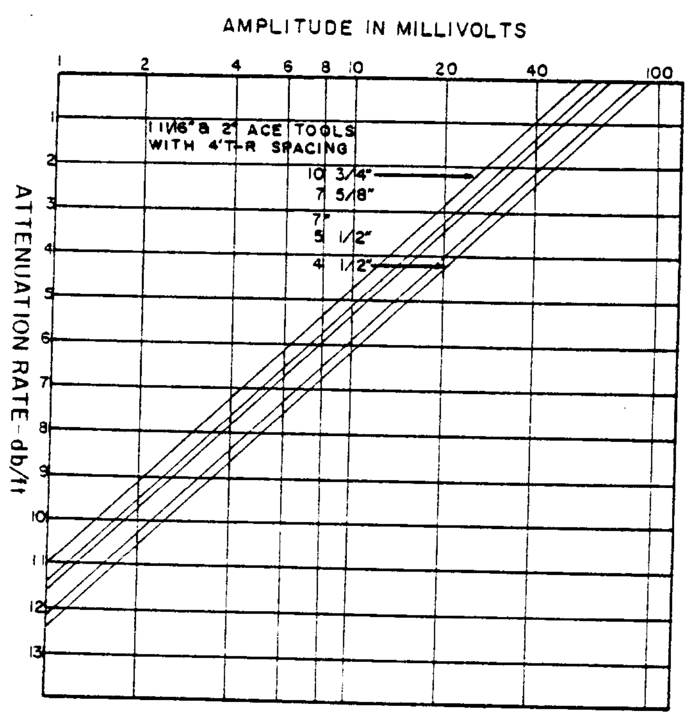

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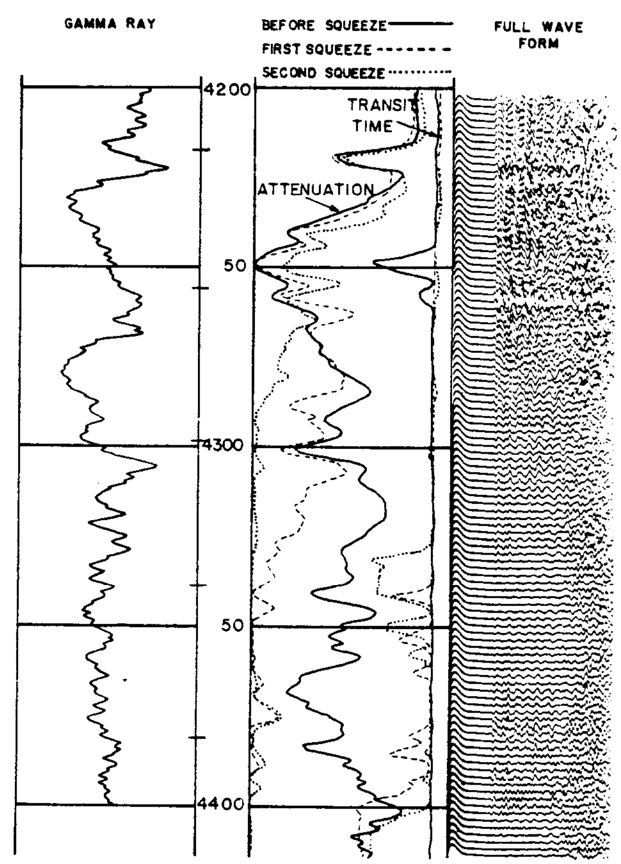

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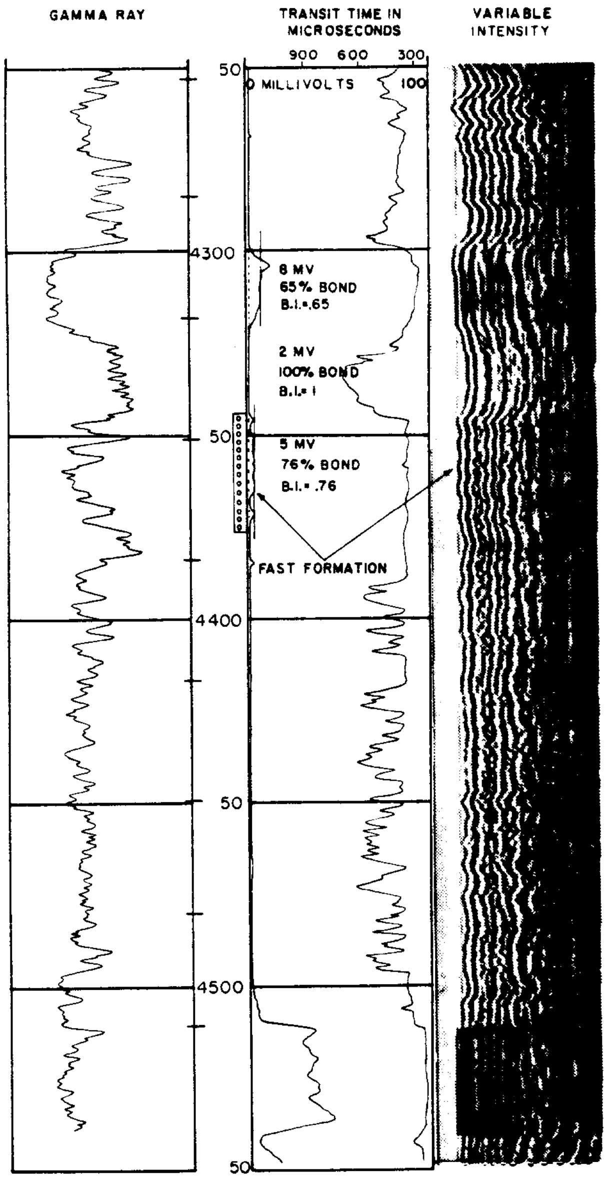

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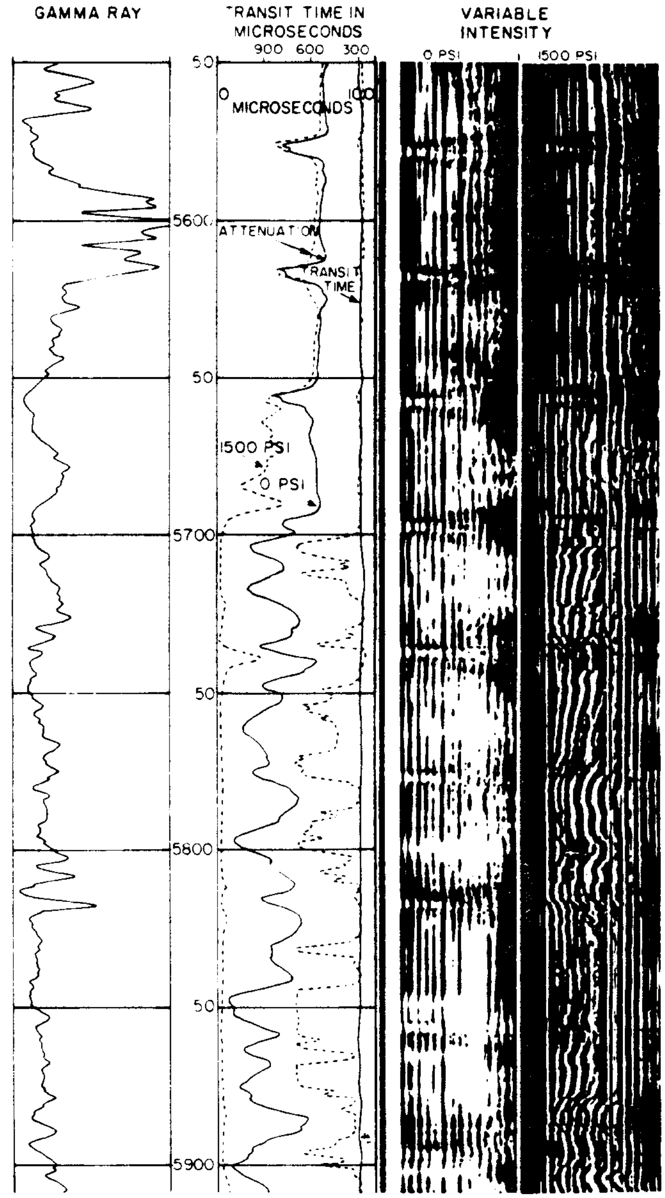

FIGURE 10