# THE CEMENT-SCAN* LOG - TOTAL CEMENT EVALUATION FOR WEST TEXAS WELLS

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## ABSTRACT

Schlumberger's Cement-Scan* log was offered to west Texas clients in June 1985. Since then, the product has greatly enhanced interpretation of cement conditions where standard cement evaluation techniques left unanswered questions. Specifically, the Cement-Scan log has provided superior answers in light (or foam) cements and in cements degraded by gas intrusion.

The Cement-Scan log is a single presentation that combines information from both the CET* cement evaluation log and the CBL cement bond log. Through the use of a statistical gas logic system, Cement-Scan measurements can be used to discriminate between water channels and gas-cut cement behind the casing. Also, a new light-weight cement compressive strength algorithm is available for use when a known light or foam cement has been used in cementing operations. A cement map (from CET data) with shadings corresponding to acceptable cement, water channels, gas-cut cement, and free gas is presented. Additionally, a radial profile presents the four materials in terms of percent circumferential coverage of each. The above information is further enhanced by presenting a bond index curve and a Variable Density display from the CBL.

The utility of the Cement-Scan log is illustrated by citing several examples from actual west Texas wells. Interpretation techniques, as well as gas logic verification, are described.

## INTRODUCTION

Using sonic and ultrasonic techniques to evaluate oil and gas well primary cementing operations is of significant benefit when answers concerning the causes and repairability of problem cement areas are desired. Specifically, the logging suite comprised of the CBL and CET logs has provided solid answers in a variety of cementing conditions. Since both logs respond uniquely to each of several possible conditions, a combination of measurements from the tools can be used to better highlight each individual cement condition. The ability of two logs to complement each other's measurement led to the development of the Cement-Scan log.

The primary cementing conditions that may be highlighted by the Cement-Scan log are:

- Acceptable cement
- Channeled cement
- Low-strength cement
- Cement contaminated by the invasion of fluids from the formation

The following pages will contain a brief overview of the CBL log and CET log followed by a detailed description of the mechanics and interpretation of the Cement-Scan log. The log's response in each of the cement conditions presented above will be covered in detail.

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## THE CBL LOG

The basic cement bond logging measurement system consists of a sound energy transmitter and two sound energy receivers spaced at 3 and 5 ft respectively from the transmitter. The CBL measurement system starts with a burst of sound energy that travels radially from the transmitter through the casing fluid, casing, casing-formation annulus and into the formation as indicated in Figure 1. The resultant received waveform is recorded both at 3-ft and 5-ft receiver. The character of the received waveform is a function of:

1) The amount of cement bonded to the casing.

2) Overall bond between the cement and the formation.

The received waveform at the 3-ft receiver is used to provide indications of the cement bond to the casing, while the waveform at the 5-ft receiver provides optimum indication of the overall bond to the formation.

3 Ft Waveform

The amplitude of the first arrival at the 3-ft receiver is used to determine the overall bonding characteristics of cement to casing. When the overall return amplitude is large, the casing-formation annulus is filled with a fluid that does not attenuate such as water, gas, or a light liquid as shown in Figure 2. When an attenuating material such as cement fills this casing-formation annulus, the received sound energy amplitude is very small, such as shown in Figure 3. The actual amplitude of the first arrival is dependent upon the amount of cement bonded to the casing. This amplitude measurement is recorded on the log and is representative of the average circumferential amount of bonded cement at each sample interval. The measurement has a vertical resolution of 3 ft (transmitter- receiver spacing).

5 Ft Waveform

The entire waveform is recorded at the 5-ft receiver. Separate components of sound energy arrive at this receiver at different times as shown in Figure 4. The arrival times are dependent upon the transit times of the media through which the components travel as illustrated in Figure 5. The combined waveform is recorded on the CBL log as the Variable Density* display (VDL).

The VDL display is a three-dimensional recording of the total energy received at the 5-ft receiver. It represents time versus depth on the x-y axis and amplitudes on the z axis as represented in Figure 6. A totally dark intensity indicates a maximum positive amplitude, while a totally white intensity corresponds to a maximum negative amplitude. The specific utilities of the VDL data are:

1) Verifying the existence of channeling as detected with the 3-ft amplitude measurement.

2) Determining overall condition of the cement bond to the formation.

Due to the nature of the CBL measurement, certain limitations exist as listed below:

1. Fast Formations - some formations have transit times faster than the casing transit time, which will cause arrivals from the formation to appear at the 3-ft receiver before the first casing arrival. Since the first arrival at the 3-ft receiver is from the formation rather than from the casing, as in Figure 7, the first arrival can no longer quantify the amount of cement present (i.e., channeling could still be present through an area affected by fast formations).

2. Microannulus

   A microannulus is defined as a small gap that may occur between cement and casing during or after the cement job. The following actions may contribute to conditions of a microannulus:

   1) Pressuring up on the casing during the time the cement is curing.

   2) Lowering the casing fluid level.

   3) Changing to a lighter casing fluid after the cement is cured.

   4) Pressure testing the casing.

   Although a microannulus normally does not communicate fluid between zones, this small annular gap could alter the amplitude of the first energy arrival and cause the log to indicate more pessimistic cement conditions than actually exist. The effects of microannulus can be minimized by pressuring up on the wellhead during logging. Applying pressure will close the annular gap and allow the amplitude response to be dependent upon the amount of bonded cement present in the casing-formation annulus. This is illustrated by comparing the amplitude from a zero-pressure pass to that obtained with 1000 psi applied as shown in Figure 8.

3. Light-Weight or Foam Cements

   The relationship between the amplitude of the first arrival at the 3-ft receiver and the developed compressive strength of the cement is presented in Figure 9. This relationship illustrates that the amplitude of the first arrival at the 3-ft receiver depends not only on the amount of cement bonded to the casing, but also on the developed compressive strength of that bonded cement. This fact becomes very apparent when a light-weight or foam cement is used in the cementing process. Since these cements have very low developed compressive strength values, the CBL response may not be indicative of the amount of bonded cement existing behind the casing.

4. Cements Degraded by Gas Intrusion

   During the cement curing stage an underbalanced pressure condition may develop at the cement-formation interface (i.e., the formation pressure is greater than the hydrostatic pressure exerted on the formation by the cement). At this point, formation fluids, namely gas, may enter the cement before it has solidified. The invasion of formation fluids into the cement may reduce the cement's ultimate integrity. The CBL measurement alone cannot differentiate between normal cements and those degraded by gas intrusion.

The above limitations of the CBL log led to the development of a logging tool that addressed these problems.

## THE CET LOG

The CET tool features an array of eight ultrasonic transducers permitting a radial inspection of the casing and the casing-formation annulus, as shown in Figure 10. The basic CET log measurement begins at each of the transducers when a pulse of ultrasonic energy is emitted from the face of the transducer. This energy causes the casing to vibrate at its specific resonant frequency. The return energy from the casing is recorded at the transducer. This is illustrated in Figure 11. The rate at which this energy decays with time is a function of the acoustic energy of the material in the casing-formation annulus. When a nonattenuating fluid, such as water, gas, or light liquid fills this casing-formation annulus, the rate of decay is much slower in time as shown in Figure 12. When an attenuating material such as cement fills this annulus, the rate of decay is much faster (Figure 13).

CET Normalization

The detected waveform at each transducer is broken up into energy windows. Figure 14 shows the windows used to determine the rate of exponential decay of the waveform, termed W2 and W3 respectively.

The W2 energy measurement is a function of the acoustic impedance of the material in the casing-formation annulus, while the W3 energy window is used to detect any interruptions in the exponential decay of the return waveform. The energy measurements taken at each transducer are normalized for each specific well environment where:

- W2N is the energy integrated and normalized in the time window W2.
- W3N is the energy integrated and normalized in the time window W3.

A graphical model exists displaying the relationship between W2N and W3N values for any of the eight transducers. This model is presented in Figure 15. Crossplotted W2N and W3N data will fall on the theoretical line depending upon the acoustic impedance of the material in the casing-formation line (i.e., water). Therefore, the W2N and W3N values can be used to infer the acoustic impedance of the material behind the casing. This is the basic measurement of the CET service.

Several laboratory measurements of cement samples were analyzed in order to relate acoustic impedance to compressive strength. An individual linear relationship was established for neat and light-weight cements, as shown in Figure 16. The CET software utilizes these linear relationships to convert the inferred acoustic impedance values to values of compressive strength. This information is presented in the form of a map as indicated in Figure 17. The map displays a 360° "picture" of the cement conditions existing behind the casing. Dark shading on the map corresponds to areas of acceptable compressive strength cements, while light shading corresponds to unacceptable cement conditions such as water, gas-contaminated cement, free-gas, etc. The maximum and minimum cement compressive strength values inferred at each sample interval are also presented.

The majority of cementing conditions can be represented with the W2N/W3N crossplot guide presented in Figure 18. With the guide, one can obtain determinations of the type of material (neat cement, light-weight cement, water, gas-contaminated cement, etc.) existing behind the casing.

Total Cement Evaluation

It can be concluded from the above discussion that information from both the CBL log and the CET log is essential for total cement evaluation. An interpretive aid has been developed which combines information from both logs to address this concept.

## CEMENT-SCAN LOG MECHANICS

As indicated earlier, the CBL log responds primarily to the amount of solid material (cement) existing behind the casing. The CBL measurement alone cannot differentiate between acceptable cement and cement contaminated by formation fluid (namely gas) intake, nor can it differentiate between water behind the casing and gas or very light liquid. In addition, the orientation of materials with respect to one another cannot be obtained with the CBL information. Rather, the CBL measurement does an excellent job of presenting the overall, dominant condition of solid versus fluid existing behind the casing of any point during the logging interval.

Adding information from the CET log to that obtained from the CBL log will allow a determination to be made concerning the types of solids and fluids existing behind the casing. The basic measurement of acoustic impedance made by each transducer on the CET sonde permits a radial inspection of cement conditions to be recorded, resulting in the specific orientation of materials existing behind the casing.

The Cement-Scan log utilizes information from the CET log to perform the typing and distribution of material existing behind the casing. As described in detail earlier, the normalized response from any specific CET transducer can be presented graphically as in Figure 19. Specifically, the acoustic impedance values from each transducer's energy windows can be used to infer the type of material existing behind the casing. The Cement-Scan software categorizes points falling on the W2N vs W3N crossplot into three separate domains as indicated in Figure 20. This categorization leads to the typing of four materials as follows:

- Crossplotted points falling in the "acceptable cement" range will be indicated as such on the Cement-Scan log.
- Crossplotted points falling in the "free gas or light liquid" range will be indiccated as free gas or light liquid on the log.
- For points falling in the third domain, a "Gas Logic" routine will be used to determine whether gas-contaminated cement or water exists behind the casing. The logic routine is necessary since an overlap zone exists where either condition could prevail.

The Gas Logic will select which condition exists for the transducer response in question by using the individual responses from the other transducers in the immediate area as a basis for the selection. For example, if the response from the transducer in question falls in the third domain, the dominant response of the other transducers in the same area will determine whether gas-contaminated cement or water exists. If the dominant response of the other transducers is to that of free gas or gas-contaminated cement, then the trandsucer in question will be coded as gas-contaminated cement. If, on the other hand, the dominant response of the other transducers is to that of water or acceptable cement, the transducer in question will be coded as water behind the casing. To verify the gas logic selection, the information presented from the CBL log will be used. This visual verification will be explained in detail later.

The material distribution is performed on the Cement-Scan log in a manner similar to that used on the standard CET log presentation. Examples of both the CET log cement map and the enhanced map presented on the Cement-Scan log are presented in Figure 21. The major difference between the two maps is that instead of presenting only dark and light shading (corresponding to acceptable and unacceptable cement conditions, respectively), the Cement-Scan map presents four distinct shadings depending upon the material selection made by the Cement-Scan program logic. Presenting the four shadings, corresponding to acceptable cement, water channeling, gas-contaminated cement, and gas or light liquid channeling, in the form of an oriented map allows the interpreter to observe the materials as they exist behind the casing and make conclusive decisions concerning the repairability of problem areas. The second difference between the maps is the absence of averaging, or image smoothing, on the Cement-Scan map. The absence of adjacent transducer averaging and vertical averaging permits the map to be used in a very definitive manner; i.e., what is inferred by each individual transducer is exactly what appears on the Cement-Scan map. In this manner, most of the areas of indecision can be eliminated.

## ACCURACY VERIFICATIONS

Since the Cement-Scan log presents information from both the CBL and the CET logs, a unique process of log accuracy verification becomes possible. This verification process is implemented by the logging engineer when generating the Cement-Scan log and is also an excellent tool to be used by any interpreter of the log. In practice, each Cement-Scan log is generated from parameters selected by the logging engineer through the use of CET-CBL crossplotted data. The accuracy of the parameter selection is then verified on the generated Cement-Scan log by noting the coherence between CBL-generated information and information generated from the CET tool.

Figure 22 presents an example of a crossplot generated from CBL and CET log data. Acoustic impedance, generated from CET transducer data, is plotted along the vertical axis, while CBL $E_1$ amplitude is plotted along the horizontal axis. It can be seen that each set of crossplotted points will fall in one of four distinct areas depending upon the material existing behind the casing. When observing the crossplotted data in this manner, the uncertainty as to whether gas-contaminated cement or water exists can be eliminated. Specifically, the CBL amplitude will read low in areas of cement (regardless of whether the cement is acceptable or contaminated with gas) and will read high in areas where water exists behind the casing. To generate the Cement-Scan log, the logging engineer will make parameter selections based upon the crossplots of this type. The selections will then determine the material discrimination appearing on the Cement-Scan log. The visual verification will then be performed on the resultant log to determine its accuracy.

The Cement-Scan visual accuracy checks are made using the "radial coverage", the "W2 HIGH and W2 LOW" curves and the Variable Density display. The curves, and the use of the curves for accuracy verification, are described below.

Four separate curves comprise the radial coverage presentation. They are:

- Bond Index (I); the bond index curve is generated from the CBL amplitude curve using the following relationship:

$$BI = \frac{\text{LOG (CBL*}E_1\text{ AMPLITUDE) - LOG (RFP)}}{\text{LOG (RBP) - LOG (RFP)}}$$

  where RBP is the CBL amplitude in conditions of 100% bond and RFP is the CBL amplitude in conditions where water, and no cement, exists behind the casing. Bond index is a measure of the radial cement coverage existing behind the casing, regardless of whether that cement is acceptable cement or gas-contaminated cement.

- Good Cement Index (GOCI): The good cement index curve is generated from CET transducer data. It is a measure of the percentage of transducers corresponding to good cement. If, for example, during one sample interval, half the eight transducers corresponded to acceptable cement, the good cement index would be 50%.

- Gas Cut Cement Index (GGCI): The gas cut cement index represents the radial coverage of gas-contaminated cement inferred from the CET transducer measurements. GGCI corresponds to the percentage of transducers indicating gas-contaminated cement during any sample interval.

- Free Gas Index (FRGI): The free gas index corresponds to the percent of CET transducers inferring free gas or light liquid during any sample interval.

All the above curves are presented in terms of percent of radial casing coverage. The bond index curve has a vertical resolution of three ft (the CBL's transmitter near receiver spacing), while the CET curves are averaged over four vertical ft.

The radial coverage curves are presented on the Cement-Scan log in terms of a radial cement profile as indicated in Figure 23. Bond index, the heavy dashed curve, is scaled from 100% to 0% from left to right across the profile. The good cement index is scaled in the same manner, with crosshatch shading to the right of the curve. The gas cut cement index is also scaled the same, with a dark gray shading from the gas cut cement index to the good cement index. The free gas index is scaled 0% to 100% from left to right across the profile with gas shading presented to the left of the curve.

The radial cement profile presents the percentage of each of the four possible types of materials existing behind the casing at any point in the log interval. The profile can be used to perform the Cement-Scan visual accuracy check by noting the relationship that exists between the bond index curve and the CET curves. For example, in an area where acceptable cement with water channeling exists, the radial cement profile would appear as shown in Figure 24. As shown, a reasonable correlation should exist between the bond index curve and the good cement index curve, thus verifying the accuracy of the data presented. The interpretation of this specific case would then be a 60-65% coverage of good cement (crosshatch shading) and a 35-40% coverage of water (with shading) behind the casing. The specific orientation of the materials would then be obtained by consulting the Cement-Scan cement map.

In areas where gas-contaminated cement and gas (or light liquid) channeling exists, the radial cement profile would appear as in Figure 25. The accuracy of the material selection is verified by noting the close correlation of the bond index curve with a free gas index curve. This correlation is apparent because the CBL (bond index) response is to that of the cement/fluid percentages existing behind the casing regardless of the type of cement (gas-contaminated or acceptable) or the type of fluid (water or light liquid and gas).

Additional verification of gas-contaminated cement can be obtained from the Variable Density display and the W2 high - W2 low curves. The Variable Density display is presented exactly the same as it appears on the CBL log. In areas of gas-contaminated cement, the Variable Density display should confirm the presence of cement. Figure 26 presents a case where the radial cement profile indicates 80-90% gas-contaminated cement. This is verified on the profile by the near-similar reading of the bond index curve. Additional verification is provided by the Variable Density display which indicates existence of formation arrivals. The final confirmation of gas-contaminated cement can be obtained from the W2 high and W2 low curves. The curves are defined as the second highest and second lowest W2N values, respectively at any given sample interval. W2 high and W2 low are presented on the Cement-Scan log scaled from 1 to 2, as indicated in Figure 27. Because of the scaling of the curves, they will normally appear only when the CET data are responding to the gas-contaminated cement or free gas/light liquid behind the casing. In this manner, the presence of one or both of the curves on the Cement-Scan log will make a final confirmation of gas-contaminated cement, free gas/light fluid, or percentages of both behind the casing. Figure 28 presents several possible conditions along with the readings of W2 high and W2 low corresponding to each situation.

Certain situations may occur where, although the information presented on the Cement-Scan log is accurate, a reasonable correlation between the bond index curve and the CET curves will not exist. These are:

- Hard, Low Porosity, "Fast" Formations

  Since in fast formations the CBL first arrival is not that of the casing but rather that of the formation, the $E_1$ arrival ca nnot be used to generate a meaningful bond index value. Therefore, a correlation will not exist between the bond index curve and the CET curves. Figure 29 presents an example of such a case. In this situation, the Varable Density display should be used to confirm the presence of fast formation arrivals, and the cement map should be used to determine if any channeling exists through the affected area. If gas-contiminated cement is indicated in an area of fast formations, the Variable Density display can be used to confirm the presence of fast formation arrivals, and the W2 high and/or W2 low curves should be used to verify the presence of gas-contaminated cement. The cement map can then be consulted to determine channel orientation.

- Microannulus:

  Since the CBL data are more sensitive to conditions of microannuli than information derived from the CET log, situations may arise where a correlation does not exist on the Cement-Scan log because of the effects of microannuli. Figure 30 presents a situation where the CBL data are indicating more pessimistic cement conditions than the data derived from the CET. The logs were recorded with no surface pressure on the casing, leading to the conclusion that a condition of microannuli is affecting the CBL data. This assumption can only be confirmed by relogging the interval with surface pressure applied and noting any changes occurring on the logs. If at all possible, both the CBL and CET data should be recorded under sufficient casing pressure to eliminate any possible miroannuli effects. If it is impossible to apply sufficient pressure, i.e., open perforations, etc., the interpreter should bear in mind the possible effects miroannuli will have on the resultant Cement-Scan log.

- Cement Bond Log Omni-directional Averaging Effects:

  Often a situation will occur where the Cement-Scan log indicates conditions of 100% cement coverage from the CBL Bond Index curve and Variable Density display, while the CET data indicates a small channel or small channels. Figure 31 illustrates a situation such as this. It can be seen that the existing cement around the channel possesses a very high compressive strength value (obtained from the CET compressive strength curves). Since the channel is small, when compared to the existing cement around the remainder of the casing, the CBL measurement, which is influenced primarily by the "average" conditions of cement around the casing, does not respond to the small channel. The Cement-Scan log helps to highlight this drawback of the CBL measurement by directly comparing the CBL results with those derived from CET data. One must remember, however, that the CBL Variable Density display is still the best indicator of the overall bond condition existing at the cement-formation interface and therefore, is necessary for total cement evaluation.

## CEMENT-TO-FORMATION BOND:

The final main utility of the Cement-Scan log is the determination of the overall bonding condition between the cement and the formation. The Variable Density data, presented exactly as it appears on the CBL log, is used to determine the overall cement-formation bond condition. By presenting the Variable Density display, the Cement-Scan log becomes an instrument that can be utilized for total cement evaluation.

The evidence of strong formation arrivals on the Variable Density display will confirm the existence of good bond between the existing cement and the formation. Figure 32 illustrates this desirable situation. If the arrivals from the formation are weak, poor bond conditions between the cement and the formation should be suspect. However, one must eliminate the possibility of formation shaliness, gas or fractured formation causing the weak arrivals before concluding that a poor bond exists. A gamma ray curve will provide indications of whether weak arrivals are caused by shaliness by noting if a correlation exists between high gamma ray readings and the weak formation arrivals. Gas effects can be checked by noting any correlation between weak Variable Density formation arrivals and indications of gas-contaminated cement or gas channels on the Cement-Scan log. Finally, evidence of fractured formations can be obtained by consulting the open hole logs. If fracture indications correlate with weak formation arrivals on the Cement-Scan log, the condition is most likely caused by fracturing and not by poor bonding to the formation. A Variable Density display recorded in open hole would be the most conclusive way to check for correlation to fractured zones.

## THE COMPLETE PICTURE

The complete standard Cement-Scan log presentation for west Texas wells is pictured in Figure 33. The curves are explained from the right of the presentation to the left.

- Variable Density

The 5-ft Variable Density display from the CBL log is presented in Track 3. One thousand microseconds of the display are presented starting on the left at two hundred microseconds after transmitter firing and ending on the right at twelve hundred microseconds after transmitter firing.

- The Enhanced Cement Map

The enhanced cement map is presented in the right half of Track 2. As indicated earlier, the enhanced map breaks the materials existing behind the casing into four distinct categories, depending on the material's inferred acoustic impedance. The four shadings correspond to: dark = acceptable cement, white = water, dark gray density = gas-contaminated cement and light gray density = light liquid or free gas.

The enhanced cement map contains no image averaging between transducers, nor any vertical averaging. As with the CET cement map, the enhanced map can be image rotated so that the low side of the casing appears in the middle of the map in a deviated well.

- Radial Cement Profile

The radial cement profile is presented in the left half of Track 2. The profile presents a breakdown of the four possible materials behind the casing in terms of the radial percent coverage of each material.

- Cement Compressive Strength Curves

The maximum and minimum cement compressive strength curves from the CET log are duplicated on the Cement-Scan log. The curves are presented in the right half of Track 1 and are normally scaled from 5000 psi to 0 psi left to right across the half track.

- W2 High and W2 Low

W2 High and W2 Low are also presented in the right half of Track 1, scaled from 1 to 2, left to right, across the half track. With this scaling, the curves will not normally interfere with the compressive strength curves since compressive strength will only develop in cements not contaminated with gas; i.e., cement possessing W2N values much lower than "1".

- Correlation and Depth Control Curves

A gamma ray and casing collar curve are presented on the Cement-Scan log in order that the log may be used when perforating as a depth control device. The curves are normally presented in the left half of Track 1, with the alternate choice of placing the casing collar curve in the depth track.

## INTERPRETATION OF THE CEMENT-SCAN LOG

The best approach to interpretation of the Cement-Scan log is to follow a common set of iterative steps for each interpretation situation. The common steps are:

1) Perform the necessary accuracy verifications as outlined earlier in the paper.
2) Determine the radial coverage of each material existing behind the casing from the radial cement profile.
3) Determine how each of the materials existing behind the casing is oriented from the enhanced cement map.
4) Determine the bond to the formation of the existing solid material using the Variable Density display.
5) For areas exhibiting either water channeling or light liquid or gas channeling, determine if the indicated channeling connects hydrocarbon producing zones to water-producing zones. If so, a cement squeeze operation should be considered.
6) For areas affected by gas contamination from the formation, determine how this phenomenon occurred and how it can be eliminated on subsequent wells.
7) If hydraulic fracturing or acidizing operations are to be performed on productive intervals, the strength and integrity of the cement above and below the fractured zone should be evaluated to determine if it will remain intact during the fracture or acidizing operation.

Use of the above iterative steps are covered in the log examples presented below.

EXAMPLE 1 (Figure 34): GOOD CEMENT Irion County, Texas

This example illustrates the Cement-Scan service's response in areas of good, or acceptable cement. The positive indications of acceptable cement are: 100% coverage of good cement indicated on the radial cement profile, no indications of channeling on the Enhanced Cement Map, strong formation arrivals on the Variable Density display (indicating good bond to the formation), and high cement strength values indicated on the maximum-minimum compressive strength curves.

EXAMPLE 2 (Figure 35) NO CEMENT Crockett County, Texas

Conditions of no cement or "free pipe" are indicated on this example. Indications of free pipe are: 100% water indicated on the radial cement profile, no cement indicated on the enhanced cement map, and strong casing arrivals indicated on the Variable Density display. If hydraulic isolation, or even casing support, is desired through this interval, a cement squeeze operation should be considered.

EXAMPLE 3 (Figure 36): CHANNELING BEHIND CASING Crockett County, Texas

In this example, channeling is first suspected by the high percentage of water existing behind the casing as indicated by the radial cement profile. The enhanced cement map reveals that this water is oriented in the form of a channel. If hydraulic isolation is desired between Zone A and Zone B, a cement squeeze into the water channel connecting Zones A and B will be necessary. In this specific case, a cement squeeze was not required since both zones were perforated for production.

EXAMPLE 4 (Figure 37): GAS-CONTAMINATED CEMENT Crockett County, Texas

This example illustrates the response obtained when encountering gas-contaminated cement with free gas channeling. The specific indications on the Cement-Scan log are: the radial cement profile containing percentages of gas-contaminated cement and free gas; the enhanced cement map indicating gas-contaminated cement and free gas channels; the Variable Density display indicating the presence of casing arrivals (channeling) and formation arrivals (cement); the absence of cement compressive strength (indicating cement weakened from gas contamination); and, finally, W2 high and W2 low curves indicating the presence of gas-contaminated cement and free gas.

Since gas-contaminated cement has no developed compressive strength, it would most likely not withstand a fracturing or acidizing operation. For this reason, attempts should be made to determine the cause of the contamination and, if possible, eliminate the problem on subsequent cement jobs. On this specific well, indications of gas in the formation were observed on the open hole logs from 5680 ft to 5720 ft. From this, it can be concluded that gas contamination most likely occurred during the cement curing process and that its origin was the gas zone identified on the open hole logs.

EXAMPLE 5 (Figure 38): CBL AVERAGING EFFECTS Menard County, Texas

This example illustrates the need for data from both the CBL and CET services for complete cement evaluation. The subject well was initially perforated for production in Zone A. The production from the perforations yielded an abnormally high amount of water, thus arousing suspicion of a possible channel existing between the perforated interval and Zone B (which, from the open hole logs, was determined to be wet). CBL and CET logs were then run on the well. From the resultant Cement-Scan log, the following was observed:

- A clear channel path existed behind the casing from Zone A to Zone B. The channel was detected from CET data, while averaging effects caused the CBL information (the bond index curve and the Variable Density display) to miss the channel.
- The Variable Density display indicated weak formation arrivals, pointing to the possibility of another channel path existing at the cement-formation interface.

Squeeze holes were placed in Zone B, and communication behind the casing was confirmed by placing a packer between the zones and pumping fluid into Zone B. A subsequent successful cement squeeze was implemented. Production from Zone A now matches predicted results.

EXAMPLE 6 (Figure 39): CHANNELING WITH FAST FORMATION Ward County, Texas

This example illustrates the fact that small channels may be masked by fast formation arrivals when interpreting the CBL data alone. The bond index curve is responding to the first arrival from the formation rather than from the casing, throughout the interval from 2700 ft to 2786 ft. The fast formation arrivals on the Variable Density display through this same zone arrive earlier in time than the expected casing arrival (see casing arrival at 2800 ft.), thus causing the formation arrivals to mask any casing arrivals that would appear. However, the CET cement map is used to highlight a small amount of channeling existing through the area of fast formation.

EXAMPLE 7 (Figure 40): FOAM CEMENT Howard County, Texas

This example illustrates the Cement-Scan log response for a foam (nitrified) cement. The compressive strength algorithm available in the Cement-Scan software permits good representative compressive strength values to be obtained in foam cements. The software also permits adjustment of the cement map to reflect accurate mapping in foam cements.

EXAMPLE 8 (Figure 41): WEAK CEMENT Irion County, Texas

Zone A is the proposed productive interval in this example. A hydraulic fracture operation is planned for this interval. Zone B is a water zone. Even though cement exists between Zones A and B, its strength may not be sufficient to contain the planned fracture to Zone A. The possible breakdown of this weak cement could cause unwanted production from Zone B through the perforations in Zone A.

## SUMMARY

The Cement-Scan log can be used in conditions of neat or light-weight cements to:

- Determine the actual quality of cement existing at the time of logging.
- Make conclusive decisions concerning the repairability of channeled cements.
- Identify the presence of abnormal cement conditions; namely, cements contaminated by formation fluid intake.
- Determine the overall conditions of bonding existing at the cement-formation interface.

In addition to acting as an aid in repairing cement on an existing well, the Cement-Scan log can be used to provide answers concerning the best cementing programs applicable to subsequent wells. By noting cement quality improvements with different cement additives or types, the Cement-Scan log can be used as a valuable instrument in tailoring individual cement programs to fit local well conditions.

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3. J. P. Masson, R. Bruckdorfer: **"CBL EVALUATION OF FOAM-CEMENTED CASINGS USING STANDARD TECHNIQUES".** SPWLA Paper presented in New Orleans, LA, June 27-30, 1983.

## ACKNOWLEDGEMENTS

We would like to take this opportunity to thank the many oil companies for furnishing the log data presented in this paper. We would also like to thank Schlumberger Well Services for permission to prepare this publication.

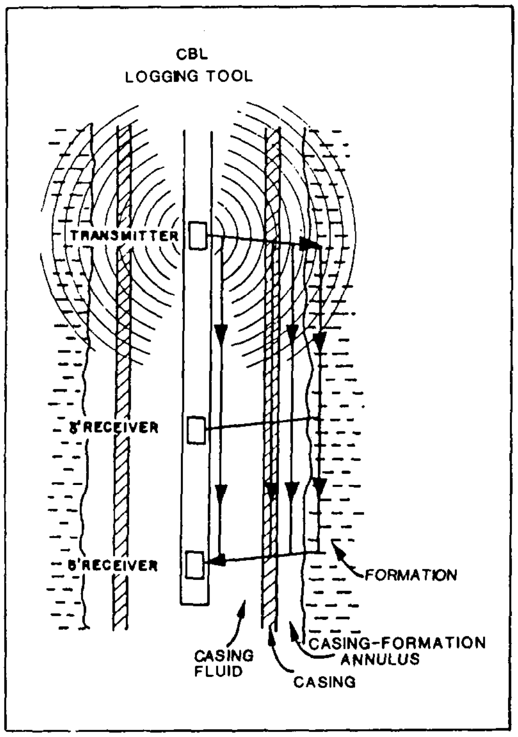



Figure 1 - The CBL downhole tool configuration

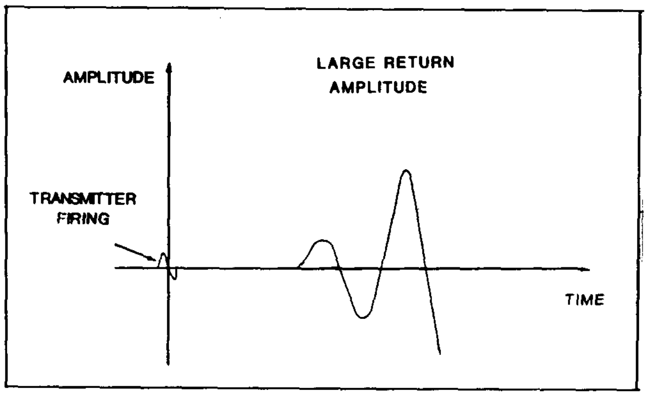
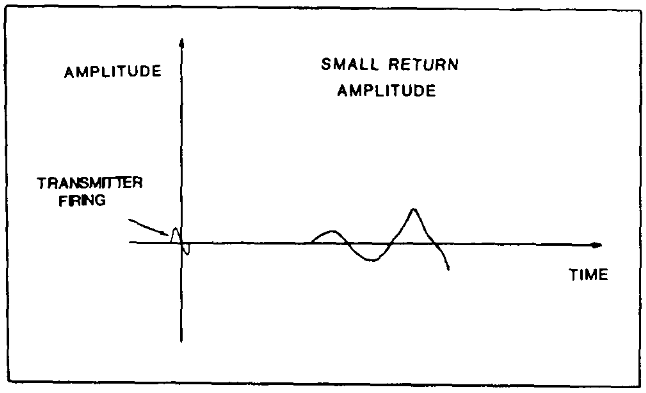



Figure 2

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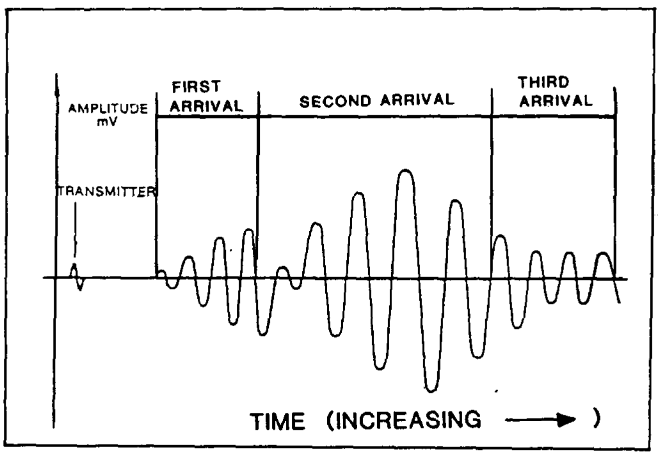



Figure 4 - Five-foot waveform

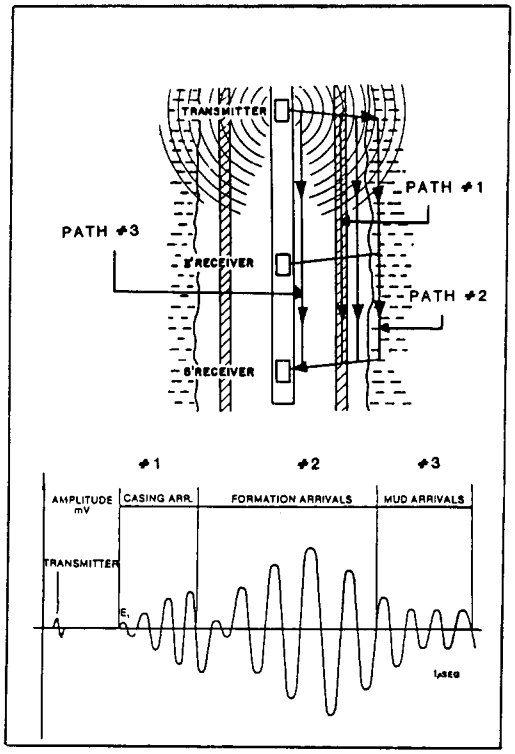



Figure 5 - Components of the five-foot waveform

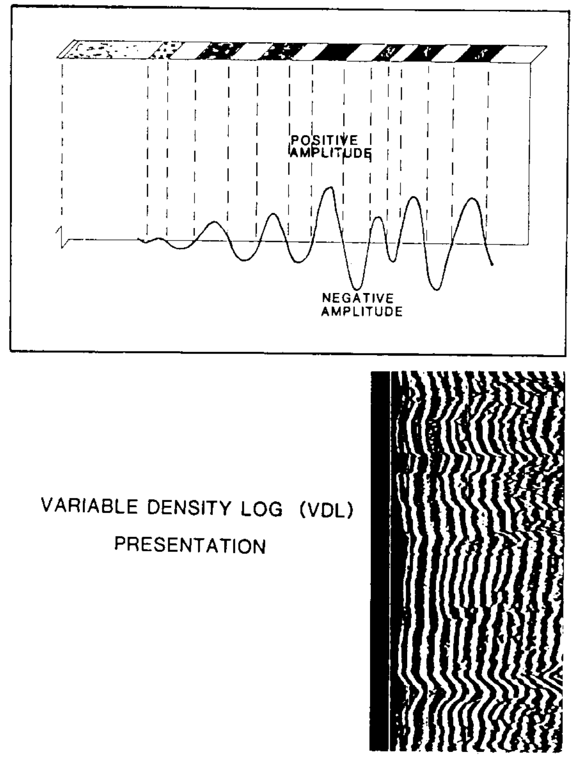



Figure 6 - The variable density display

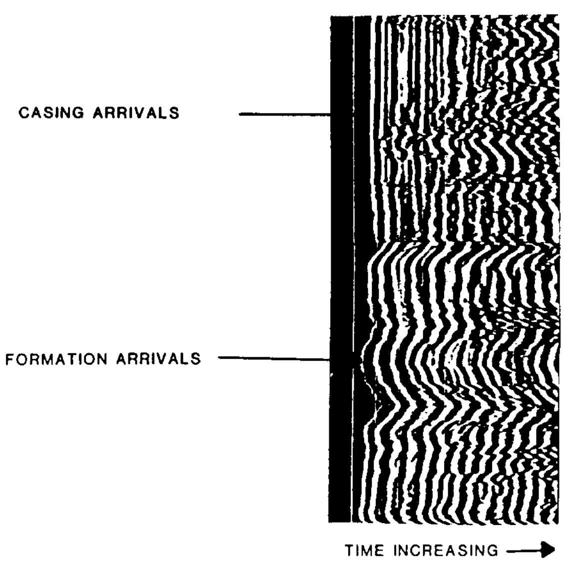



Figure 7 - Arrivals from the formation appear at the three-foot receiver before the first arrival from the casing

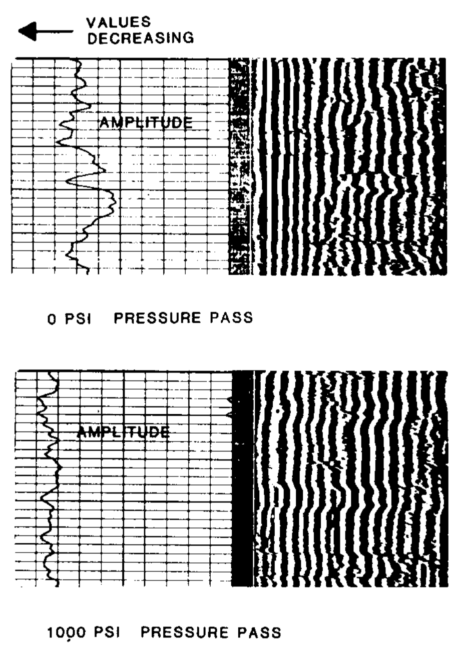



Figure 8 - CBL microannulus effect

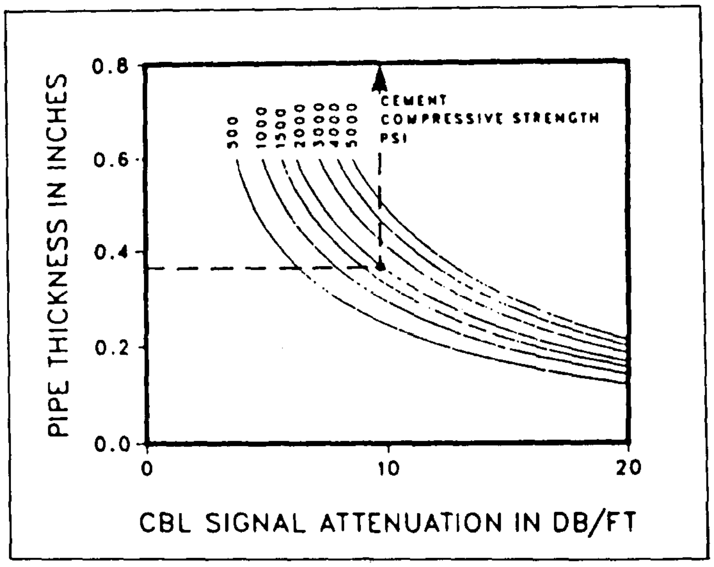



Figure 9 - CBL amplitude response as a function of cement compressive strength

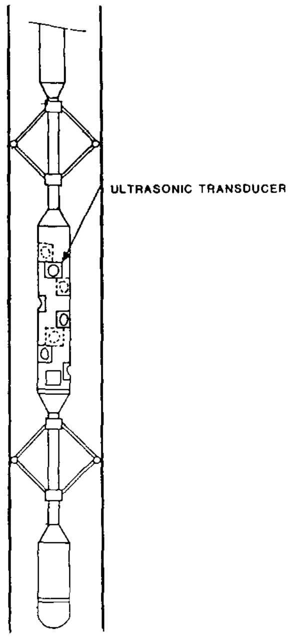



Figure 10 - Cement evaluation tool*

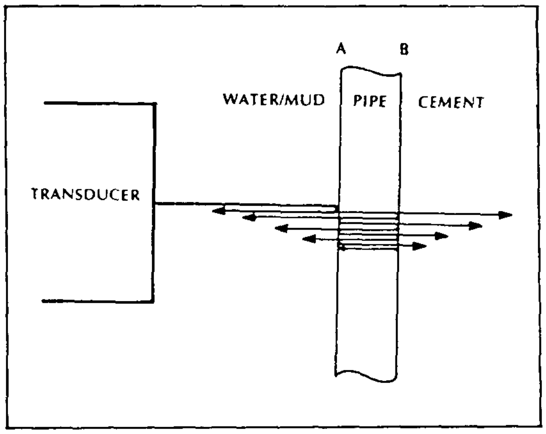
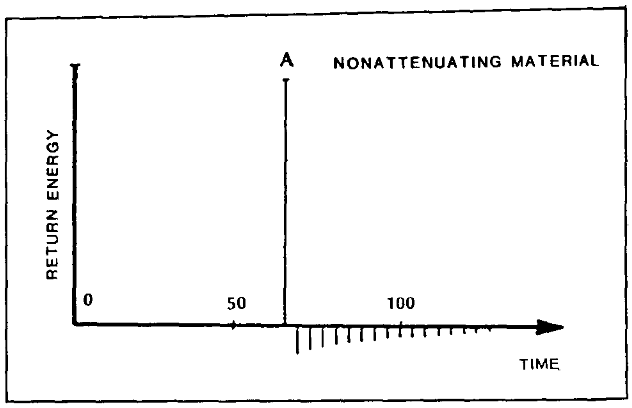



Figure 11

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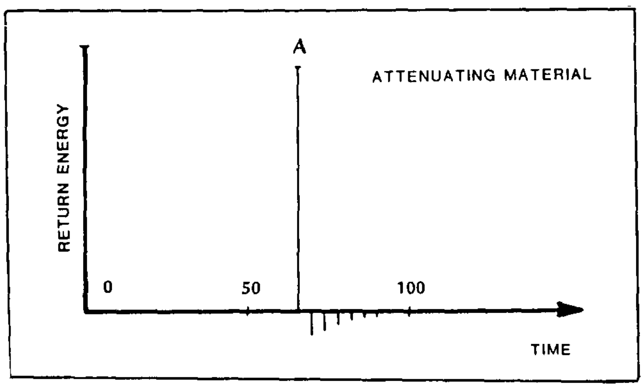


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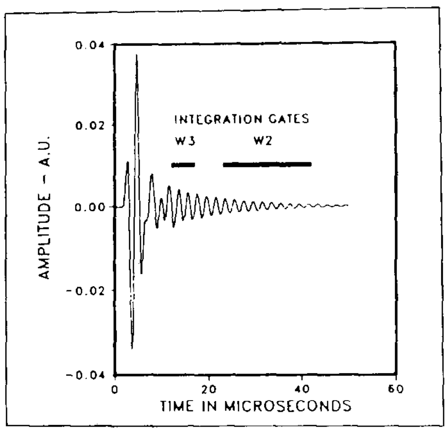


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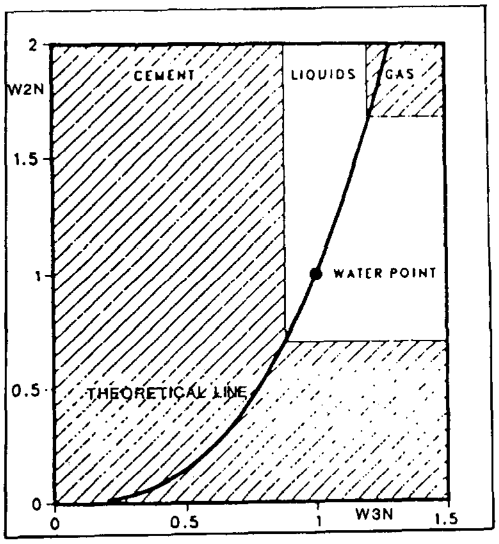


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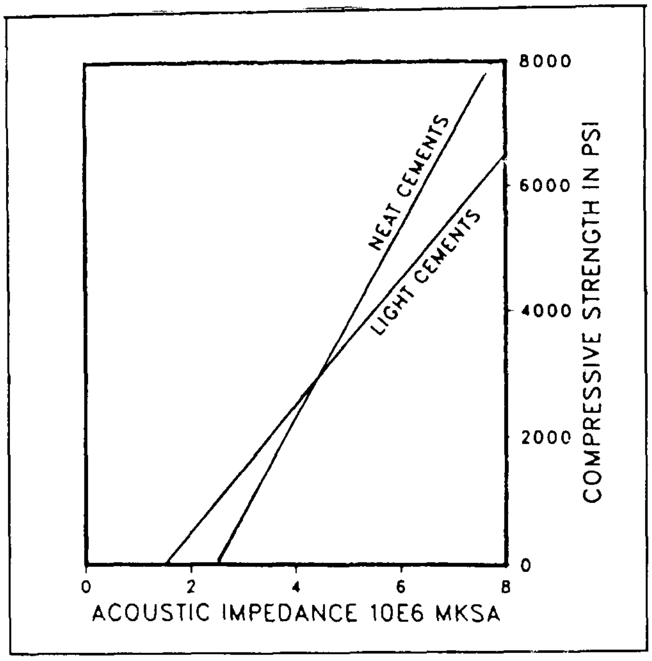



Figure 16 - The linear relationship between acoustic impedance and compressive strength for neat and light weight cements

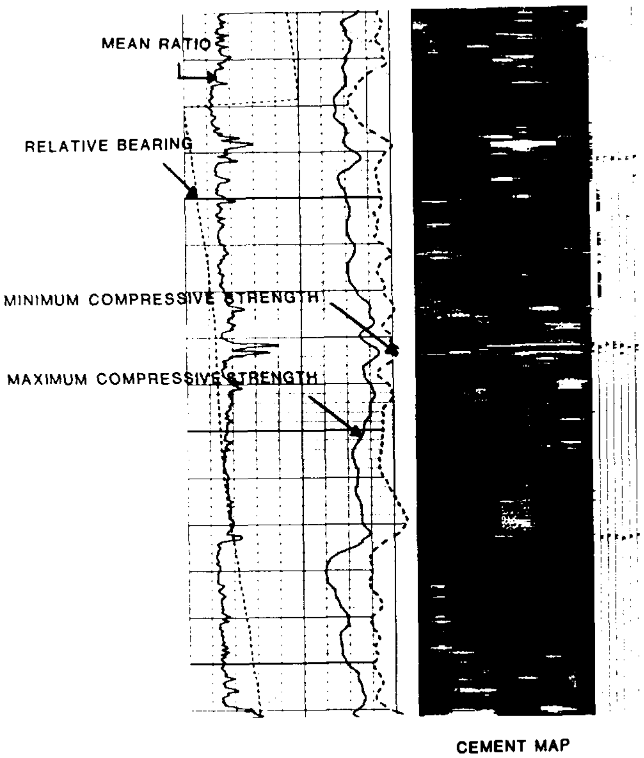



Figure 17 - Cement evaluation log

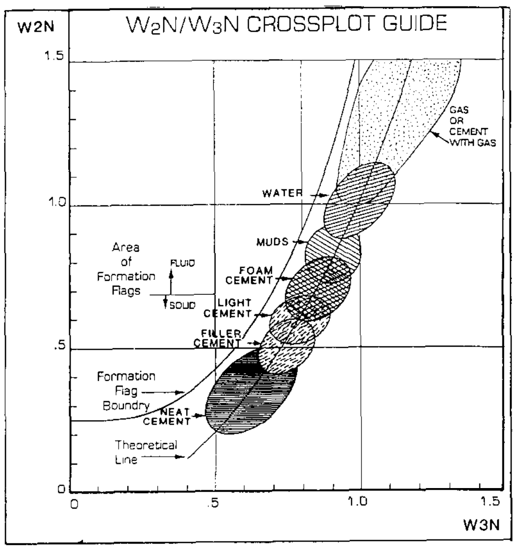



Figure 18

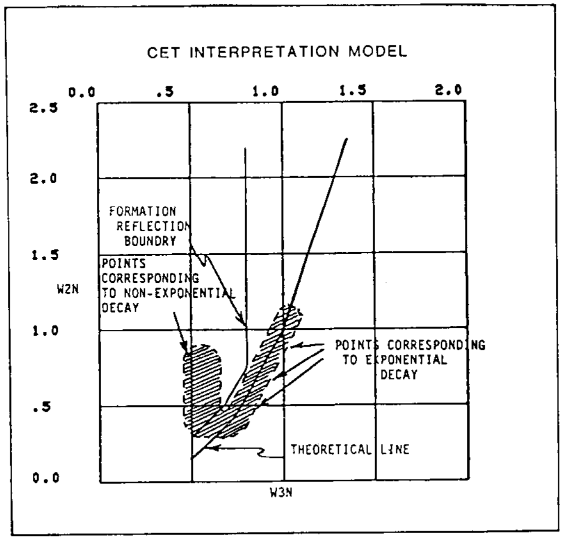



Figure 19 - Crossplot of CET normalized transducer response. W2N valves are used to infer the acoustic impedance of materials in the casing-formation annulus.

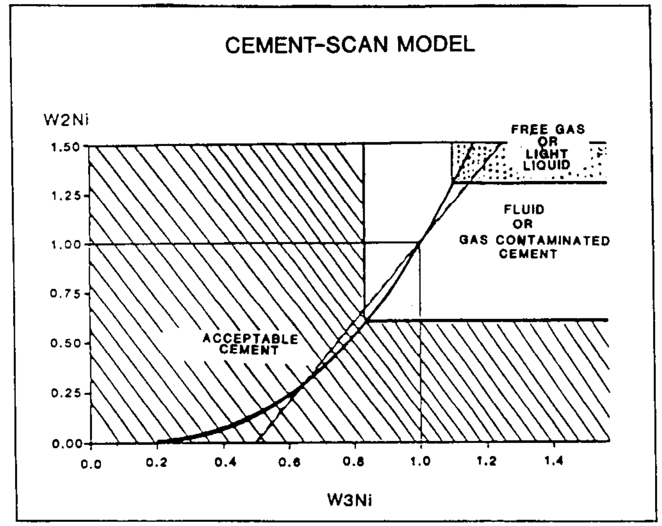



Figure 20

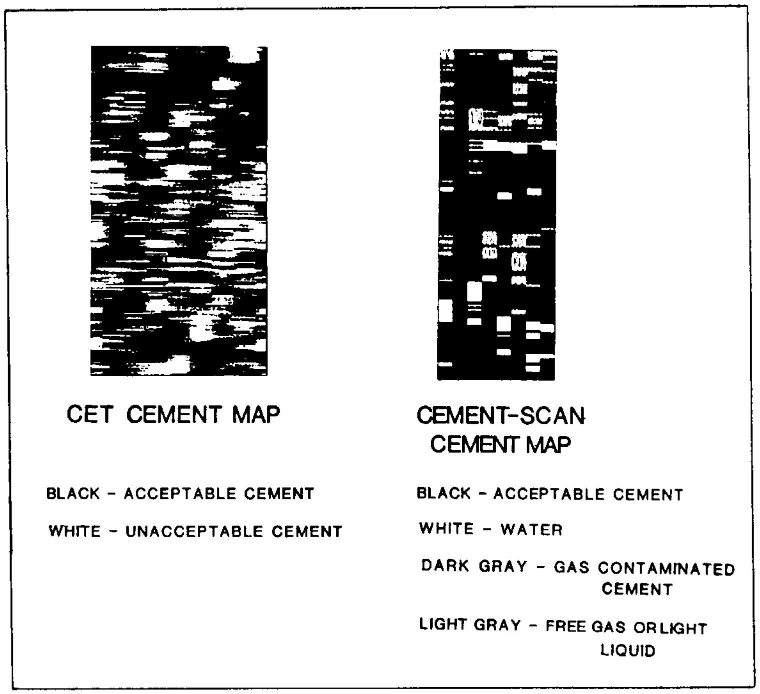



Figure 21 - A comparison of the CET cement map and the map presented on the Cement-Scan log

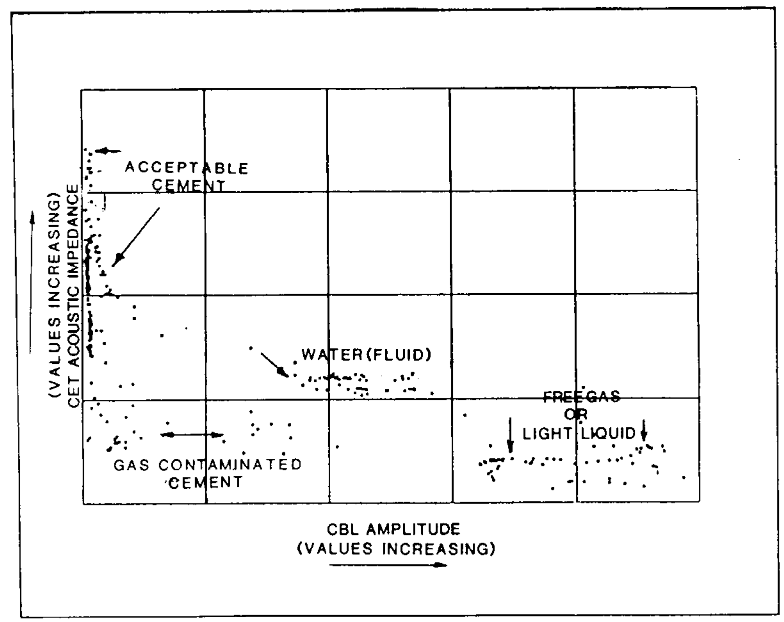



Figure 22 - Crossplot of acoustic impedance vs. CBL amplitude

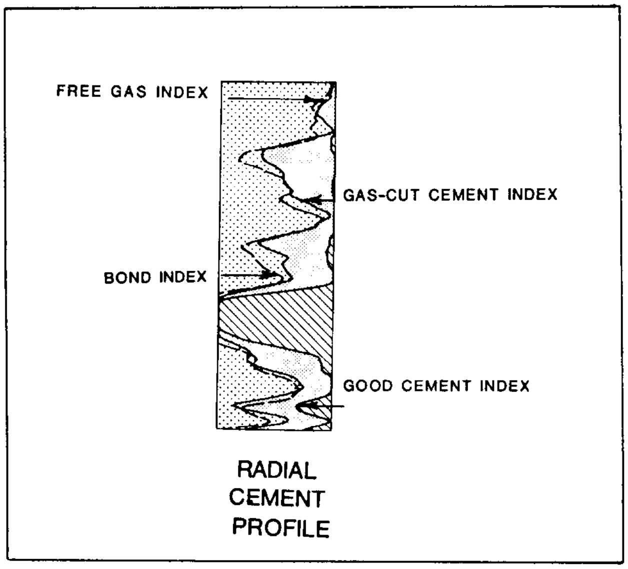



Figure 23 - The radial cement profile as presented on the Cement-Scan log

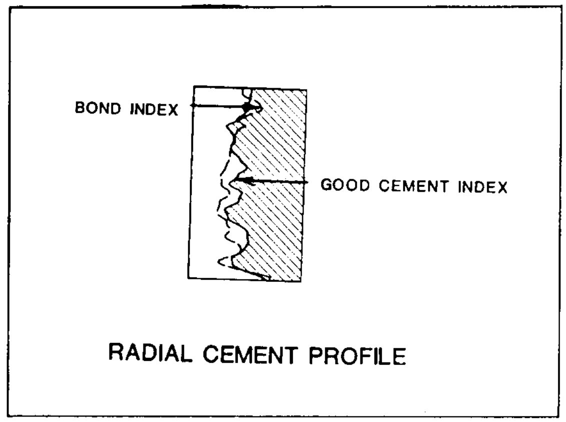



Figure 24 - Example of the radial cement profile indicating acceptable cement with water channeling

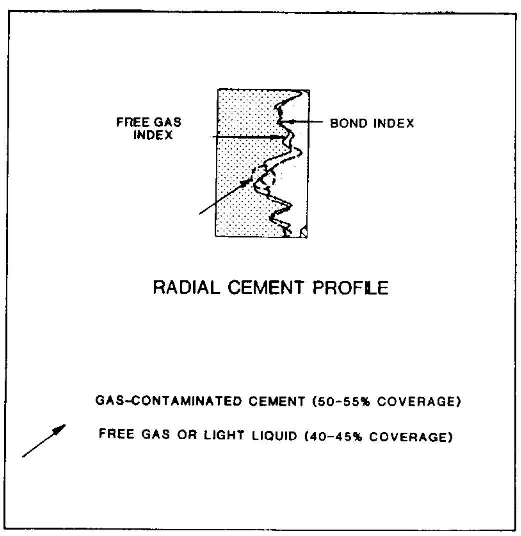



Figure 25 - Example of the radial cement profile in an area of gas-contaminated cement and free gas (or light liquid) behind the casing

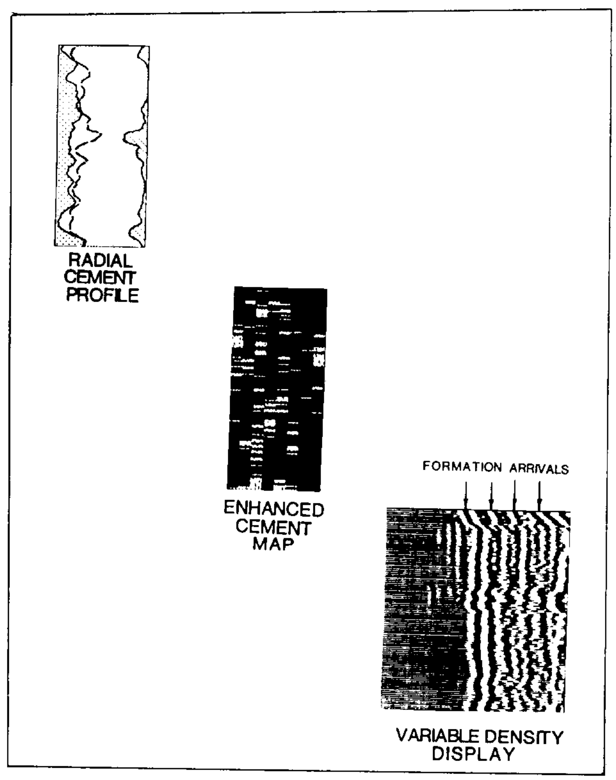



Figure 26 - Gas - contaminated cement with gas channels

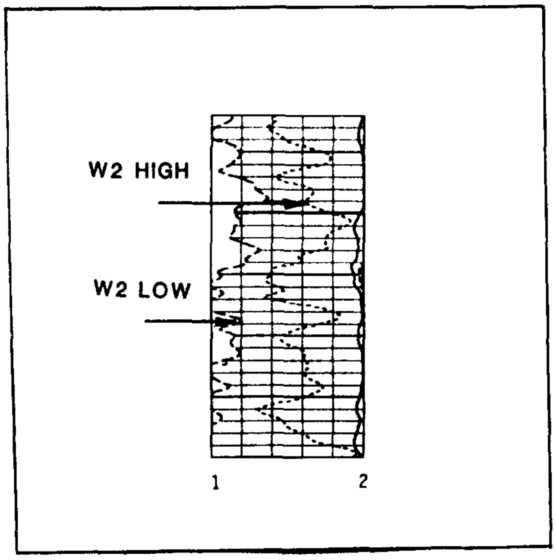
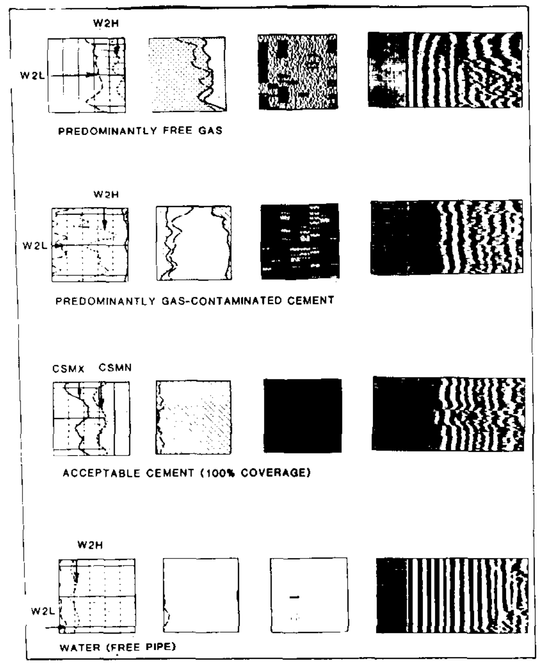



Figure 27




NOTE: ACCEPTABLE CEMENT WILL BE ACCOMPANIED BY THE APPEARANCE OF CSMX AND CSMN; W2H AND W2L WILL NOT APPEAR

Figure 28

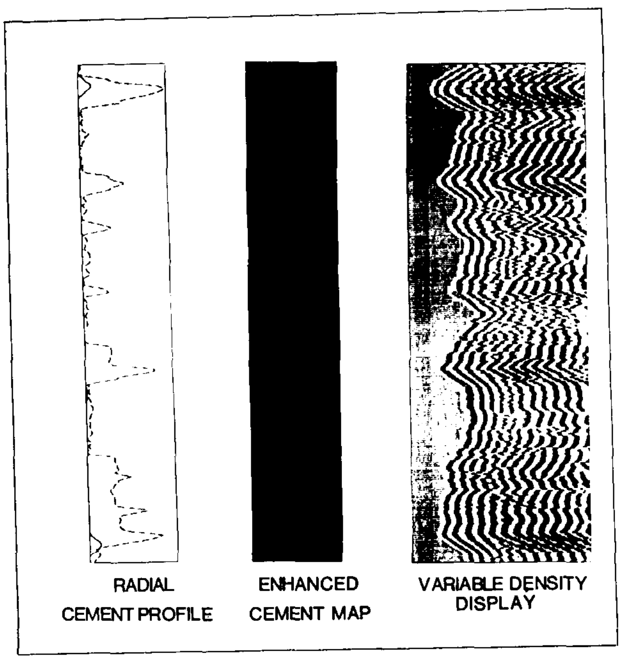



Figure 29 - Fast formation arrivals in a well-cemented interval

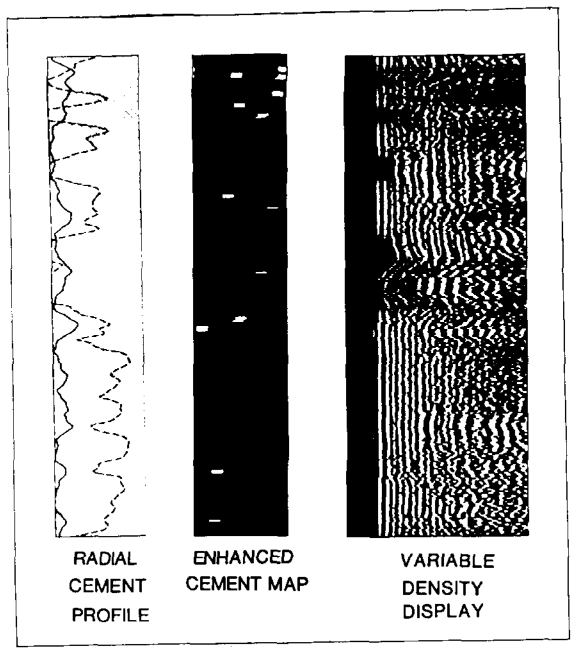



Figure 30 - Microannulus condition affecting CBL-derived data

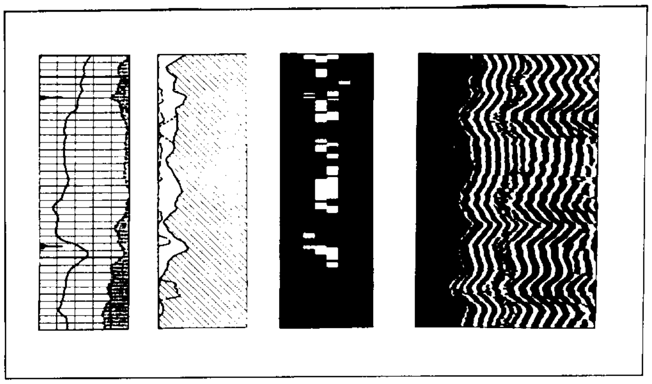


Figure 31 - Example of averaging effects on CBL-derived data. Cement map indicates a small channel.

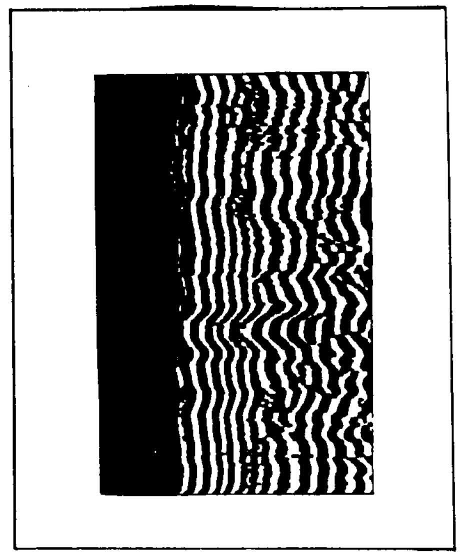


Figure 32 - Variable density display indicating good bond to the formation.

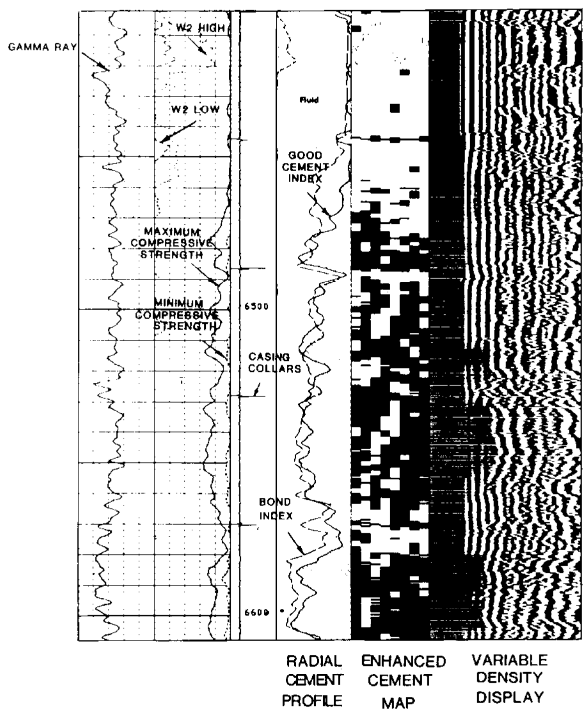



Figure 33 - The Cement-Scan log

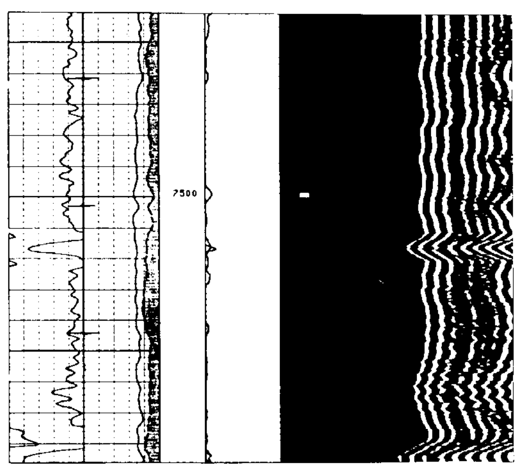



Figure 34 - Good cement

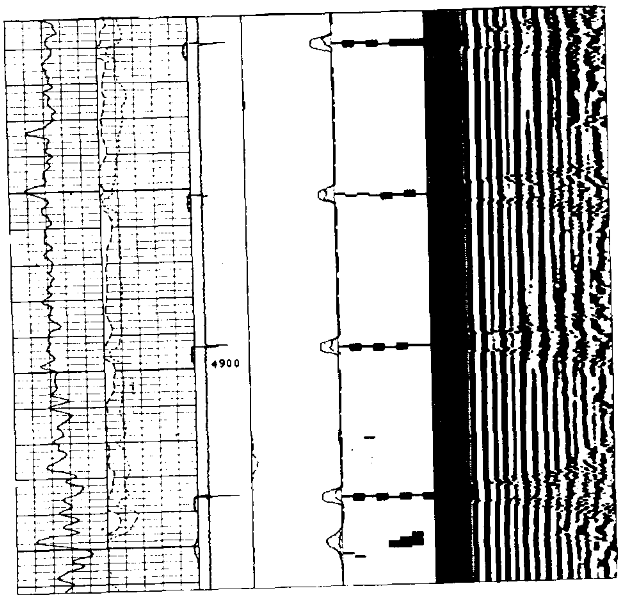



Figure 35 - No cement

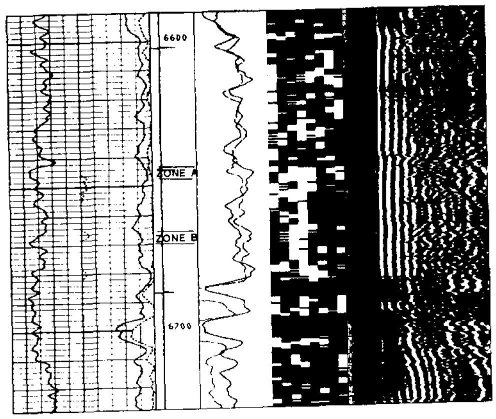



Figure 36 - Channeling behind the casing

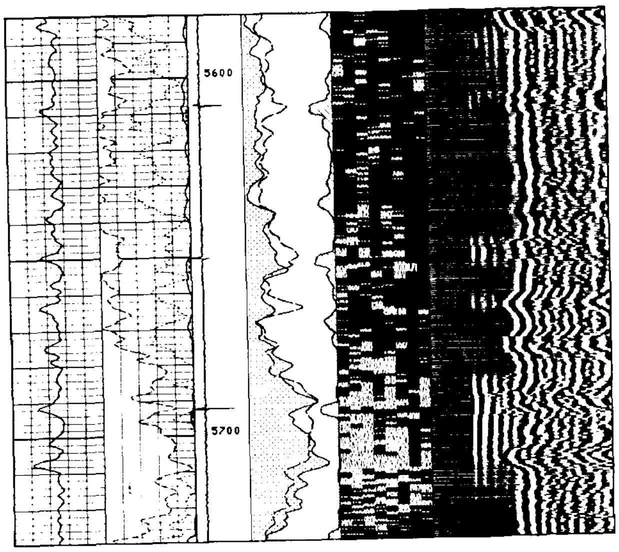



Figure 37 - Gas-contaminated cement

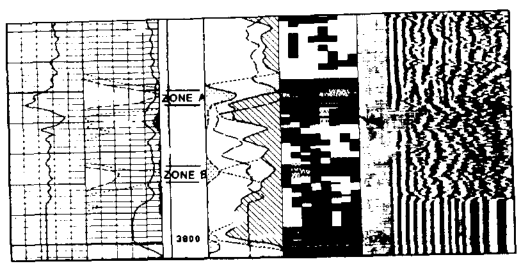



Figure 38 - CBL averaging effects/ poor bond to the formation

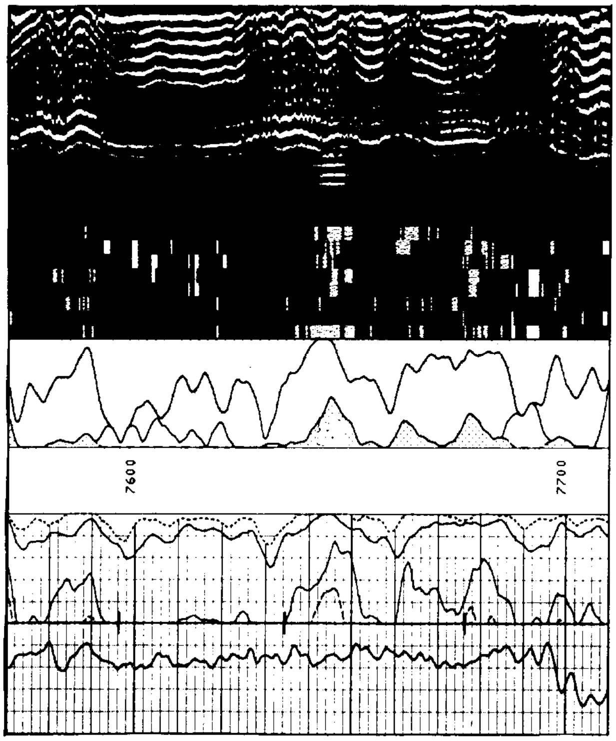



Figure 40 - Foam cement

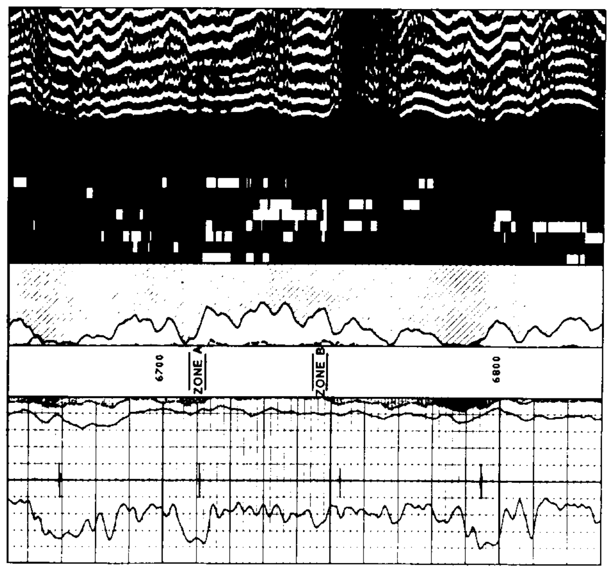



Figure 41 - Weak cement

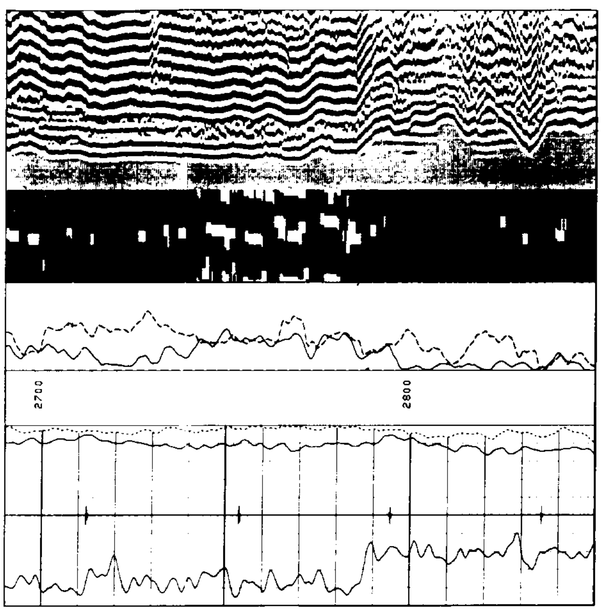



Figure 39 - Channeling with fast formation