Through Casing Sonic Transit Time Measurement Using the Array-Sonic Tool *

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ABSTRACT

Borehole sonic transit time measurements have been used by engineers and geologists in west Texas since the mid-1950's. The great majority of this sonic data has been acquired in open hole. With recent improvements in acquisition and processing technology, reasonable data can now be obtained in cased wellbores.

The purpose of this study is to compare cased hole data with the established open hole data standard. The evidence suggests that usable compressional and shear transit time data can be obtained through casing. There are over 120,000 cased wellbores in west Texas as of this writing. A large percentage of these were surveyed prior to the development of most current petrophysical and geophysical processing techniques that require sonic inputs. With this technology, these wellbores can now be properly evaluated.

INTRODUCTION

Borehole sonic transit time measurements have been used in a wide variety of applications over the last 30 years. The compressional transit time measurement has been used by the petrophysicists primarily to define porosity and lithology. The geophysical community has also used the compressional measurement to correlate compressional surface seismic velocities with well depth. With the advent of the shear measurement in 1981 geophysicists have used the borehole shear measurement to correlate shear surface seismic data with well depth. Completion engineers have also used the compressional and shear measurements to better define the mechanical properties of the reservoir prior to stimulation.

The great majority of the transit time information has been acquired in open hole. Once casing had been set, it was generally assumed that reliable sonic transit time data could not be obtained. This was due to the poor correlation between open hole and cased hole data acquired with conventional two receiver-two transmitter sonic tools (Figure 1). The Long-Spaced Sonic (LSS*) tool (Figure 2) improved this correlation somewhat, however it was still difficult to determine the quality of the data recorded at the wellsite. In an open hole environment, the observed compressional and shear

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transit times are representative of the virgin formation, with minor uncertainty from drilling damage, invasion, and washouts. In a cased wellbore, the recording environment includes this plus a cement sheath of varying thickness and metal casing. The combination of cased and open hole responses produced a complex situation that conventional sonic tools could not deal with reliably. With improvements in waveform processing and by modifying the tool to include a receiver array, the quality of the data can be determined at the wellsite. In addition, the agreement between open hole and cased hole data is much better.

THE ARRAY SONIC TOOL

The Array-Sonic Tool* (SDT*) was introduced to the Permian Basin in 1985. It is described in detail in references (1) and (2). The key difference between this tool and the previous sonic tools is an array of eight receivers spaced 6" apart. The receivers are positioned 8 ft from the closest of two transmitters (Figure 3). The waveform generated by a transmitter firing is recorded at each receiver yielding a series of waveforms shown in Figure 4. The Slowness Time Coherence (STC) processing algorithm looks to see if the peaks arrive at a point in time that is consistent with the receiver spacing (Figure 5). If the arrivals are "coherent", they are used in the processing. If the arrivals fall outside the coherence window, they are discarded as noise. The quality of the data is apparent from the coherence, in contrast to a conventional sonic log where a delta T will be calculated in all cases. The output of the STC processing is displayed as a "dot log" (Figure 6). The field engineer can examine the slowness and set windows for the various arrivals. This labelling process then connects the dots that are within the windows selected. In addition, casing arrivals can be anticipated and thus excluded. If the cement-casing-formation bond is good, the casing arrivals will be negligible (Figure 7). If the bond is less than perfect, the casing arrivals will appear as an additional signal (Figure 8). If the formation arrivals are consistently slower than the casing arrivals, they can be discriminated from the casing arrivals even with less than optimum bond.

APPLICATIONS

The shear and compressional information acquired in cased hole can be used in a variety of applications. Compressional transit times can be converted to porosity units, provided the lithology is known. The compressional transit times can also be integrated to correlate depths with P-wave seismic time data. If the compressional data is combined with cased hole compensated neutron data, the lithology can be better defined. The shear transit time can be used to evaluate lithology and help in the detection of gas in sandstones (Figure 9). In addition, it can be integrated for correlation with S-wave seismic data. The shear and compressional data can be combined to determine the hydraulic fracture gradient contrast between the perforated intervals and the boundary zones (Figure 10). This application is discusssed fully in reference (4), with a discussion of Permian Basin applications of this technology are in references (5) and (6). Recent work done suggests that the waveform data can also be used to determine the height of the created hydraulic fracture after the treatment. This is accomplished by comparing post-treatment waveform data with pre-treatment waveform data (Figure 11). As this figure suggests, the SDT can also record a cement bond log and variable density log on the same trip in the hole. An example of the CBL/VDL presentation is shown in Figure 12.

COMPARISON WITH OPEN HOLE DATA

With the exception of the before and after frac surveys shown in Figure 11 and the CBL/VDL survey shown in Figure 12, all of the beforementioned applications have been well documented using open hole shear and compressional sonic data. To validate that the same applications exist for the cased hole data, a direct comparison of open hole and cased hole data is in order. Two case studies are presented to accomplish this. The first well is a Clearfork dolomite reservoir in Mitchell County, Texas. The second well is a Spraberry siltstone reservoir in Midland County, Texas. These two lithologies represent the majority of west Texas reservoirs.

WELL NUMBER 1- MITCHELL COUNTY, TEXAS CLEARFORK

Well Number 1 has a comparison of an open hole Long-Spaced Sonic and a cased hole SDT. Cement evaluation was conducted prior to the cased hole sonic survey (Figures 12 and 13). Some channeling was indicated, with the overall bond good. A comparison of the open hole and cased hole compressional transit times is seen in Figure 14, and the shear transit times in Figure 15. Except in thin beds, there is reasonable agreeement between the two measurements. A difference in response is expected in thin beds due to the difference in bed resolution of the tools. The LSS tool has a 2 ft. receiver spacing, while the SDT records signals over a 3.5 ft. array. The bed resolution difference will cause the LSS to read higher or lower than the SDT depending on the transit time of the beds. Reference (7) discusses fully the differences in response between the Array-Sonic and other sonic measurements. Even with the variations noted, the average difference was 0.6 microseconds/ft. higher for the cased hole compressional measurement with a standard deviation of 1.97 microseconds/ft. (refer to Table 1 for a statistical summary). The correlation coefficient from a regression of all data was .866. The average difference for the shear measurement was .31 microseconds/ft. higher for the cased hole, with a standard deviation of 2.48 microseconds/ft. These numbers are similar to those observed in reference (2) for a North Sea carbonate, where the difference between open hole and cased hole compressional data was .03

microseconds/ft. with a standard deviation of 1.8 microseconds/ft. The shear data in reference (3) varied by an average of 1.5 microseconds/ft. with a standard deviation of 3.7 microseconds/ft. In Well Number 1, the correlation coefficient between open and cased hole shear data was .943, or better than the compressional. The greater variation in the compressional measurement leads to an even greater variation in the shear/compressional ratio and the calculated fracture gradient. The shear/compressional ratio had an average variation of .01 higher for the cased hole data, with a standard deviation of .07 (Figure 16). The fracture gradient was .01 psi/ft. higher on the average for the cased hole measurement, with a standard deviation of .03 psi/ft. (Figure 17). It was calculated using Poisson's ratio and the transversely elastic model discussed in reference (4). The correlation coefficient was very low for both the ratio and the fracture gradient, with a .173 coefficient for both. From a look at the data, the predominant difference was in the thin bed zones. In terms of actual pressures (fracture gradient x depth), the difference can be seen in Figure 18. Even with the thin bed problem, the standard deviation of all data was 92.5 psi. This assumed that the pore pressures were equal in all zones. In most developed west Texas reservoirs, the pore pressure side of the transversely elastic model dominates the frac gradient differences among zones, and an uncertainty in the rock stress component of the gradient may not be critical to designing an effective completion. A possible method to help tighten this correlation in thin bed zones might be a comparison of the cased hole compressional data with other porosity measurements such as a neutron or density log. This would be valid where secondary porosity was not an issue.

WELL NUMBER 2: MIDLAND COUNTY, TEXAS LOWER SPRABERRY

Well Number 2 was evaluated in open and cased hole with the SDT. Cement evaluation was done prior to the cased hole sonic evaluation, and it is shown in Figures 19 and 20. There is some channeling from 7820 to 7880, and a micro-annulus above 7815. The hole was washed out badly from 7860 to 7970. Figure 21 shows the comparison between the open hole and the cased hole compressional data, while Figure 22 shows the comparison between the open hole and cased hole shear data. The average difference for the compressional data is .83 microseconds/ft. higher for the cased hole data and 1.06 microseconds/ft. higher for the shear data. The standard deviations are 1.65 and 2.07 microseconds/ft., respectively. This is tighter than the LSS/SDT comparison done in Well Number 1, predictably so due to the similar bed resolution of the two passes. The correlation coefficients are .927 for the compressional and .959 for the shear data. This is again reasonable, especially in light of the adverse hole and cement conditions. The shear/compressional ratios had an average difference of .01 higher for the cased hole data, with a standard deviation of .06 (Figure 23). The fracture gradient had a net average difference of zero psi/ft., with a standard deviation of .03 psi/ft. (Figure 24). The cased hole calculated frac pressures varied by an average of 34.9 psi.higher for the cased hole data, with a standard deviation of 203.4 psi. (Figure 25). The majority of the variance was in the poor hole and cement areas.

CONCLUSIONS

The above comparisons show that reasonable shear and compressional sonic data can be obtained through casing with the SDT. The ideal formation for it to be run in has thick beds with an in-gauge hole. In addition, the cement quality should be adequate for a good variable density display to be made. In holes with less than these ideal conditions, careful attention should be paid to the coherence of the data. If the dot display is not consistent, the data should be treated with caution.

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3. Leslie, H.D. and Mons, F.: "Sonic Waveform Analysis:Applications," presented at the SPWLA 23rd Annual Logging Symposium, July 6-9, 1982.

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Summary of Statistical Data

Open Hole - Cased Hole Data Points

	Delta T Compressional (microseconds per ft.)	Delta T Shear (microseconds per ft.)	DTS/DTC Ratio	Frac Gradient (psi/ft)
Well Number 1				
Maximum Difference	5.03	6.77	0.25	.13
Average Difference	-.60	-.31	.01	.01
Standard Deviation	1.97	2.48	.07	.03
Correlation Coeff.**	.87	.94	.17	.17
Slope (m)	.89	.73	.76	.76
Std. error of x est.	.03	.01	.23	.24
Intercept (b)	6.49	26.54	.43	.14
Well Number 2				
Maximum Difference	2.00	4.00	.11	.06
Average Difference	-.83	-1.06	.01	.00
Standard Deviation	1.65	2.07	.06	.03
Correlation Coeff.**	.90	.96	.14	.17
Slope (m)	.86	.77	.53	.57
Std. error of x est.	.06	.03	.47	.47
Intercept (b)	8.10	23.39	.87	.25
Std. error of y est.	1.59	1.44	.06	.03

** From $y = mx + b$ best fit line, with y = cased hole and x = open hole.

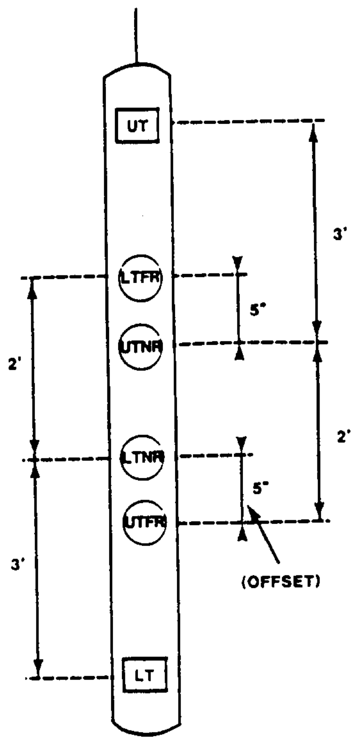


Figure 1 - BHC sonic tool

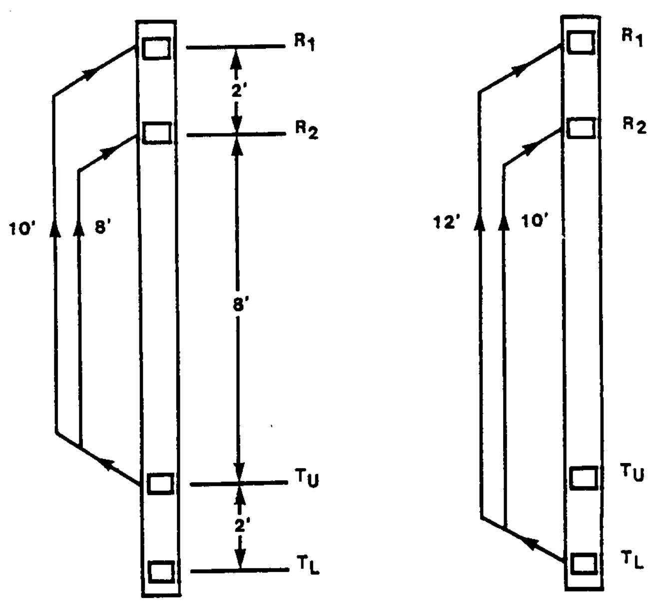


Figure 2 - Long spacing sonic tool

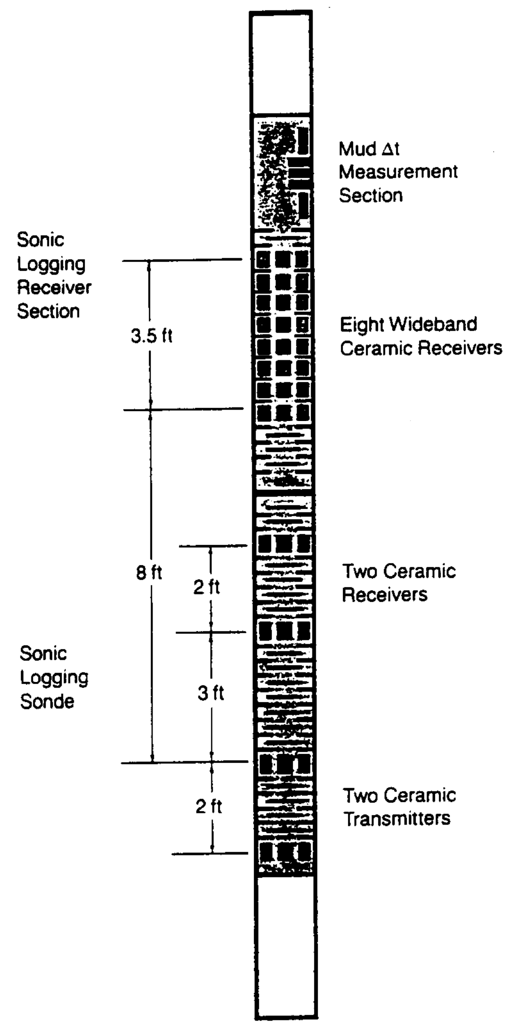


Figure 3 - Array-Sonic Tool
(SDT)

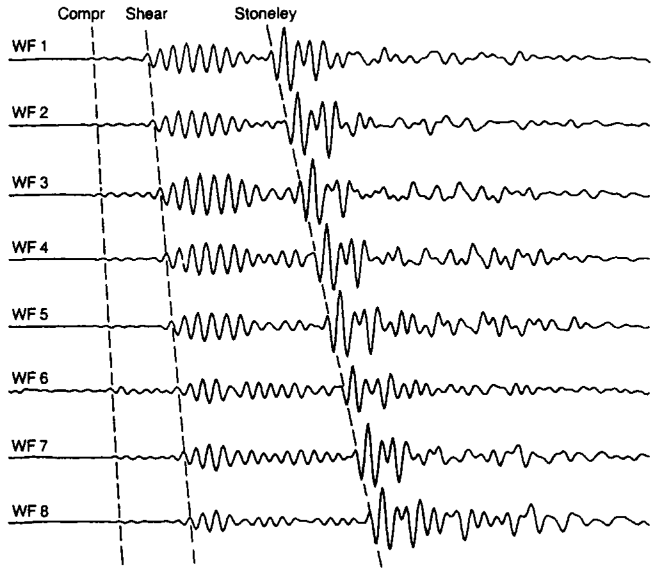


Figure 4 - Array-Sonic waveforms in open hole

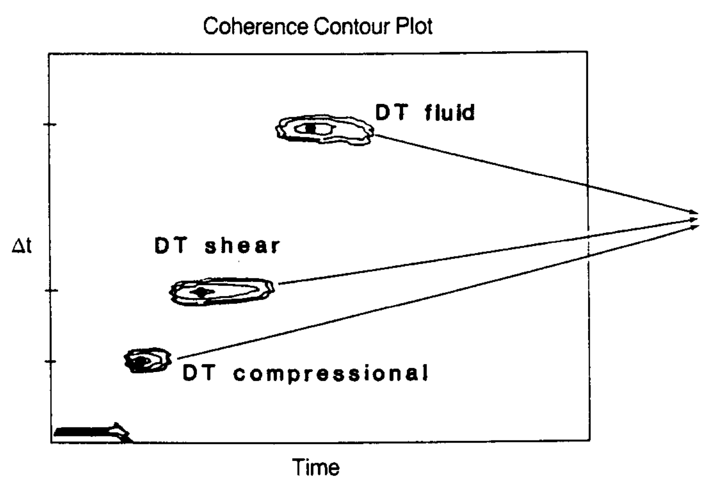
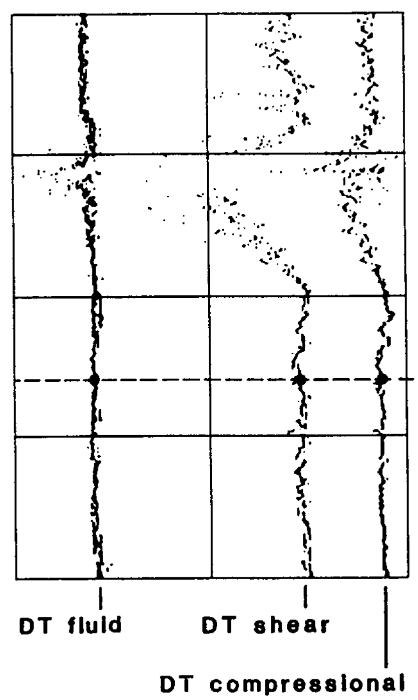


Figure 5



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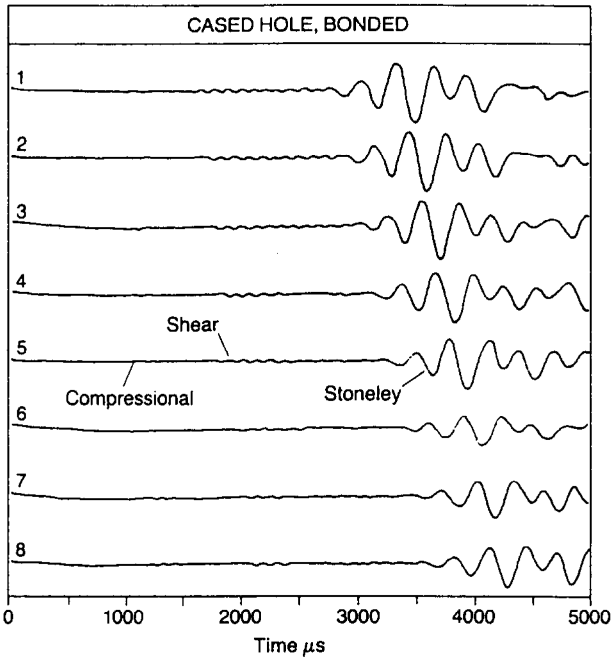


Figure 7 - SDT waveforms in well-bonded casing

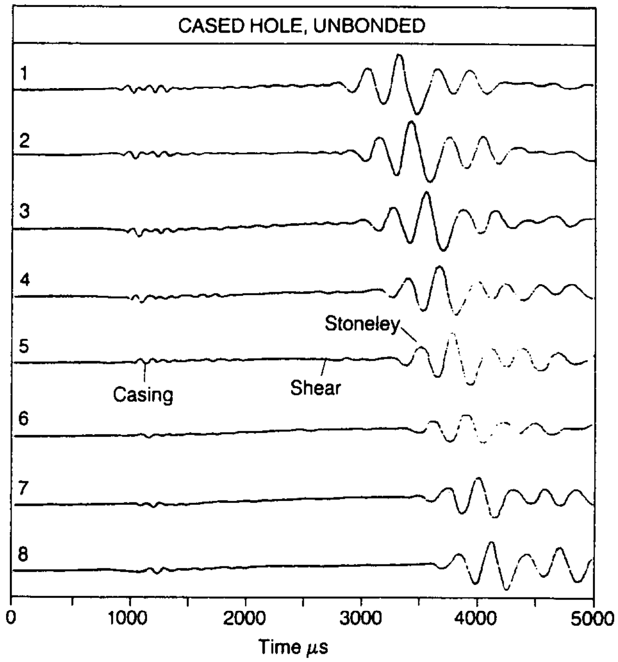


Figure 8 - SDT waveforms in poorly bonded casing

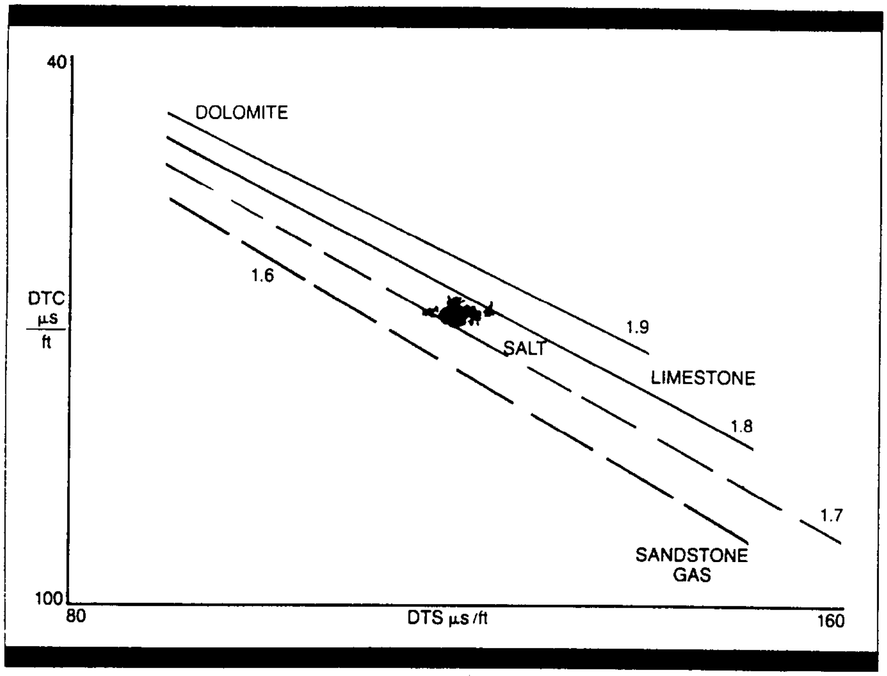


Figure 9 - DTS/DTC ratios vs lithology

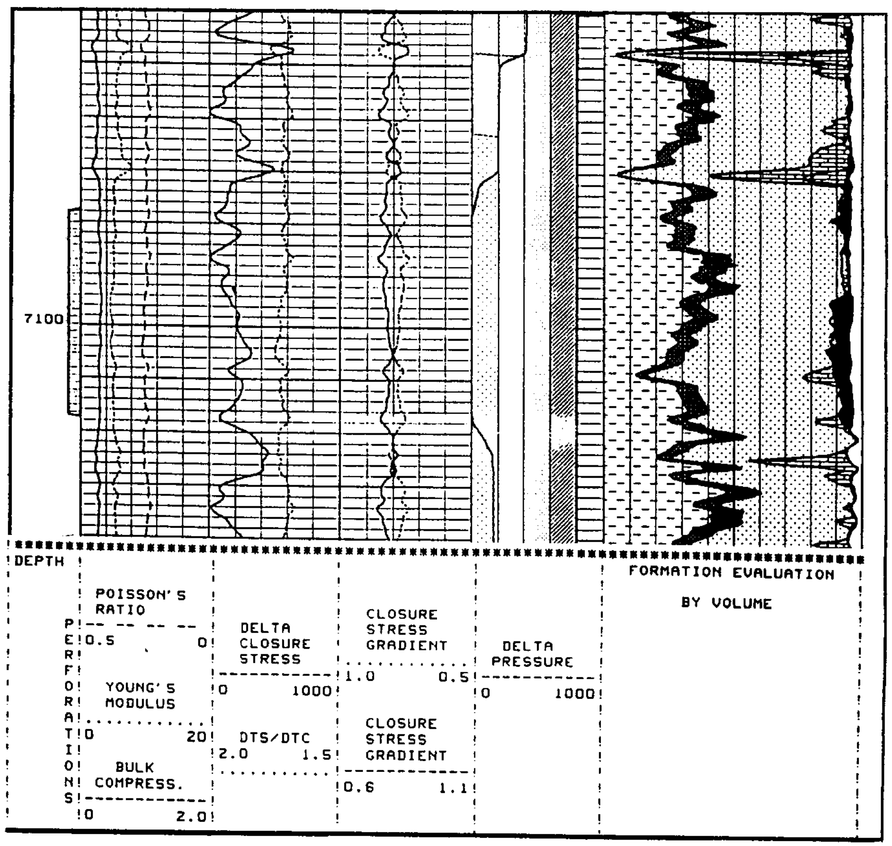


Figure 10 - Frac gradient data from shear and compressional sonic data

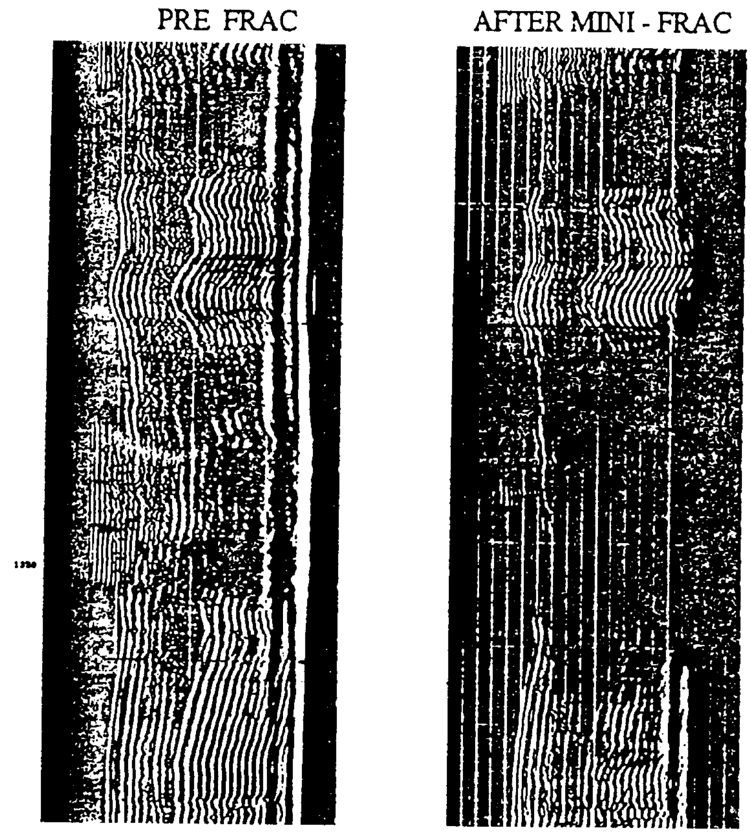


Figure 11 - Before and after frac SDT waveform data

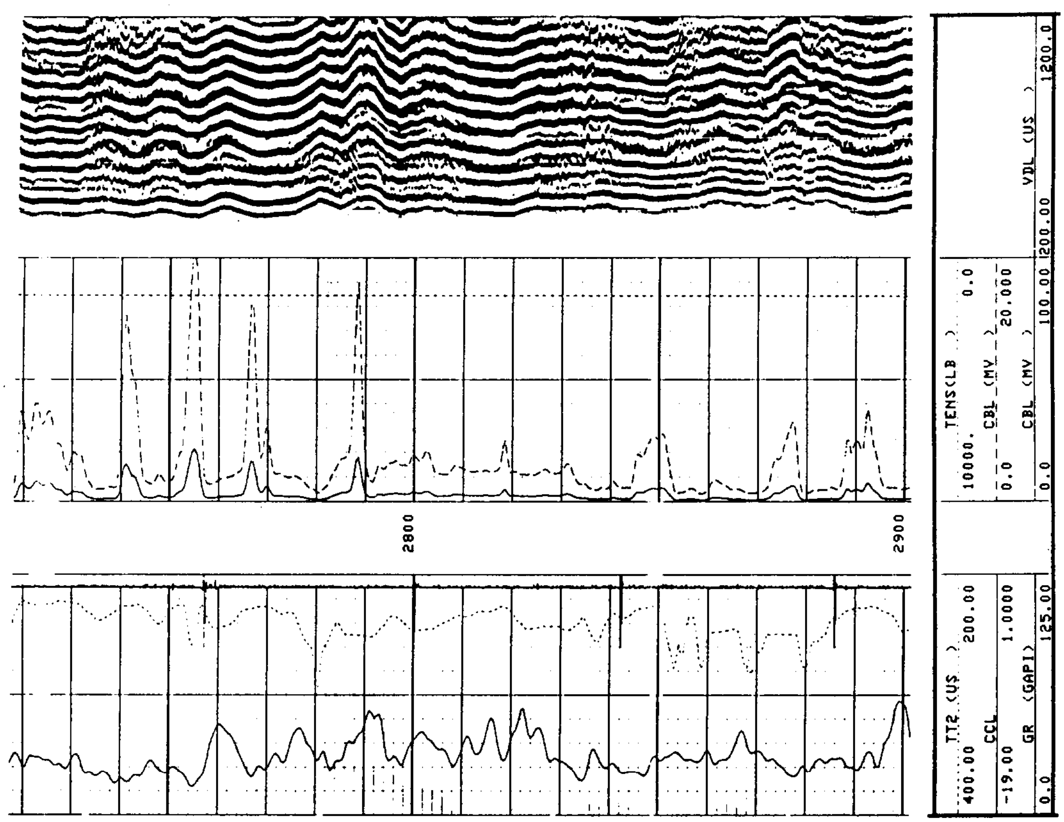


Figure 12 - Cement bond log, Well No. 1

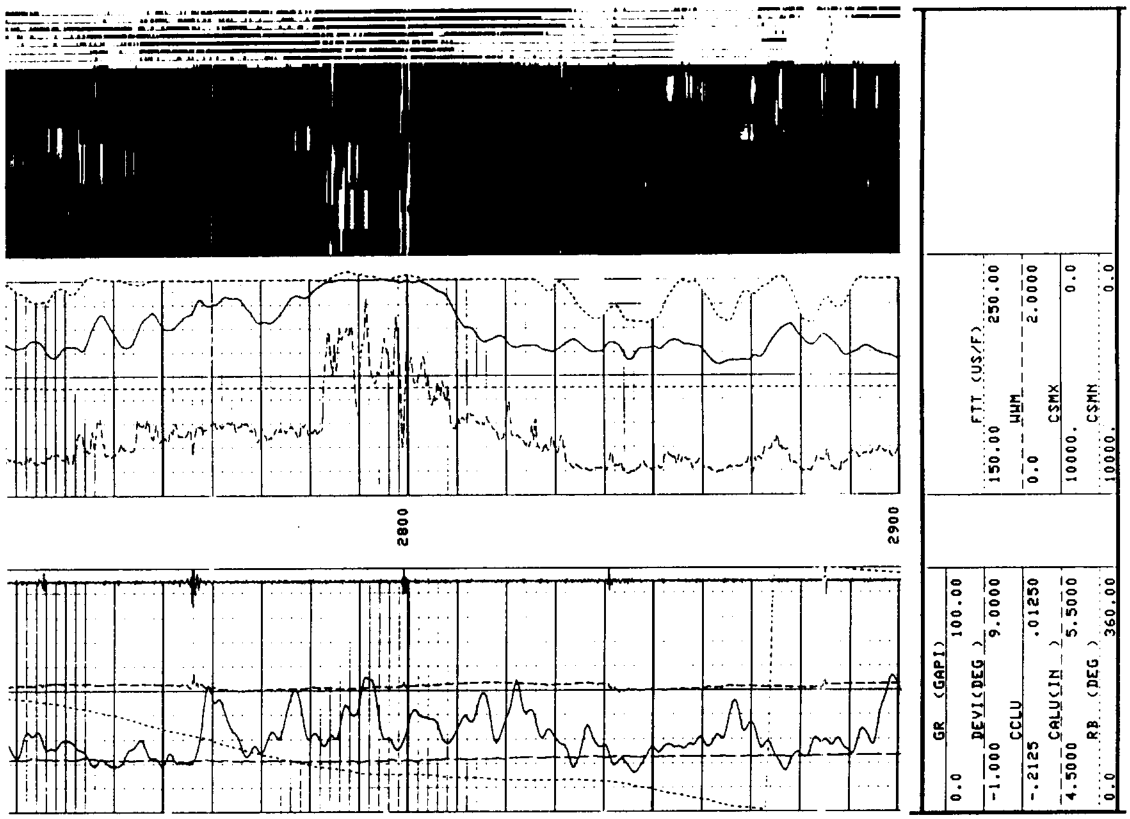


Figure 13 - Cement evaluation log, Well No. 1

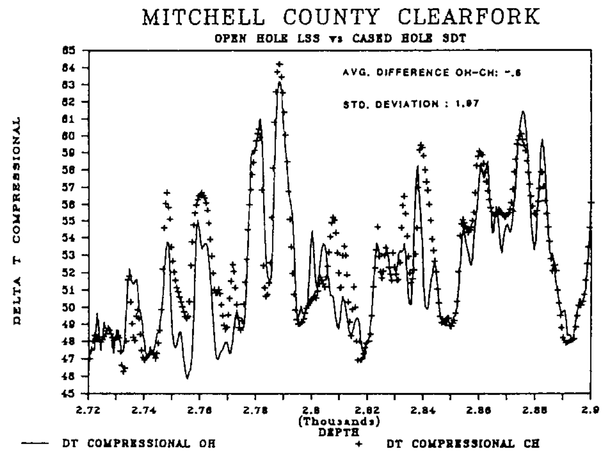
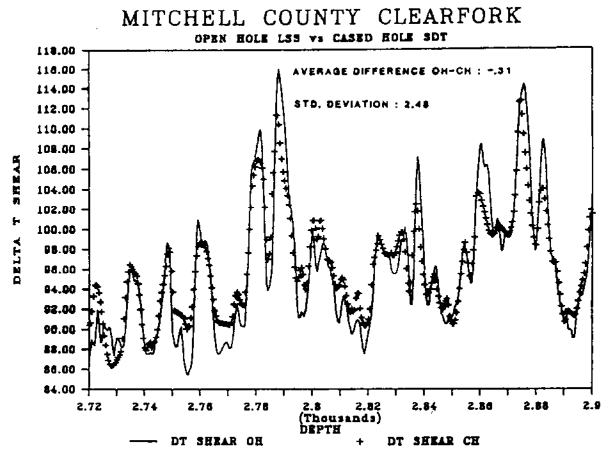


Figure 14



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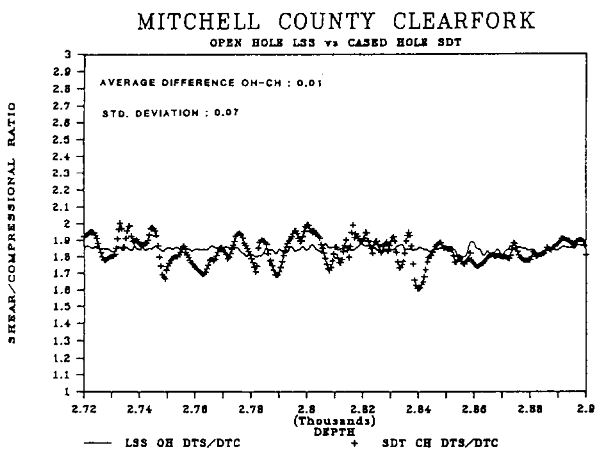

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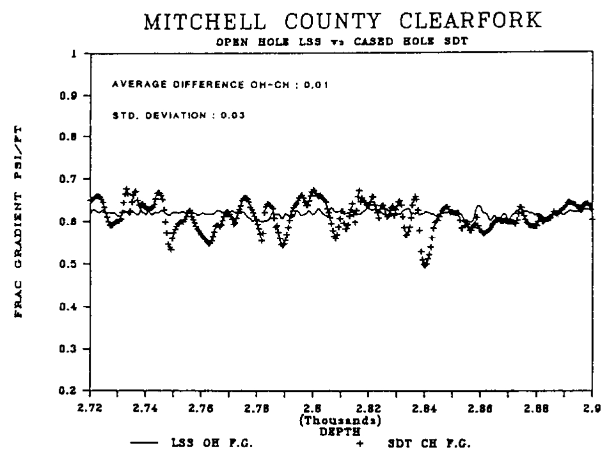

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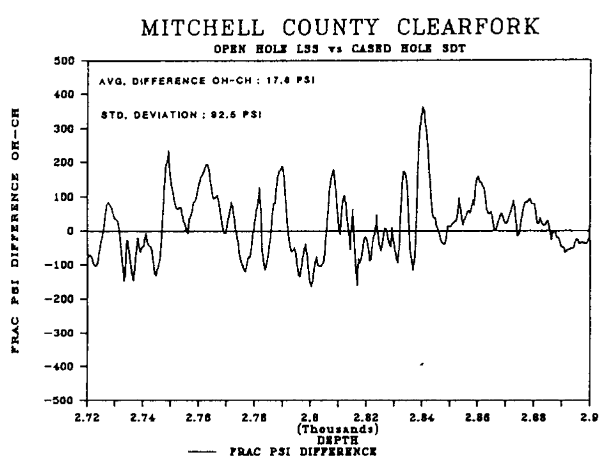

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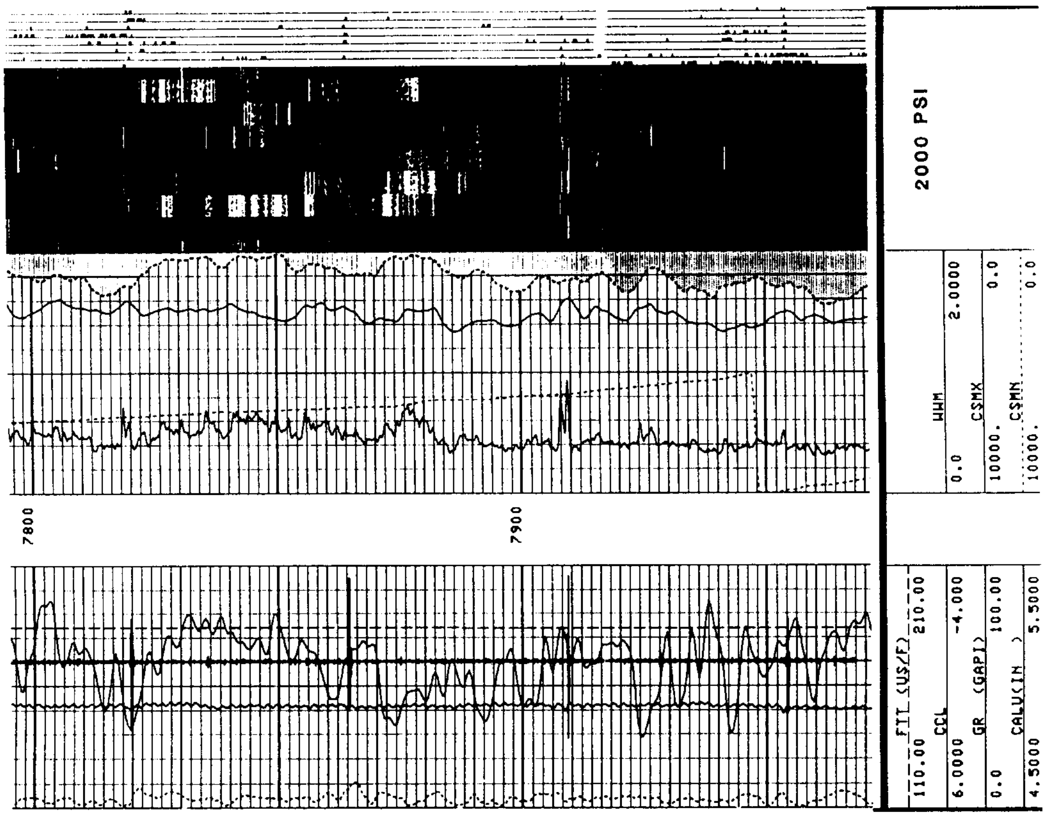


Figure 20 - Cement evaluation log, Well No. 2

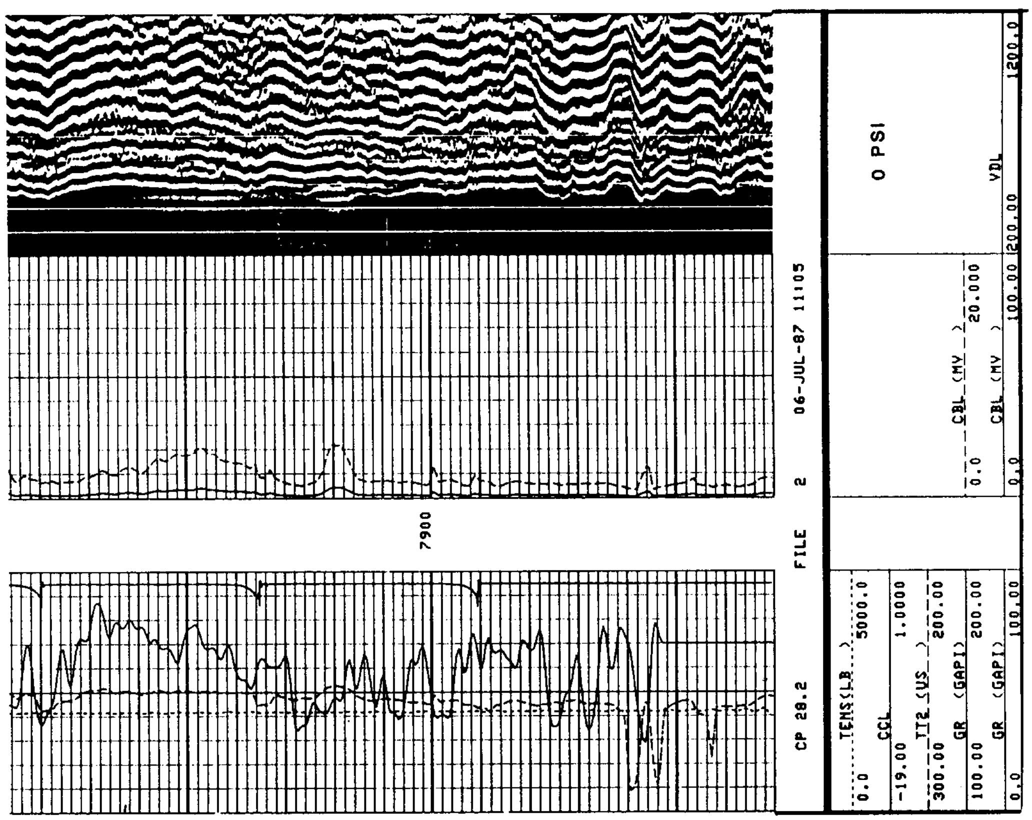
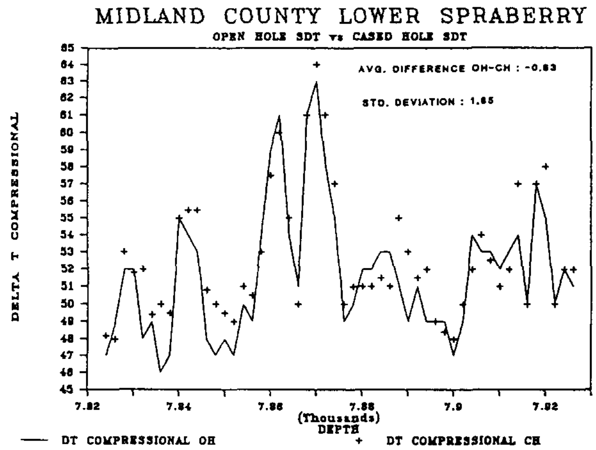


Figure 19 - Cement bond log, Well No. 2



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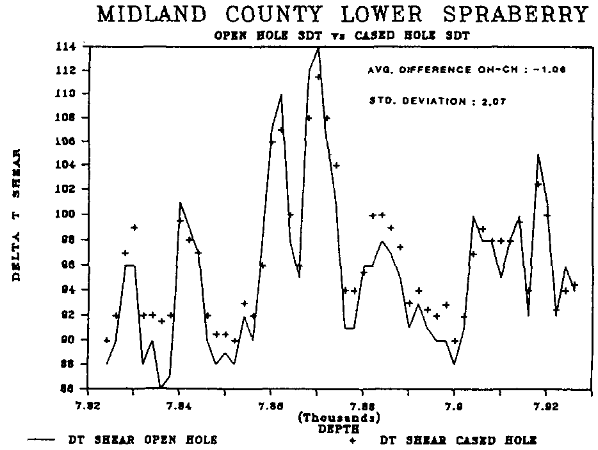

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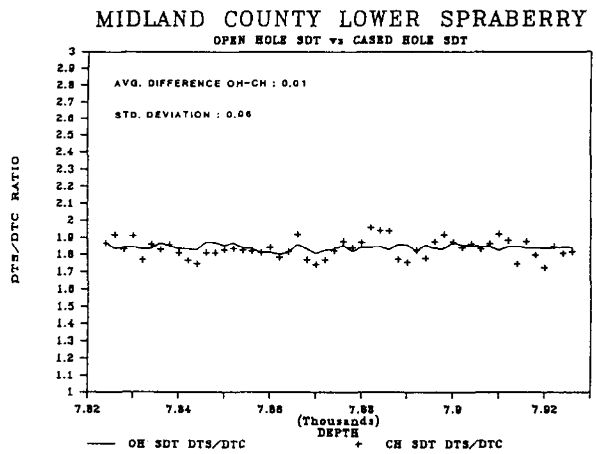

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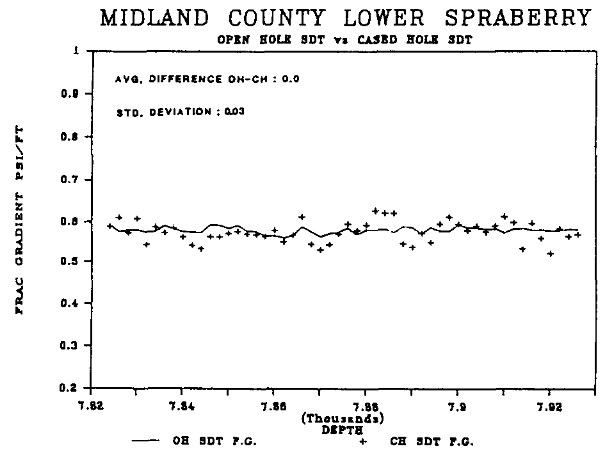

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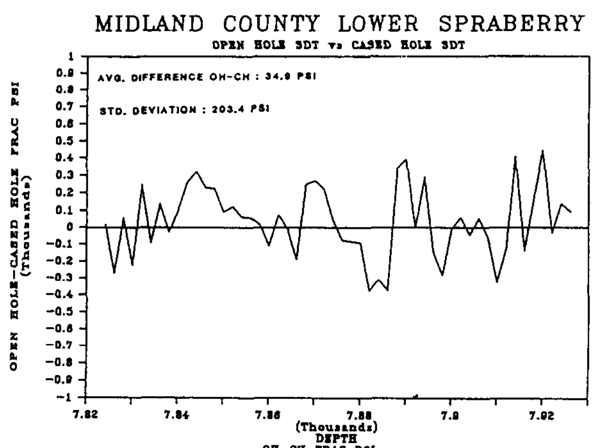

Figure 25