A comparison of LWD and wireline dipole sonic data

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Abstract

Data measured by both wireline and LWD tools in the same borehole are compared. Discrepancies in shear velocities as calculated from the data are on average around 5% and discrepancies between compressional velocities are less than 3%. The consistency of the bias between logs suggest it is related to the calculation of velocity. Comparison of industry and ERL velocity processing show excellent agreement and give an example of possible spread of velocity data due to processing chain. A short section of data in an unconsolidated zone shows velocity differences of just over 10% with an opposite trend to the over all bias. Dispersion analysis of the waveforms show this is consistent with a damaged zone surrounding the borehole wall caused by drilling.

1 Introduction

The old adage 'time is money' is especially true in the petroleum industry. The high cost of operations during oil exploration requires that borehole measurements be made not only accurately but also as quickly as possible. In recent years this has meant a shift from traditional wireline tools which operate only after a well has been drilled to newer LWD (logging while drilling) or MWD (measurements while drilling) tools. The sonic or acoustic logging tools are one class of tool which have been developed to operate in this manner. While the basic characteristics of both the wireline and LWD tools remain similar, there are differences in tool design which affect the measurements and must be considered when interpreting the respective waveforms. The LWD tools typically have a larger diameter and are hollow in the center to allow for mud flow. Conversely wireline tools are solid and smaller in diameter. The tools also operate in different frequency ranges, which greatly affects processing and should be considered when extracting velocities. Additionally the offset between the source and first receiver in the LWD tool is approximately half of the offset in its wireline counterpart. This is important when logging in very fast formations ($Vp > 4kms^{-1}$) as modal arrivals may not be well separated.
The aim of this paper is to compare velocity analyses as calculated for both LWD and wireline waveforms in the same formation. While there is a body of work documenting waveform processing for both tools, there have been few studies that document comparisons of the two tools Boonen and Tepper (1998). LWD tool analyses have been published by Goldberg et al. (2003), Tang et al. (2002) and Market et al. (2002) and wireline published works include Chen (1988), Winbow (1988) and Brie and Saiki (1996).

2 The Data

Our data set consists of both LWD and wireline data collected over the same interval in the same well. There are both monopole and dipole logs measured by the wireline tool and dipole logs from the LWD tool. The wireline data was taken approximately ten days after the drilling was completed. Figure 1 shows the formation compressional velocities and 3 shows the formation shear velocities as calculated by industry processing. In both figures the left hand side shows the velocities in ms^{-1}, with red denoting wireline and blue denoting LWD, and the centre columns show the percentage difference between the two tools measurements. The last column shows the gamma ray as measured by the wireline tool. It is evident, from these plots that the formation is slow (fluid velocity ¿ shear velocity) along most of the interval with a fast section below x775 ft.

2.1 Compressional Velocities

The compressional velocity log shows a consistent difference of about 1-4% between the two tool measurements, with the wireline being consistently faster. The small difference between P wave velocities is probably due to the velocity processing techniques. The mean difference of 2% is not really a concern in terms of the absolute value of the velocities. The large peaks in the percentage difference plot are due to the difference in depths at which each tool took a measurement. The rate at which the borehole is drilled is not constant and so the LWD takes measurements as a function of time. This leads to uneven sampling along the borehole. Conversely, wireline tools take measurements as a function of depth and so are evenly sampled along the z axis. For the purposes of calculating the percentage difference between the logs the LWD data was interpolated to have samples at the same depths as the wireline which can lead to the large spikes seen in the percentage difference plot. The fact that the bias is consistent along the log suggests it is not related to formation properties. There was a 10 day delay between measurements and it is possible that some of the measured properties can change over this period. This is referred to as alteration. Time lapse acoustic logs often show a difference in measurements as pore and drilling mud fluid equilibrate down hole. This is especially problematic where shales are present as they can swell altering both the geometry of the borehole and the acoustic properties, Blakeman (1982), Wu et al. (1993). Although alteration is a possible scenario which can account for the small discrepancies in velocities, it seems unlikely the whole formation would produce the same bias. If the bias was due to alteration, and thus formation related, one would expect to see the difference between the logs vary as a function of depth. Figure 2 shows a scatter plot of the compressional velocity data. It is easy to see from this representation that the data fall around the equality line indicating a good match at all velocities.

2.2 Shear Velocities

In figure 3 the shear velocities also show consistent differences between the logs. The mean percentage difference is between 5-7% but in the zone between x600 and x620 the difference is over 10%. This zone is of additional interest because the bias changes from LWD measurement being faster to the wireline being faster. It is clear from the gamma ray data at these depths that there is a change in lithology in the same zone. The decrease in GAPI from 90 to 55 indicates a change in formation from mudstone to loose sands. Figure 4 shows a scatter plot of the two data sets. The plot shows how the bias changes with velocity. In the zone between x600 and x620 the shear velocity is between 1200 and 1400 m/s which corresponds to the shift below the line of equality in figure 4. For lower and higher velocities the data tend to be above the equality line, indicating a consistent bias.

3 Velocity Processing

The logs shown in section 2 were the result of industry processing of the waveforms. They are useful as an overview of the formation structure and indicate where zones of interest might lie. In this section we present the velocities as calculated by ERL from the waveforms. This gives an indication of how much spread there is in velocity calculation. The two data sets were processed slightly differently due to frequency ranges and tool geometry. Both tools used dipole sources and the shear velocities are extracted from the flexural mode. The wireline data were filtered between 1-3 kHz and then the velocities were picked from semblance peaks. The LWD data were filtered between 5-15 kHz, the peaks were picked from semblance and a correction was made

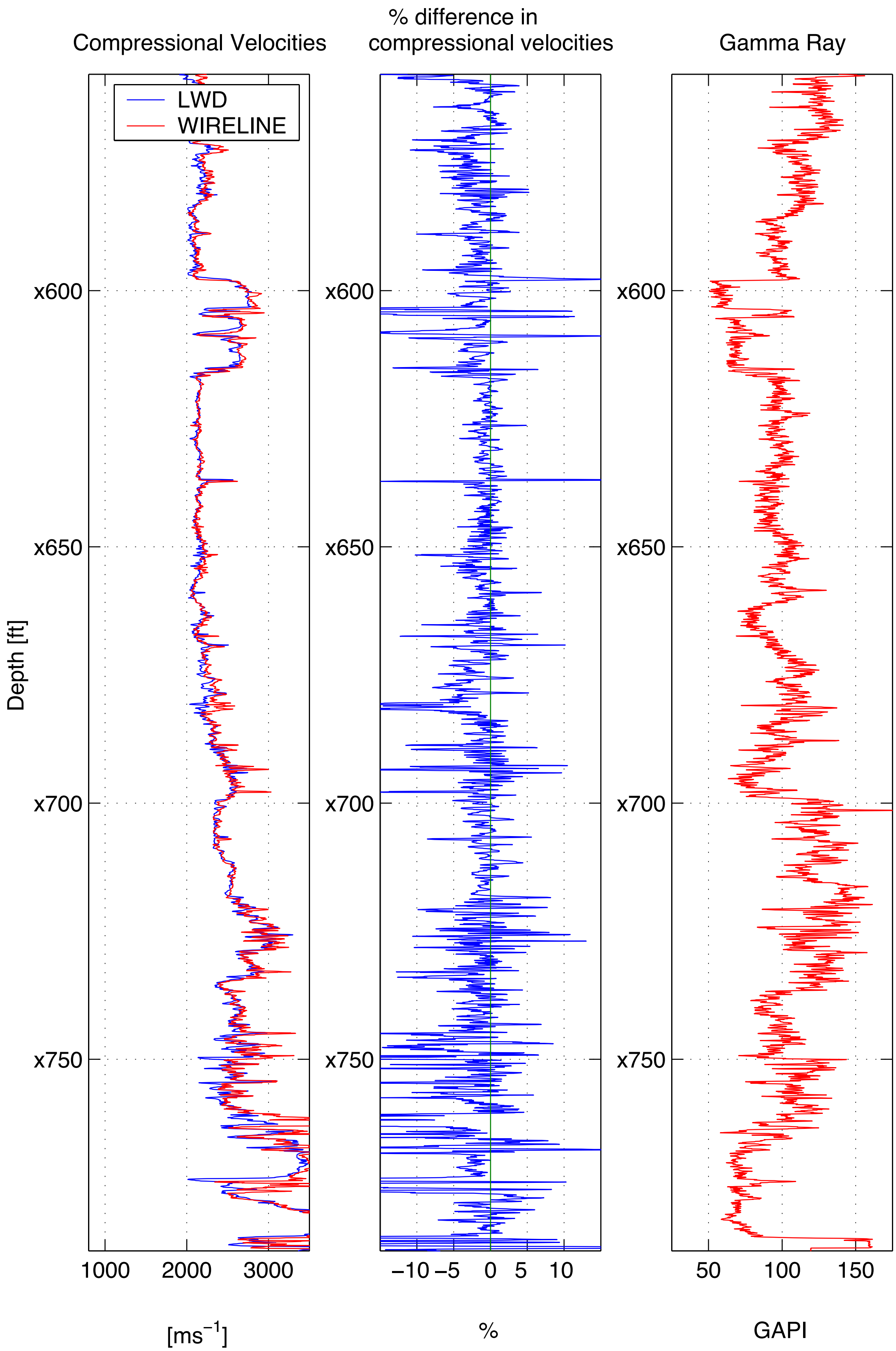

Figure 1: Compressional velocities for Wireline and LWD data, percent difference between wireline and LWD velocities, and gamma ray data.

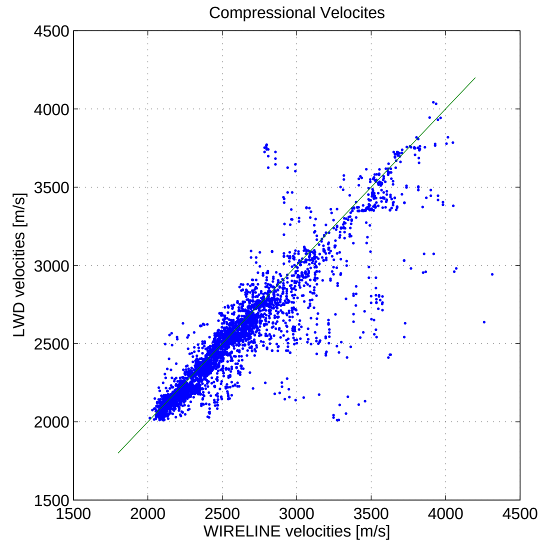

Figure 2: A scatter plot of compressional velocities as measured by the LWD and wireline tool.

to account for the dispersion of the flexural mode. It is well established that the flexural mode asymptotes to the shear velocity at low frequencies. Thus is is desirable to filter the data in the lowest frequency band possible before calculating velocities. For the LWD measurements drilling and circulation noise is present below 5 kHz and is filtered out Market et al. (2002). Figure 5 shows the velocities as calculated by ERL overlaying the semblance curves for the two data sets. The LWD curve has been shifted according to the correction given by figure 6. The correction applied is a function of frequency and borehole diameter. The flexural mode is quite flat over the 5-15 kHz range and thus the correction at 10 kHz was used to correct the velocity picked by the semblance peak. In figure 7 the industry and ERL processing for both tools are shown. This figure gives an idea on the spread due to the processing schemes.

4 Zone of interest x600 to x620

The zone between x600 and x620 shows a different behavior to the rest of the data. Here the LWD shear velocities are up to 15% slower. The rest of this paper will focus on this anomalous zone in an attempt to explain the phenomena.

Both tools measure in a different frequency range and have different offsets between source and first receiver. As a general rule of thumb, the tool sees one inch into the formation for every foot separating the source and first receiver, Baker (1984) and the low frequencies (1-3 kHz) see 2-3 borehole diameters while the high frequencies ($>$ 3kHz) see less than one borehole diameter, Plona et al. (2002). This means the LWD tool sees the formation much nearer to the borehole wall than the wireline tool. As the drill bit turns it can cause damage to the formation that is close to the borehole wall. In this scenario the damaged zone whose velocity will be lower is seen by the LWD tool while the virgin formation is seen by the wireline tool. To illustrate this phenomenon we have calculated the dispersion curves for both the homogeneous and damaged formation. The homogeneous model has a compressional velocity of 2780 m/s, a shear velocity of 1400 m/s and a density of 2050 g/cc. The damaged layer model uses the velocities shown in figure 8. Figure 9 shows the analytic calculation of the dispersion curves for both the LWD and wireline geometry. This behavior was first modeled for the wireline case by Plona et al. (2002), where any deviation from the dispersion curve calculated for the homogeneous model is considered to be caused by either intrinsic or induced anisotropy. Borehole damage can be considered as a form of induced anisotropy if the damage has a preferential direction.

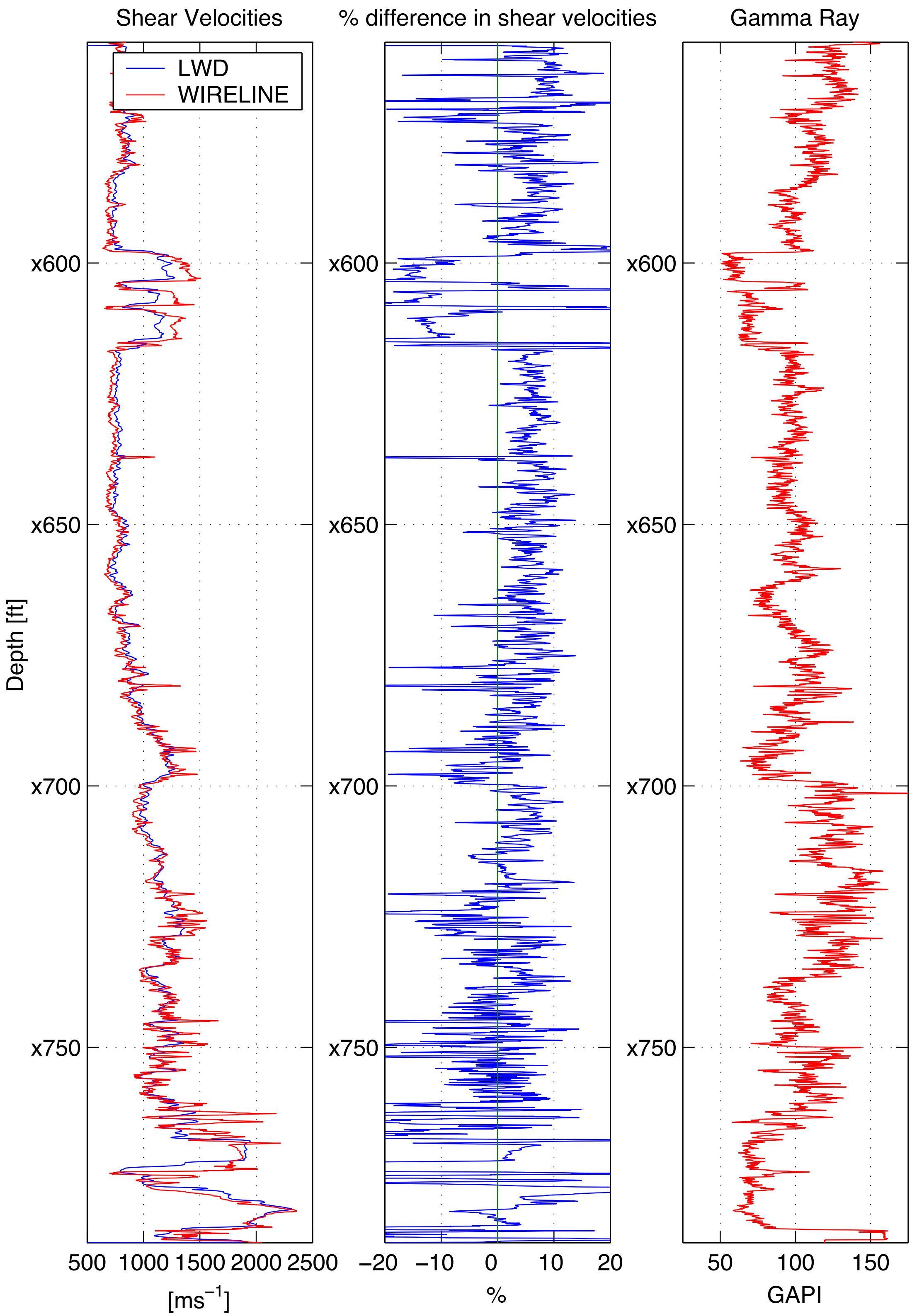

Figure 3: Shear velocities for Wireline and LWD data, percent difference between wireline and LWD velocities, and gamma ray data.

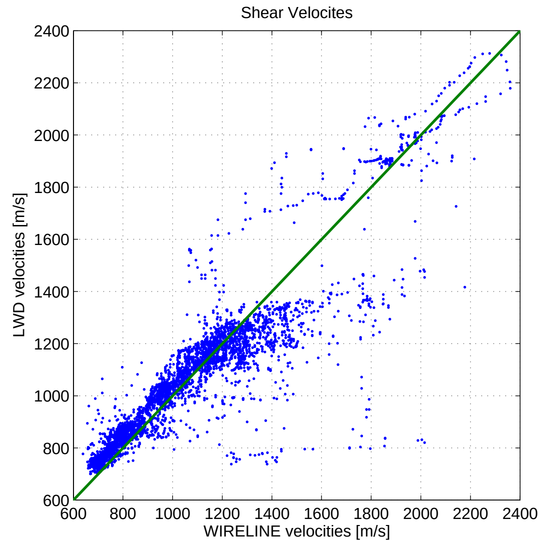

Figure 4: A scatter plot of shear velocities as measured by the LWD and wireline tool.

If the zone between x600 and x620 has been damaged close to the borehole wall it is possible to see a steepening of the dispersion curve. We have chosen depths between x680 and x700 for comparison. The logs indicate that this deeper zone is of a similar composition as the damaged zone. It has similar signatures in both the velocity and gamma ray logs but does not show the 10% velocity difference between the tool measurements. From the two zones, depths were picked that had the same velocities as measured by the wireline tool. Figures 10 and 11 show examples from the wireline and LWD data where the separation of the dispersion curves can be clearly seen. Figure 10 shows two depths with a shear velocity of 1300 m/s and figure 11 shows two depths with a shear velocity of 1350 m/s (as calculated from semblance). The curves in red come from data between x600 to x620. The curves in blue come from data in the undamaged zone between x680 and x700. This clearly shows a steepening in the curves from the damaged zone similar to that seen in the analytic calculation. The dispersion calculated for the LWD logs also shows a separation similar to that seen in the analytic curves shown in figure 9

After filtering the drilling noise the LWD data sees the shear velocities at 5 kHz and above. Thus if the zone is damaged, and therefore asymptotes to a lower velocity at high frequency, the dispersion correction as calculated from figure 6 will be insufficient and the estimated shear velocity will be slower than the correct value. In zones of unconsolidation, that are susceptible to damage caused by drilling, it is important to account for the slower velocities surrounding the borehole, either by making a sufficient correction, or using lower frequencies/larger offset to see deeper into the formation.

5 Conclusions

Two data sets taken in the same well over the same depths were examined. There is good agreement between the LWD and wireline data. Differences averaged around 5% for the shear data and around 2% for the compressional data. There was one zone of interest where the two logs differed by more than 10% and the bias was in the opposite direction to the rest of the trend. Dispersion analysis of this anomalous zone, between x600 and x620, was consistent with analytic dispersion curves calculated for radially varying layers. The changes in velocity within these layers may be due to damage around the borehole wall caused by the drilling. Cracking or micro-fracturing of the formation causes weakening which is seen as a decrease in shear velocity and the LWD tool which operates at a higher frequency and with a smaller offset between source

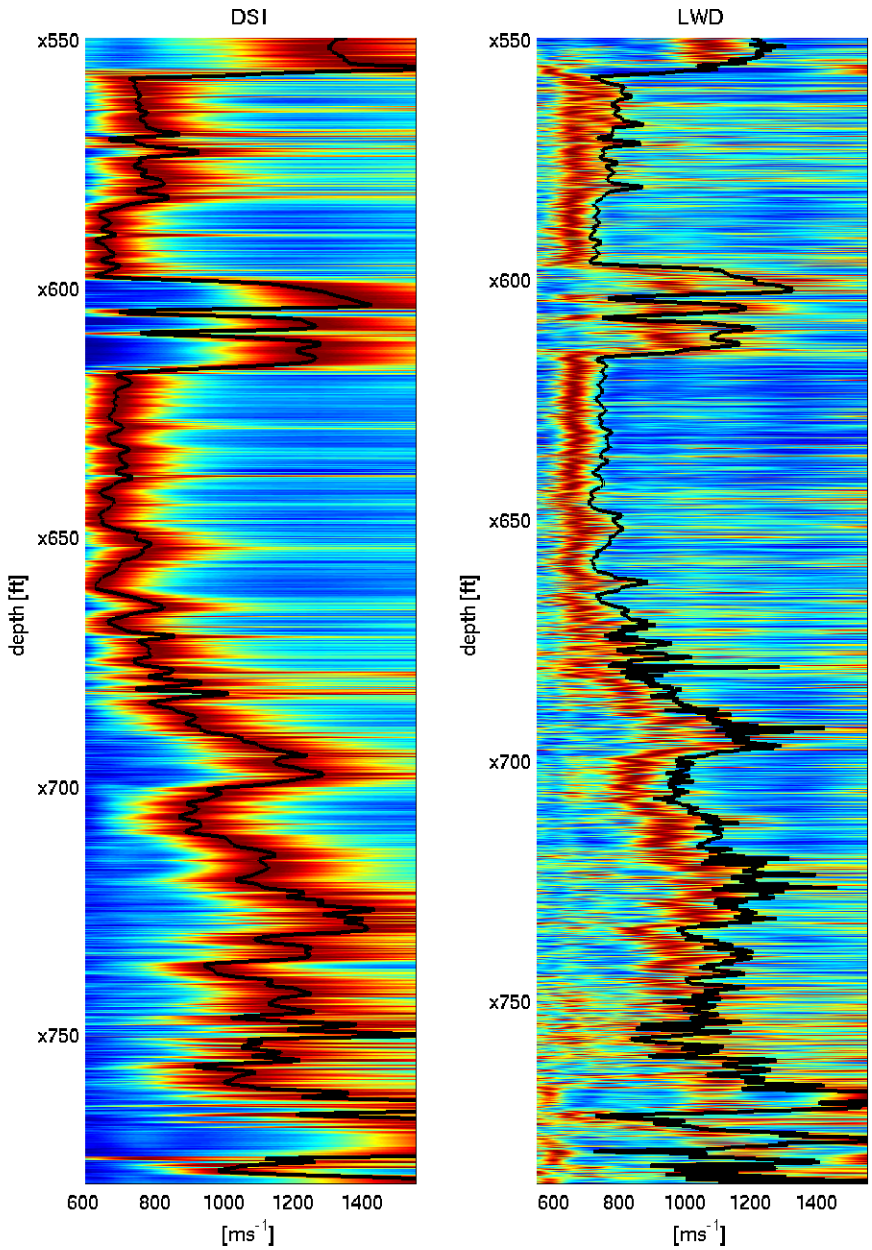

Figure 5: Velocities as calculated by ERL.

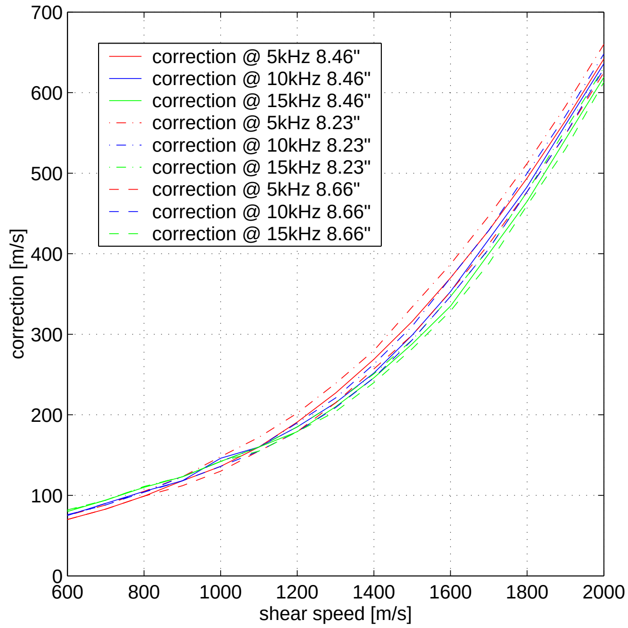

Figure 6: Correction applied to LWD data to account for dispersion.

and receiver sees this damaged zone and thus a lower velocity.

Acknowledgements

This work was supported by the Borehole Acoustics and Logging Consortium and the Founding Member Consortium at the Earth Resources Laboratory

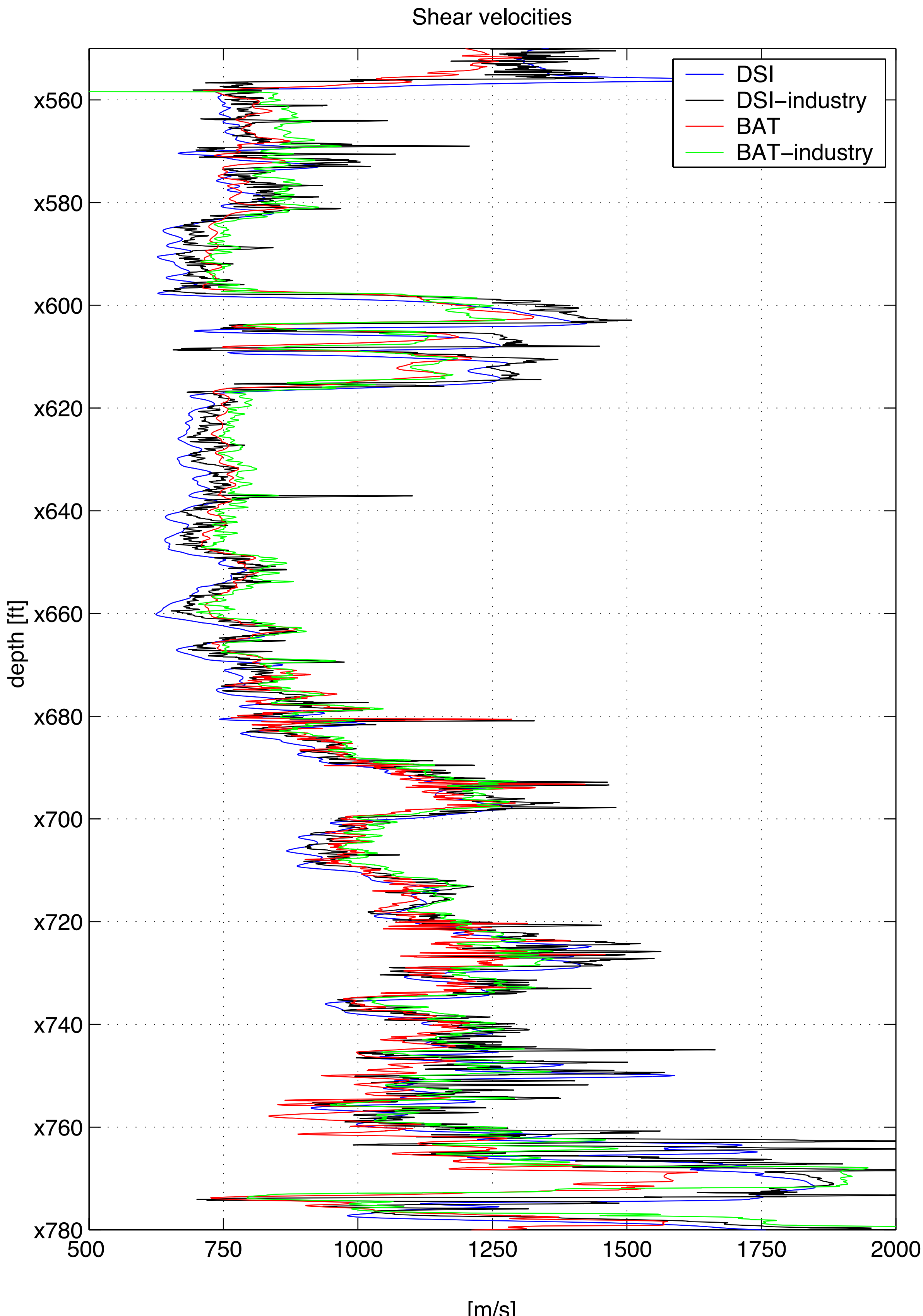

Figure 7: ERL and industry processes results for shear wave velocities.

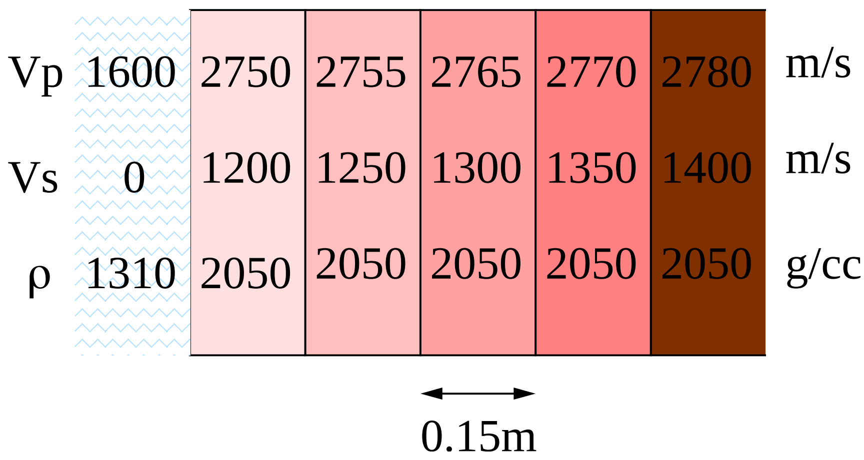

Figure 8: Radially layered model used to simulate a damaged zone.

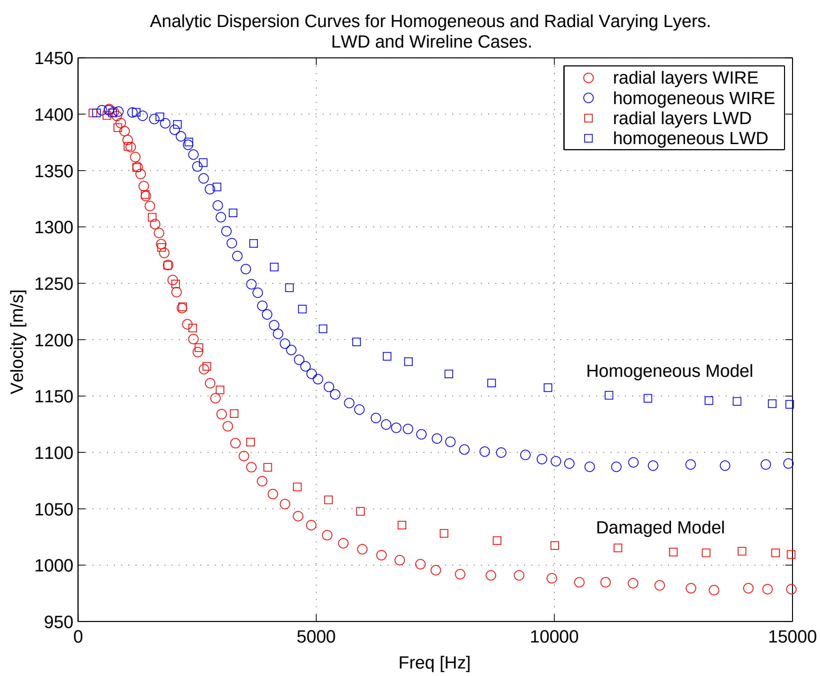

Figure 9: Analytic dispersion curves for Homogeneous and Damaged borehole models.

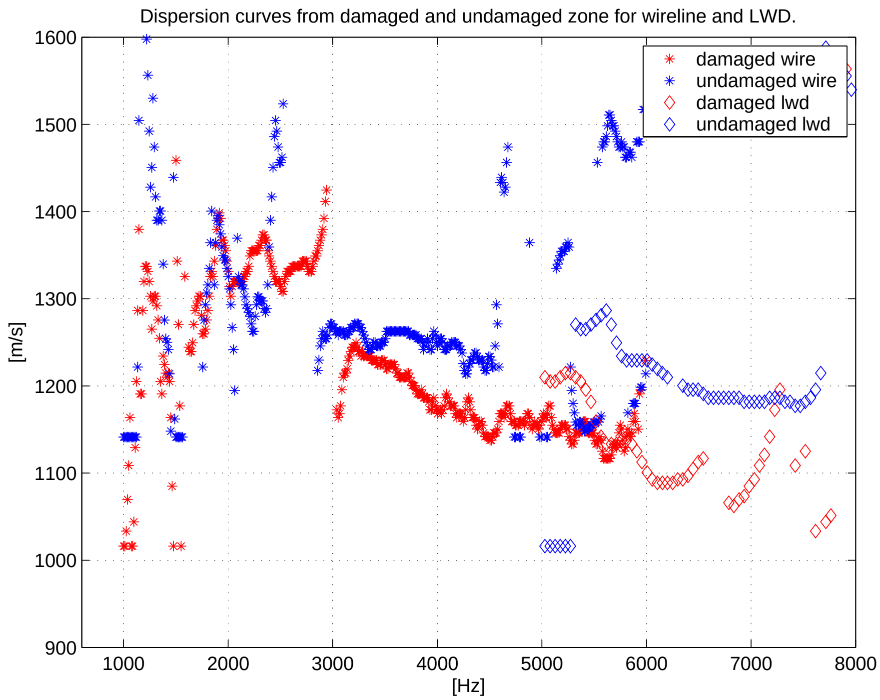

Figure 10: Comparison of dispersion curves from the damaged and undamaged zone, using wireline data.

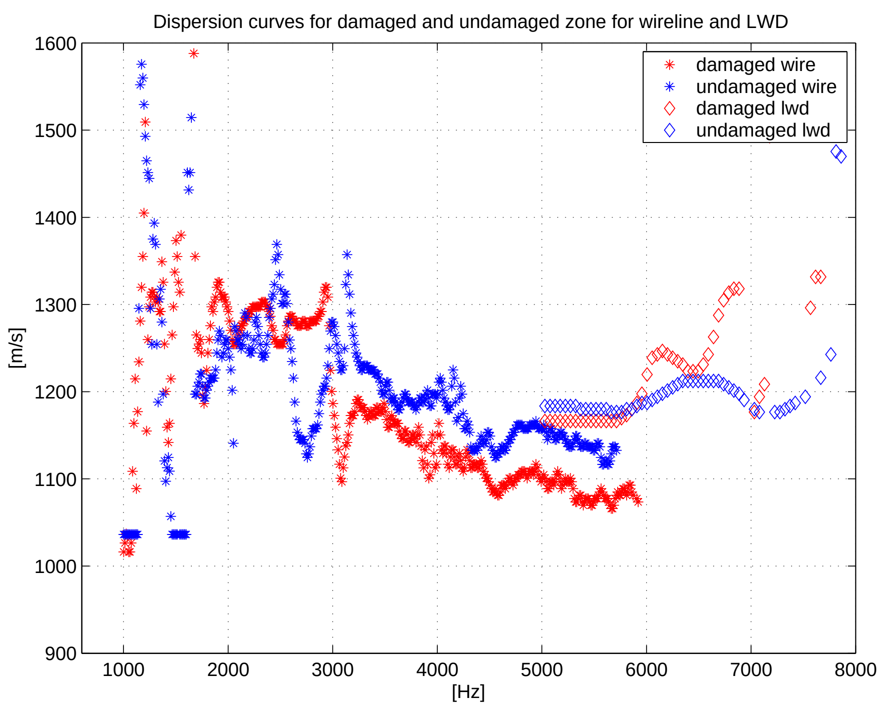

Figure 11: Comparison of dispersion curves from the damaged and undamaged zone, using wireline data.

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