Investigating methods to transform acoustic impedance inversions into depth

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ABSTRACT

The prime use of seismic reflection data is to map subsurface time structure. Attribute analysis seeks to extract or refine information about the nature of the subsurface. Seismic data can be used for attribute analysis but by converting it into impedance the inherent properties of rock layers can be analyzed. Seismic data, when converted into depth, becomes easier to interpret and easier for geologists and engineers to work with. Depth conversions are usually completed using sonic logs or check shots but impedance sections can also be used.

Impedance is the product of velocity and density so if density can be approximated then velocity remains. In 1974, Gardner et al. found a relationship between density and velocity which can be used to estimate the density from impedance using the original stationary parameters. Densities can also be provided from nearby wells and by creating non-stationary Gardner parameters. Once the velocity has been separated from the density it can be used to transform the section into depth. Formation tops from the Hussar seismic data were converted to depth and compared to the formation tops from nearby wells. This allowed each method to be evaluated for accuracy and precision. The standard Gardner method had a mean error of 131 ± 66 m averaged over all wells. The log density method had a mean error of a mean error of 115 ± 48 m. The time variant Gardner method had similar results of 86 ± 39 averaged over all wells.

Even though the time variant Gardner's rule produced a depth conversion where the tops varied less with depth the top picks were different from the well picks ranging 50 to 120 meters. Further investigation must be done to limit these errors which could be reduced by better inversions in the overburden and better density estimation methods.

INTRODUCTION

Seismic data can be used to estimate rock property attributes but impedance sections are the most directly estimated property of the layers. While sections in time can be helpful, depth sections show the true bed thickness and are easier to use during interpretation and reservoir characterization. Commonly seismic data is converted to depth by using time-depth curves derived from check-shots or sonic logs from nearby wells. This paper investigates the use of velocity sections from impedance inversion to compute the time to depth curves. The velocity logs are derived from the impedance logs by estimating the density log. Three alternate methods: Gardner's rule (Gardner et al. 1974) with standard parameters, a time variant Gardner's rule and the density from wells, will be used to estimate the density.

The resulting velocity section can then be used to calculate the depth of each sample in the impedance section. The errors and accuracy of each method will also be discussed.

METHOD AND RESULTS

For this study we used the Hussar data set as described in Lloyd and Margrave (2012). An impedance section was created using the time-variant balanced seismic data (Figure 1) and the BLIMP (BandLimited IMPedance) algorithm (Ferguson and Margrave, 1996). For the low-frequency content 0 to 2 Hz from the average impedance log will be used. This impedance section can be seen in Figure 2 which was created in Lloyd and Margrave (2012b). The wells have also been conditioned and have been tied to the seismic data. For this purpose an overburden and underburden of interval velocities derived from stacking velocities have been used. Once the section has been inverted we can find an approximate velocity curve and density curve.

Once an acoustic impedance inversion has been computed we can extract the velocity and density curves using Gardner's equation for the density. The impedance section, I, is the product of density, ρ, and velocity, V, as

$$I_k = \rho_k V_k, \tag{1}$$

where k is the sample number on any trace. From Gardner et al (1974) we know that density can be estimated as

$$\rho_k = m{V_k}^{\alpha}, \tag{2}$$

where m and α are constants. If we substitute equation 2 into equation 1 we get

$$I_k = m{V_k}^{\alpha} V_k = \ m{V_k}^{\alpha+1} \tag{3}$$

Solving for velocity the equation becomes

$$V_k = \left(\frac{I}{m}\right)^{1/(1+\alpha)} \tag{4}$$

Once we have the velocity we can then use this to translate the inversion into depth, z,

$$z_i = \sum_{k=1}^{i} V_k * t_k. \tag{5}$$

For the first case we will use the standard Gardner parameters where m=311 and α=.25. Figures 4, 5 and 6 compare the calculated density and velocity from impedance to the density and velocities measured in the well. For better comparison the well velocity and density have been filtered using the matching filter seen in Figure 3. Several tops are also plotted on the figures to compare how accurate the velocity curves from inversion are. Table 1 contains the depth of each top pick in the well and inversion at each well location. The differences in depth between the well and inversion and their variance are also recorded. While some variation between the well tops and the inversion tops is expected, we don't expect a large variation within the differences or the differences increasing with depth. There is also a systematic error where inversion tops are consistently lower than the well tops. This systematic error is probably due to the overburden not being adequately estimated in the inversion.

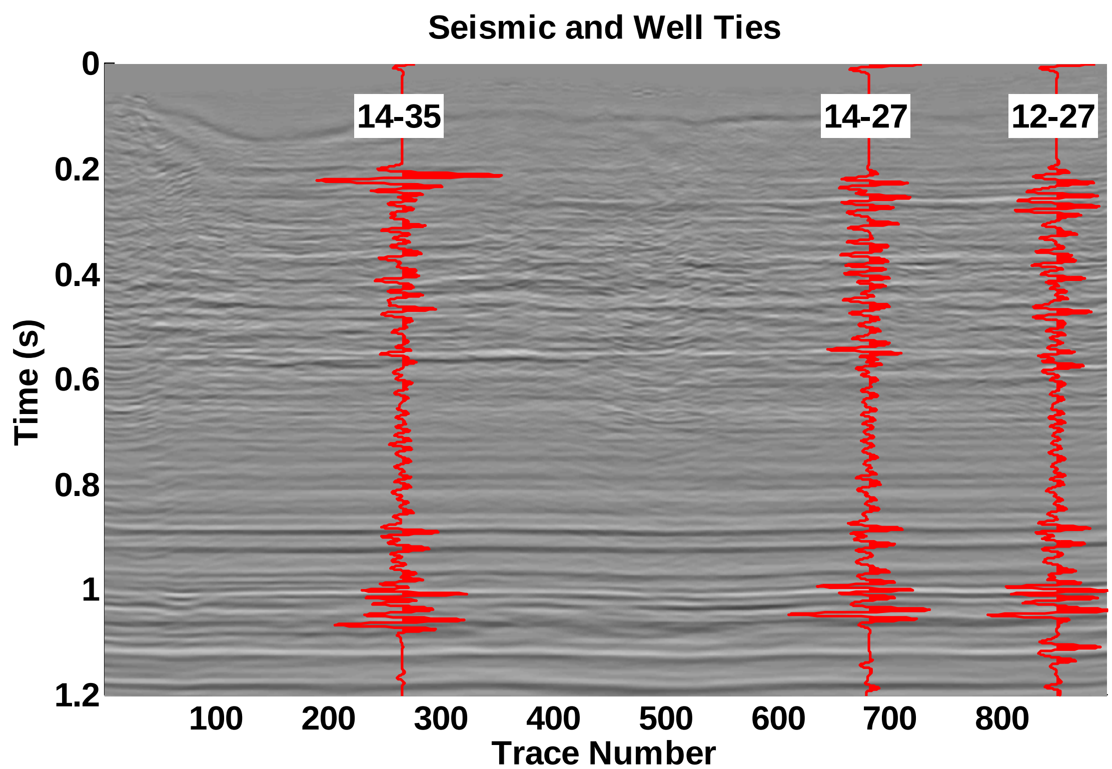

FIG 1: Seismic data and well ties for the dynamite and 10Hz geophones after migration and well ties.

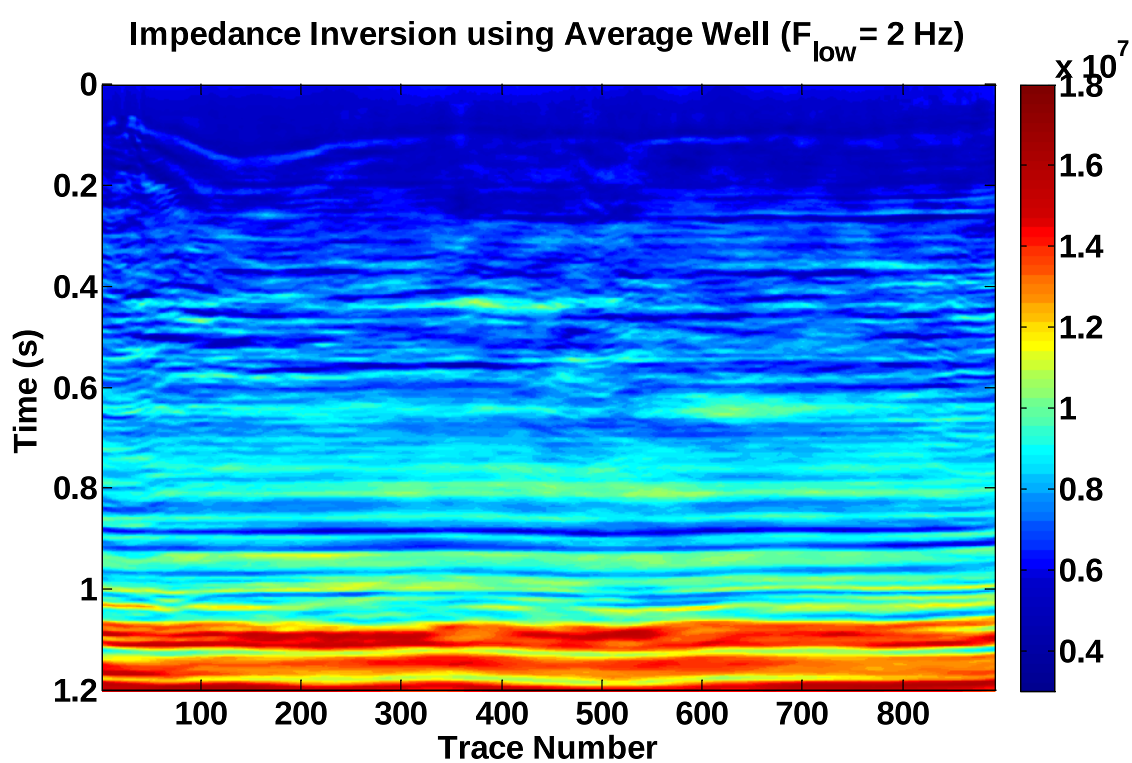

FIG 2: Impedance inversion calculated using the average well and a low cut off of 2 Hz.

Table 1: The depths from picking tops in both the well log and the inversion using standard Gardner parameters.

	Belly River	Colorado	Viking	Manville	Pekisko	Range
Top Depth From 12-27	516	892	1307	1402	1554	-
Top Depth from Inversion	581	964	1409	1505	1659	-
Difference	-65	-72	-102	-103	-105	40
Top Depth From 14-27	469	838	1250	1342	1487	-
Top Depth from Inversion	563	961	1411	1508	1654	-
Difference	-95	-123	-161	-166	-168	73
Top Depth From 14-35	472	828	1243	1333	1505	-
Top Depth from Inversion	583	968	1422	1519	1694	-
Difference	-111	-140	-179	-187	-189	78

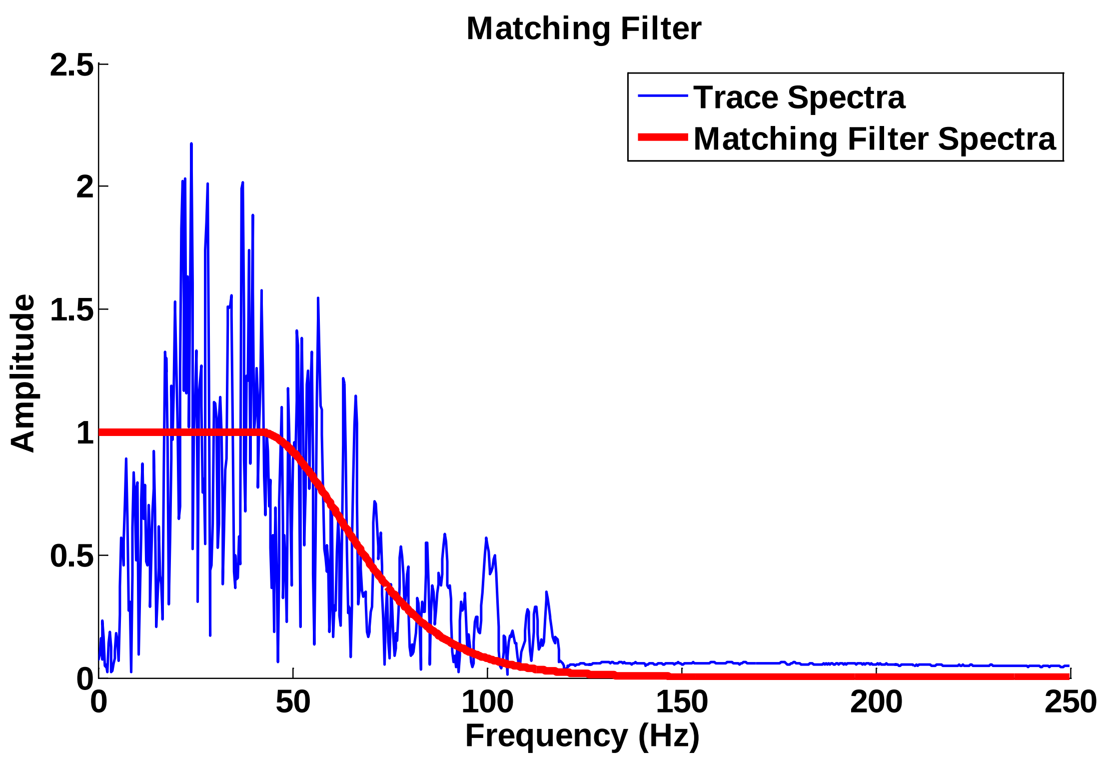

FIG 3: Matching Filter used to remove the high frequencies present in well impedance, density and velocity.

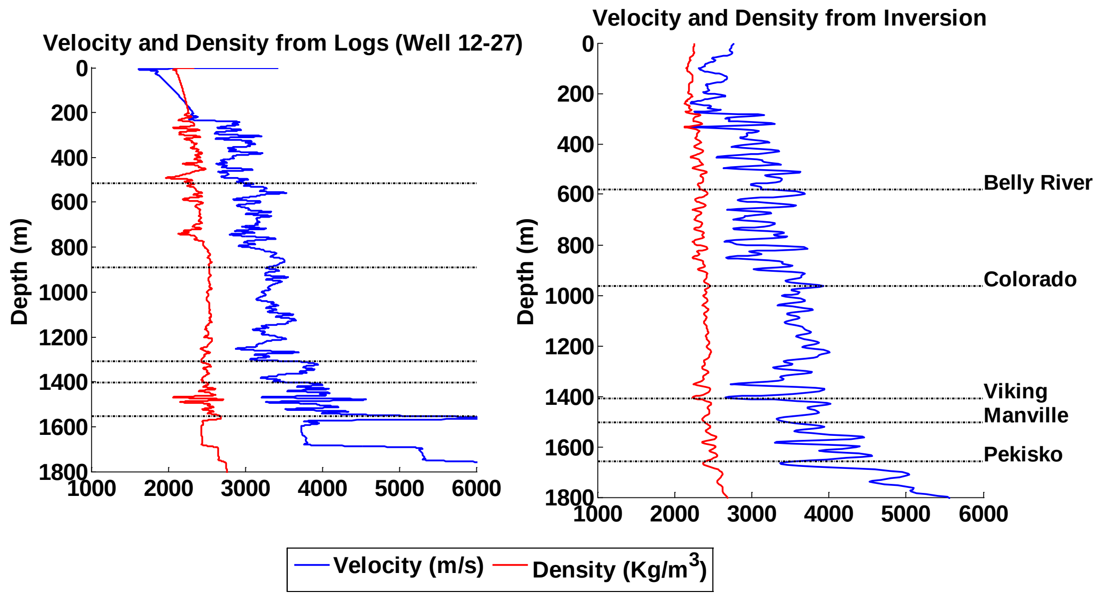

FIG 4: The filtered well velocity and density are shown in depth on the left side of the plot for well 12-27. The velocity and density derived from impedance and Gardner's rule is shown in the plot to the right.

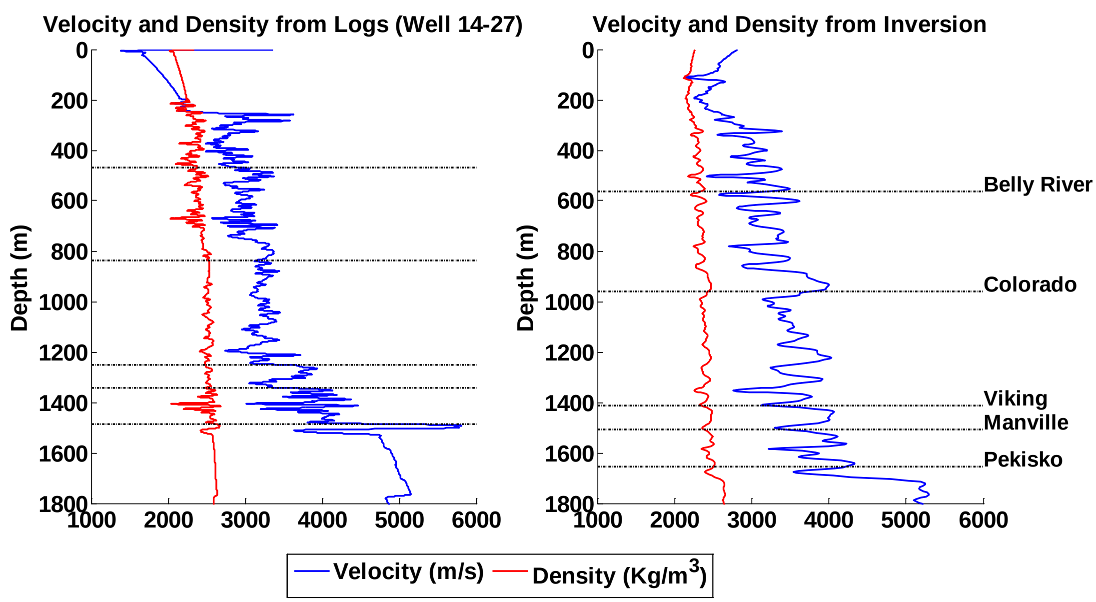

FIG 5: The filtered well velocity and density are shown in depth on the left side of the plot for well 14-27. The velocity and density derived from impedance and Gardner's rule is shown in the plot to the right.

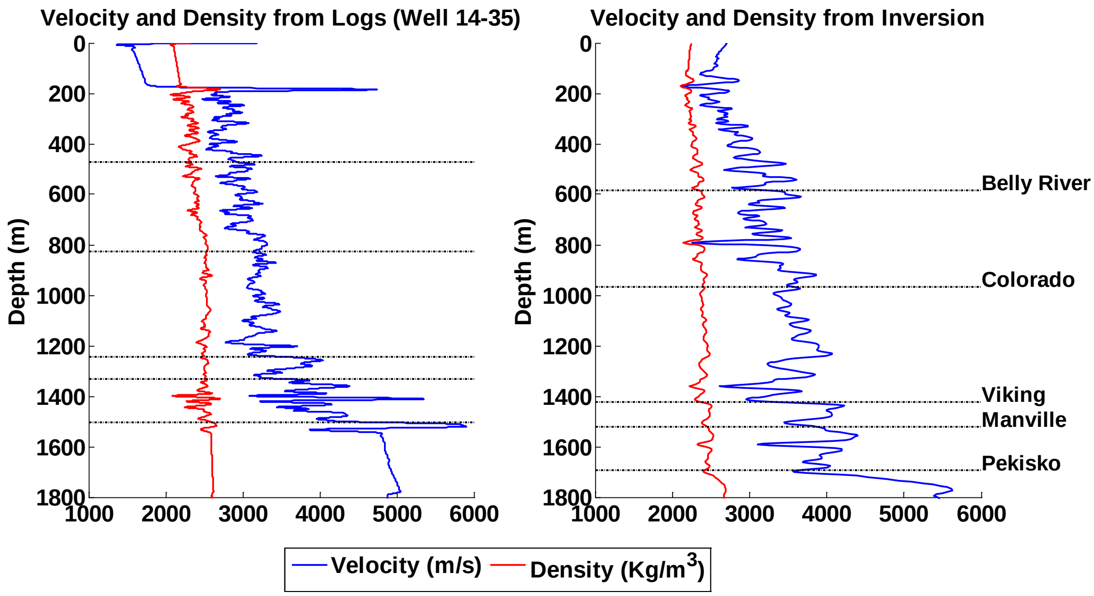

FIG 6: The filtered well velocity and density are shown in depth on the left side of the plot for well 14-35. The velocity and density derived from impedance and Gardner's rule is shown in the plot to the right.

Since we are comparing the well log and inversion at a well location we can use the density curve from the wells themselves in the estimation of velocity from impedance. The density must be conditioned by sampling it using the same time vector as the seismic. Once this is done it can be substituted into equation 1 and solved for the velocity. In areas where there is no well control, density logs will need to be estimated using surrounding wells These results are shown in Figures 7, 8 and 9. Table 2 shows that this method has comparable variance in the differences to the time variant Gardner method but has an absolute difference that is comparable to the standard Gardner method. For wells 14-27 and 14-35 the differences increase in depth like before but well 12-27 has very irregular differences.

Table 2: The depths from picking tops in both the well log and the inversion using well log density sampled in seismic time.

	Belly River	Colorado	Viking	Manville	Pekisko	Range
Top Depth From 12-27	516	892	1307	1402	1554	-
Top Depth from Inversion	587	960	1384	1477	1630	-
Difference	-71	-68	-77	-75	-76	9
Top Depth From 14-27	469	838	1250	1342	1487	-
Top Depth from Inversion	570	960	1387	1482	1628	-
Difference	-102	-122	-137	-140	-141	39
Top Depth From 14-35	472	828	1243	1333	1505	-
Top Depth from Inversion	590	964	1395	1490	1663	-
Difference	-118	-136	-153	-158	-158	40

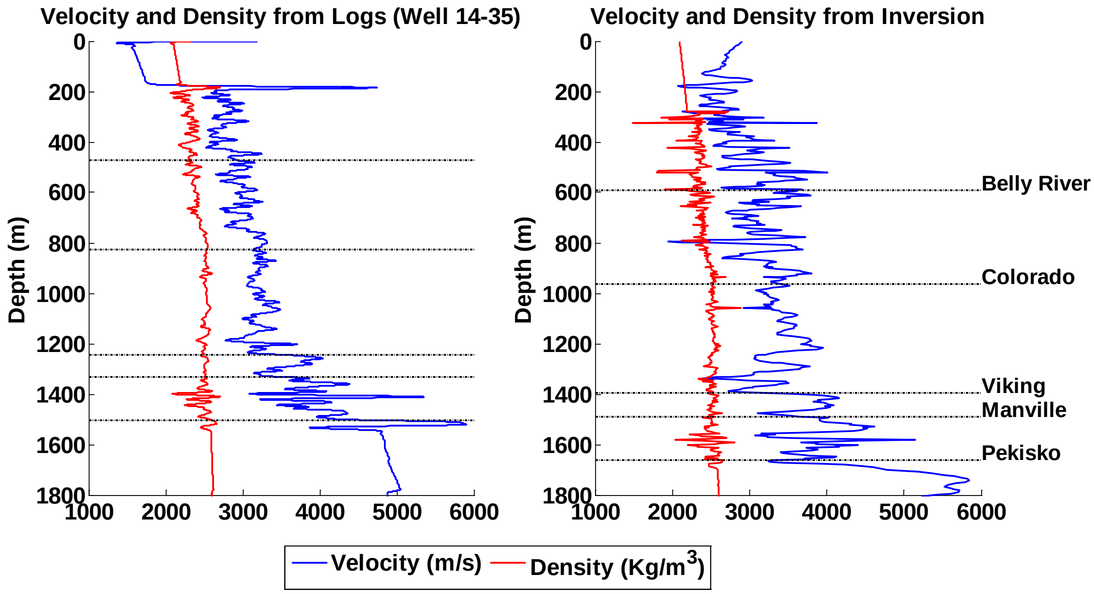

FIG 7: The filtered well velocity and density are shown in depth on the left side of the plot for well 12-27. The curves on the right are the density sampled at the seismic times and the velocity derived from impedance.

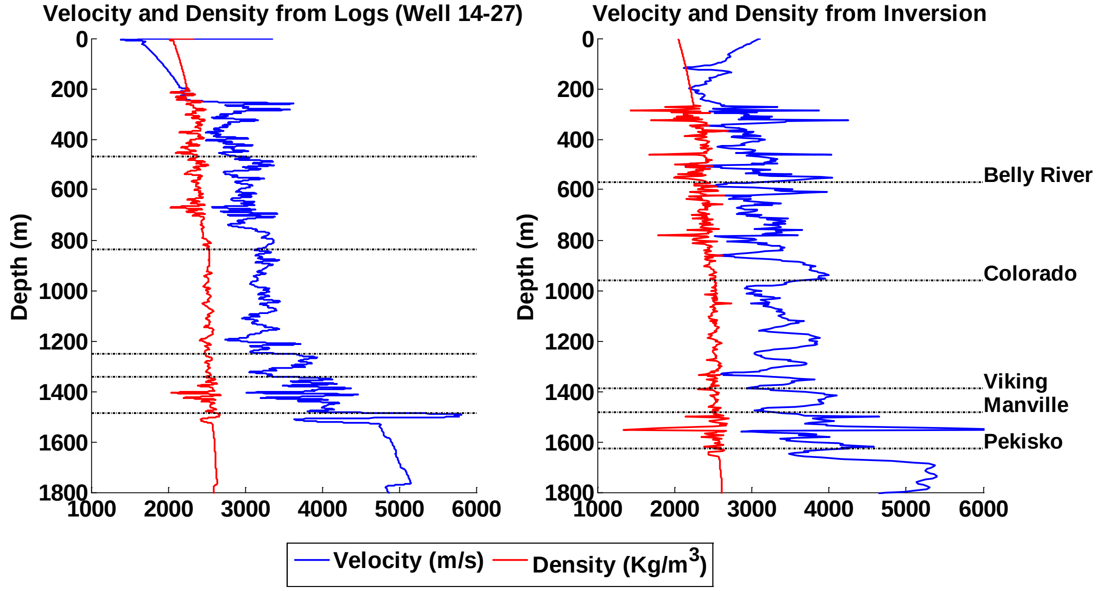

FIG 8: The filtered well velocity and density are shown in depth on the left side of the plot for well 14-27. The curves on the right are the density sampled at the seismic times and the velocity derived from impedance.

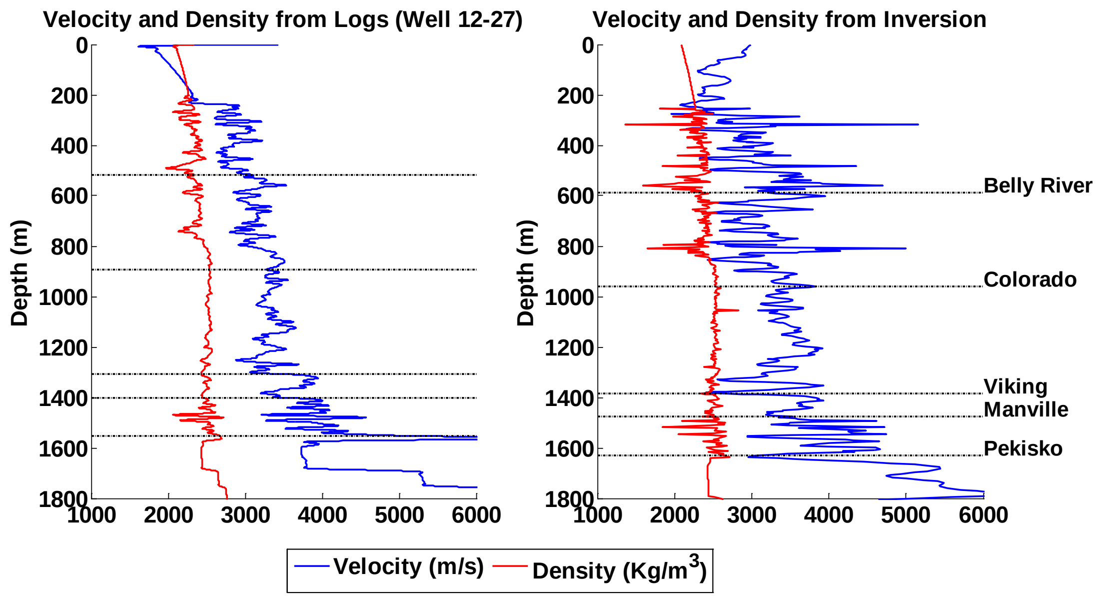

FIG 9: The filtered well velocity and density are shown in depth on the left side of the plot for well 14-35. The curves on the right are the density sampled at the seismic times and the velocity derived from impedance.

Another way to constrain the density is to use a time-variant Gardner method. By breaking the well logs into time intervals and then deriving Gardner parameters for each interval, these parameters are illustrated in Figure 7, a better estimate can be found between the velocity and density. Windows 100ms wide and using increments of 10 ms were used to calculate and apply the new parameters for each well. The parameters for each 100ms window are plotted corresponding to the time at the center of the window in Figure 10. These parameters vary widely but the parameters in each well vary similarly. The depth-conversion results from this method are shown in Figures 11, 12, and 13. This figures show a better correlation between the well velocity and the inversion velocity. They also show inversion tops that are at similar depths to the log tops. Table 3 shows the pick depths and differences. This method has much smaller ranges, especially in well 12-27 where the maximum difference is only 55 meters and is consistent ±8 meters throughout the well. We are still seeing a trend of the differences getting larger with depth but this is about half as large as with use of standard Gardner parameters.

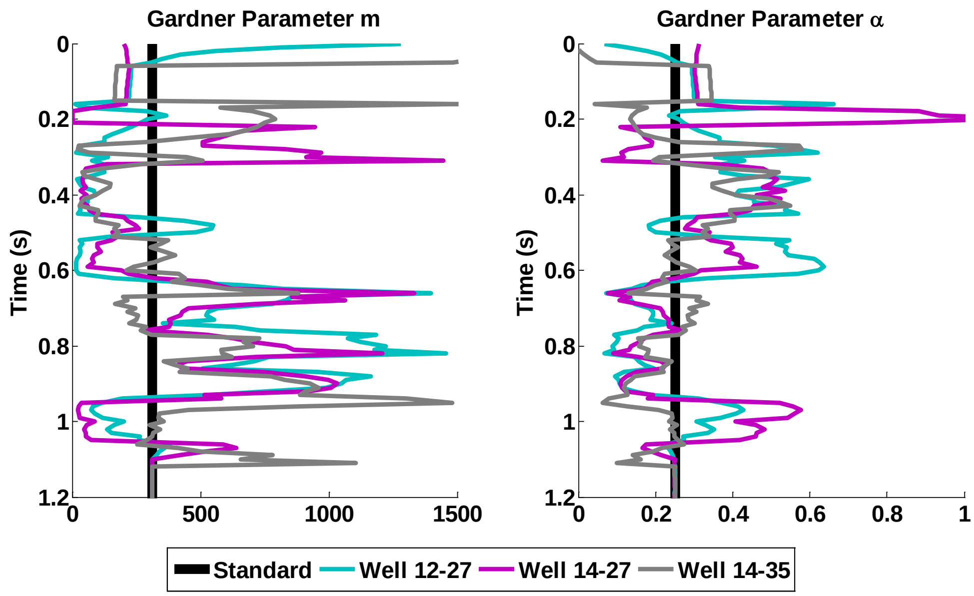

FIG 10: The time-variant Gardner parameters calculated in windows 100 ms wide and 10ms increments. These were calculated in the time domain such that they can be applied to the inversion which is also in time at this point in the process.

Table 3: The depths from picking tops in both the well log and the inversion using time variant Gardner Parameters.

	Belly River	Colorado	Viking	Manville	Pekisko	Range
Top Depth From 12-27	516	892	1307	1402	1554	-
Top Depth from Inversion	566	939	1362	1456	1608	-
Difference	-50	-47	-55	-54	-54	8
Top Depth From 14-27	469	838	1250	1342	1487	-
Top Depth from Inversion	541	925	1351	1446	1590	-
Difference	-72	-87	-101	-104	-103	32
Top Depth From 14-35	472	828	1243	1333	1505	-
Top Depth from Inversion	565	934	1362	1457	1629	-
Difference	-93	-106	-119	-124	-124	31

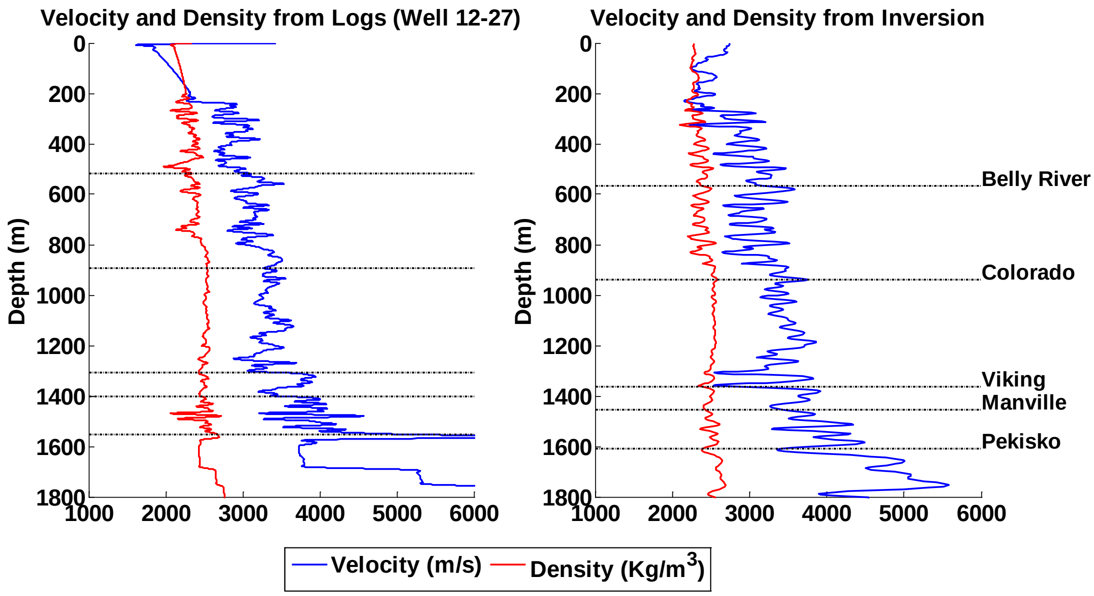

FIG 11: The filtered well velocity and density are shown in depth on the left side of the plot for well 12-27. The velocity and density derived from impedance and a time variant Gardner's rule is shown in the plot to the right.

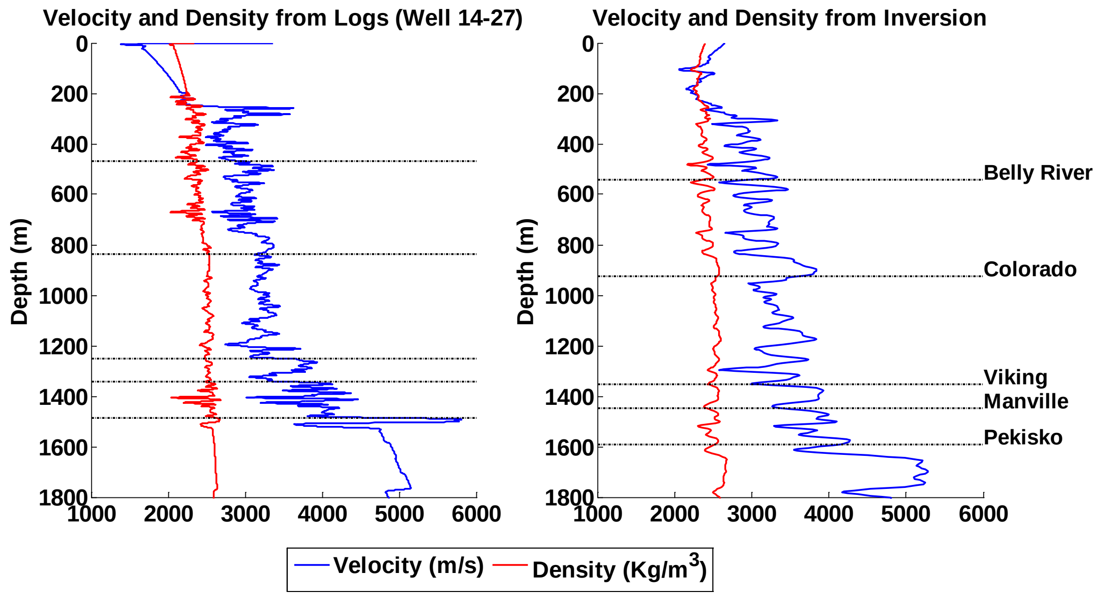

FIG 12: The filtered well velocity and density are shown in depth on the left side of the plot for well 14-27. The velocity and density derived from impedance and a time variant Gardner's rule is shown in the plot to the right.

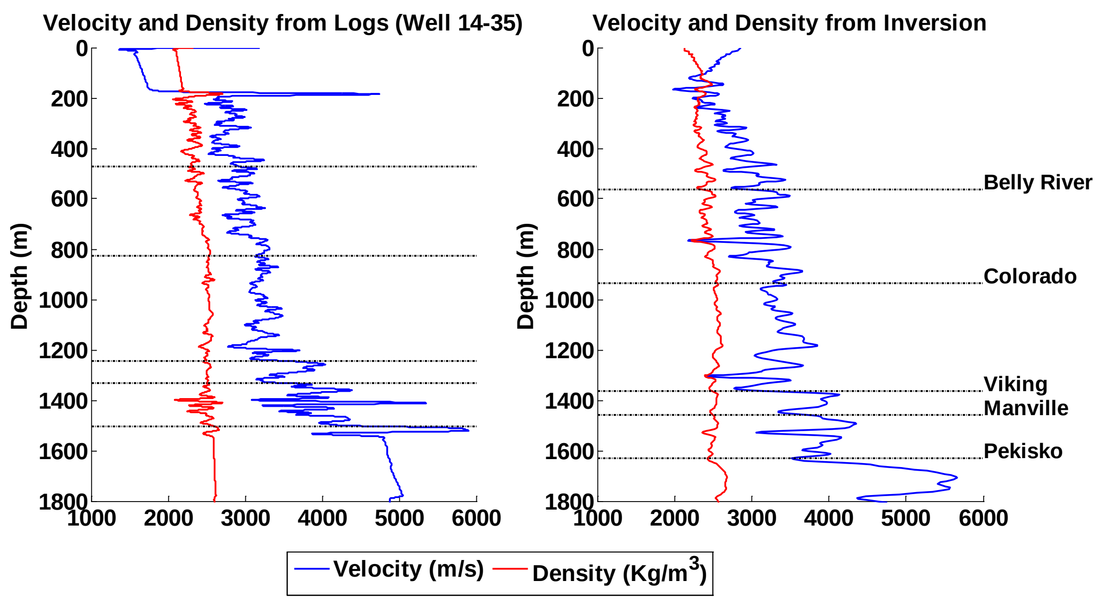

FIG 13: The filtered well velocity and density are shown in depth on the left side of the plot for well 14-35. The velocity and density derived from impedance and a time variant Gardner's rule is shown in the plot to the right.

Using Tables 1, 2 and 3 we can see that the time variant method provides the most consistent tops and the tops with the least error. This method was used to create density and velocity sections using all the seismic data. To do this the time variant parameters were derived from well data that were propagated through the section using a weighted average method described in Lloyd and Margrave (2012). The density section in depth can be seen in Figure 10. To compare the features in depth to those in time Figure 11 shows the depth section in time. To be able to compare these sections 1.13 seconds is approximately 1800m. From these figures we can see that the overburden has shrunk in size and the layer at 1600 has become thicker. Figure 12 shows the velocity in depth with its corresponding time section in Figure 13. The details in the reservoir (1400 -1600 meters) can be seen in much better detail in the depth section than the time section.

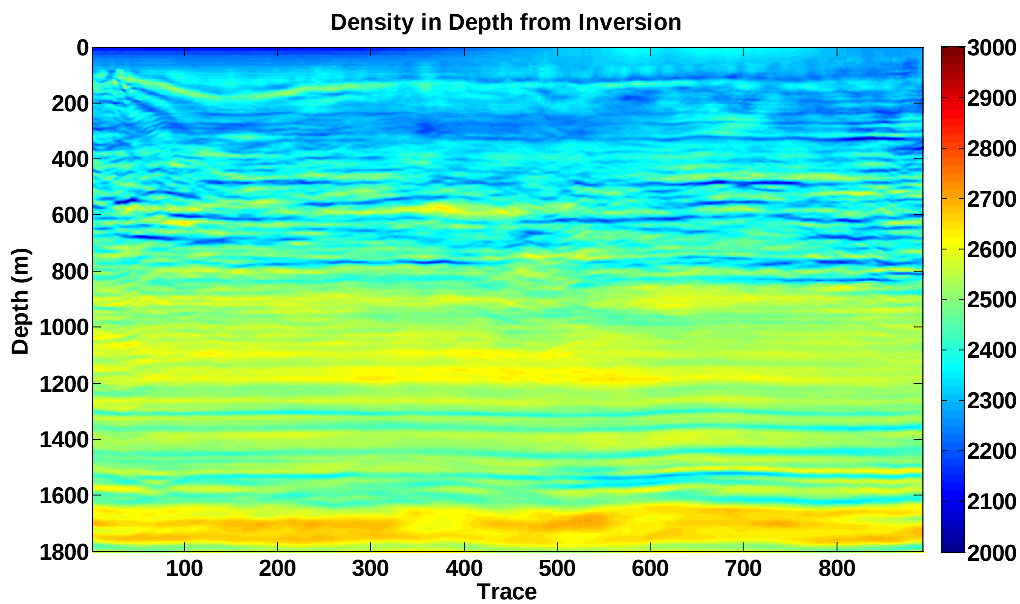

FIG 14: The density section after converting to depth, using time variant Gardner's rule.

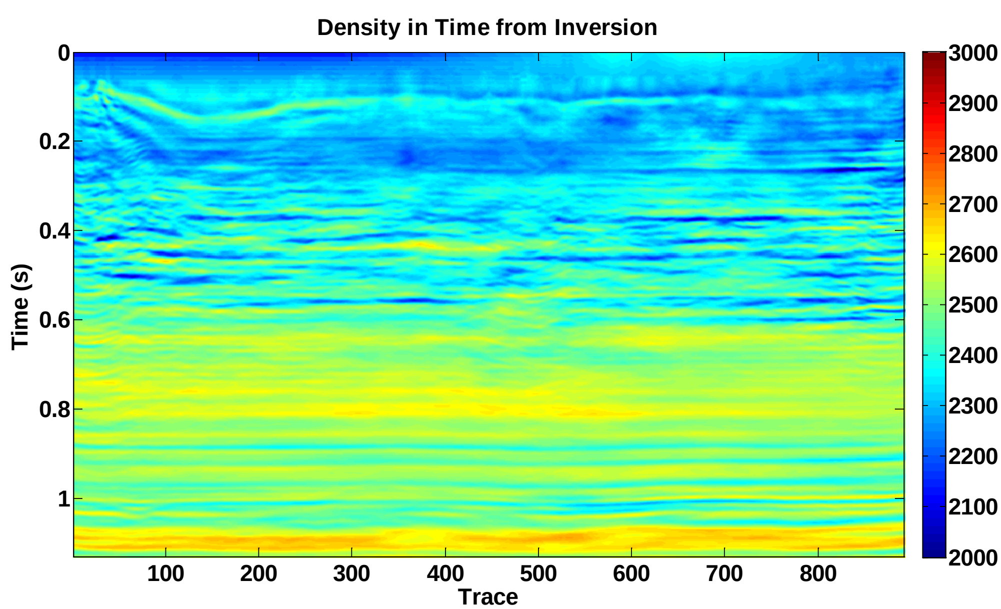

FIG 15: The density section in time, before converting to depth.

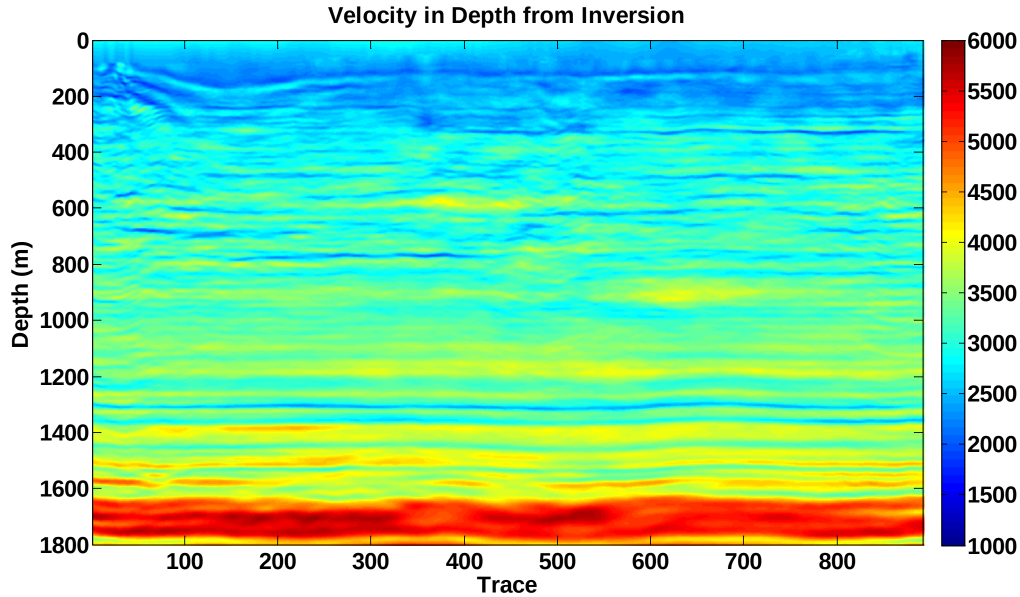

FIG 16: The velocity section after converting to depth, using time variant Gardner's rule.

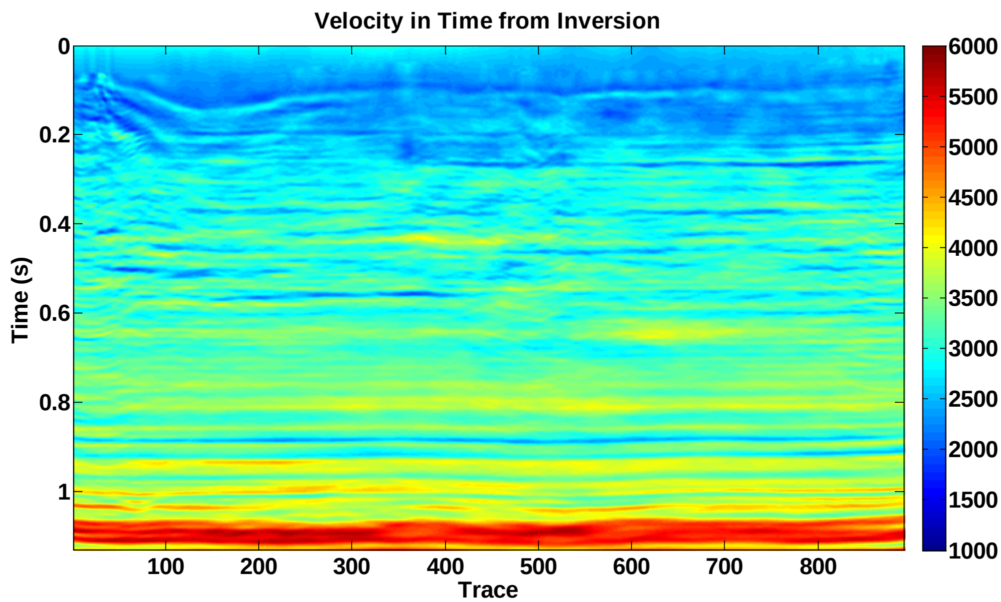

FIG 17: The velocity section in time before converting to depth.

CONCLUSIONS

Converting impedance sections to depth can be very useful for geologists and reservoir engineers. While check shots and sonic logs can create time-depth curves, using impedance sections allows an independent conversion for each trace. Gardner's rule is very helpful with this as the parameters derived by nearby well logs can be used to approximate the density logs.

The time-variant version Gardner's rule produced the most accurate results, with using the measured well-log density coming second and standard parameter Gardner's rule being the least accurate. All of these methods still needed a shift to get a good correlation to the well velocities.

This difference could be caused by many factors including, errors in the density estimates, seismic processing errors but most likely caused by inaccurate impedance inversions especially in the overburden. Further analysis will be needed to reduce the errors but this study shows that there is great potential for transforming impedance sections into depth.

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