

Acoustic impedance inversion using stacking velocities: Hussar example

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ABSTRACT

In band-limited acoustic impedance inversion low frequencies must be provided from a non-seismic source. Impedance logs, estimated at wells from standard sonic and density logs, are commonly used however other sources such as impedance sections created from stacking velocities can be used. Stacking velocities must first be conditioned by interpolating on a grid that is the same size as the seismic data. For this purpose the PCHIP (Piecewise Cubic Hermite Interpolating Polynomial) algorithm was used. The next step is to convert the stacking velocities to interval velocities. Densities can be estimated using Gardner's equation and the interval velocities and from there an impedance section can be calculated by multiplying the densities and interval velocities. Information from this impedance section in the 0-2 Hz band was combined with the seismic data from Hussar using the BLIMP (Band-Limited IMPedance) algorithm. The inversion has high lateral variation so a second inversion was calculated using the mean of the impedance section. The mean inversion had a percent error of 11% between 0.2 and 1.05 seconds where as the regular inversion had a percent error of 12% in the same interval. Good results were obtained using the stacking velocities from standard processing but these had sparse picks. Better results are likely to be obtained with finer stacking velocity picks and constraining the conversion of stacking velocities to interval velocities.

INTRODUCTION

To conduct an acoustic-impedance inversion using band-limited seismic data the essential low-frequency information must be extracted from data other than the seismic reflectivity estimate. Well logs are commonly used for this purpose (Lindseth 1979); however stacking velocities can also be used to provide the low-frequency component (Oldenburg, 1984). In this study we condition the stacking velocities such that they are continuous over the section and then convert them to interval velocities. We can then use Gardner's equation to calculate densities and thus can get a low-frequency impedance section. This section can then be used with band-limited seismic data in BLIMP (Ferguson et al, 1996) to produce our impedance inversion.

METHOD

Stacking velocities are picked during processing of the seismic data. For this paper we will use the Hussar data set as described in Lloyd and Margrave (2012). Stacking velocities are picked sporadically, in this case every 50 traces and are coarsely sampled when compared to the temporal sample rate of the seismic data.. Conditioning the stacking velocities involves using approximations to fill the stacked section volume using the same time and trace locations as the seismic data. Figure 1 represents how sparse the picks are in the data. The first step to condition the stacking velocities is to interpolate the picks to a regularly spaced grid in time using a linear operator. A time vector

sampled at 25 milliseconds was used (Figure 2). The next step was to interpolate the data onto the seismic grid in both space and time and for this the PCHIP (Piecewise Cubic Hermite Interpolating Polynomial) algorithm (Fritsch and Carlson, 1980) was used, Figure 3. This algorithm uses a series of polynomials to interpolate the data and connects them in a way that is not always continuous. This algorithm was chosen as cubic approximations underestimate the velocities at smaller times and the spline approximation overestimates the velocities at higher times (Figure 4).

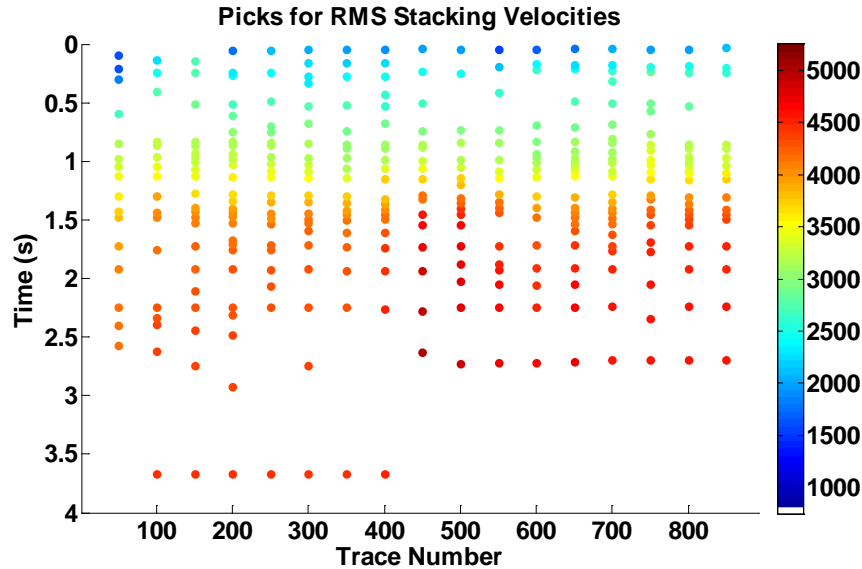


FIG 1: Stacking velocity picks made during processing. The picks have good time coverage at the zone of interest but poor spatial coverage. Each point is the location of the pick and the color refers to the stacking velocity at that pick.

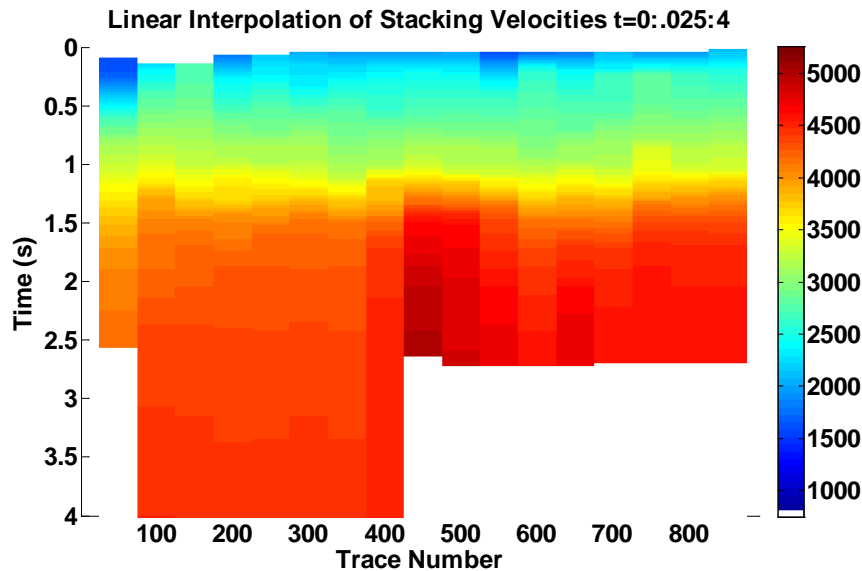


FIG 2: A linear interpolation of the stacking velocity picks coarsely sampled at data points per second. The white represents where there is no data as linear interpolation cannot extrapolate.

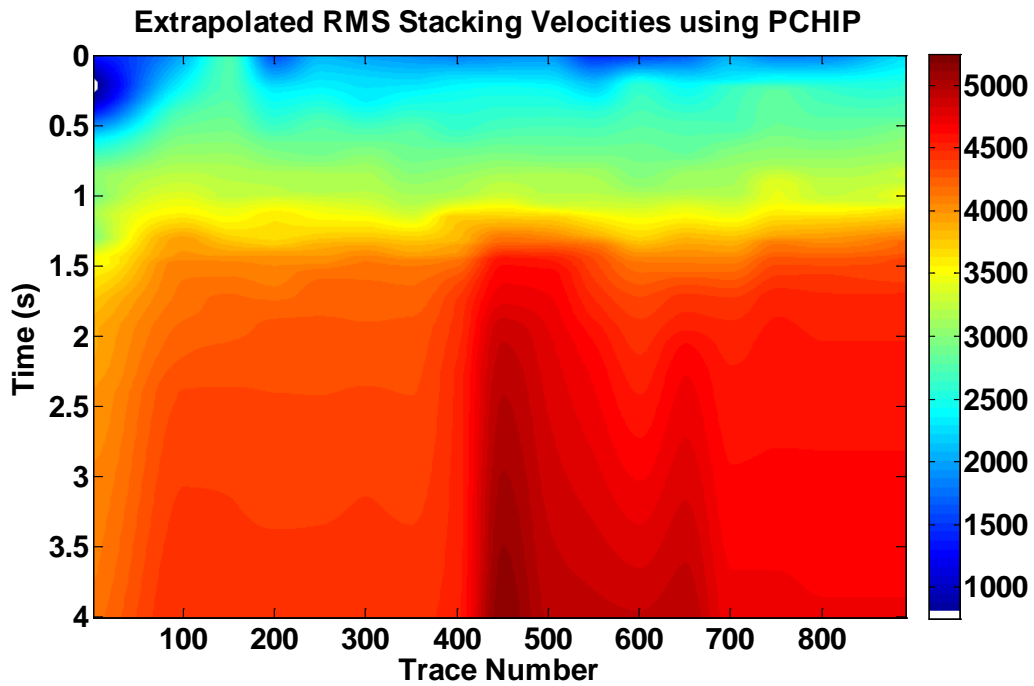


FIG 3: The PCHIP algorithm is used to interpolate between points and extrapolate where there is no data. This result is sampled at .002 seconds and 1 trace number.

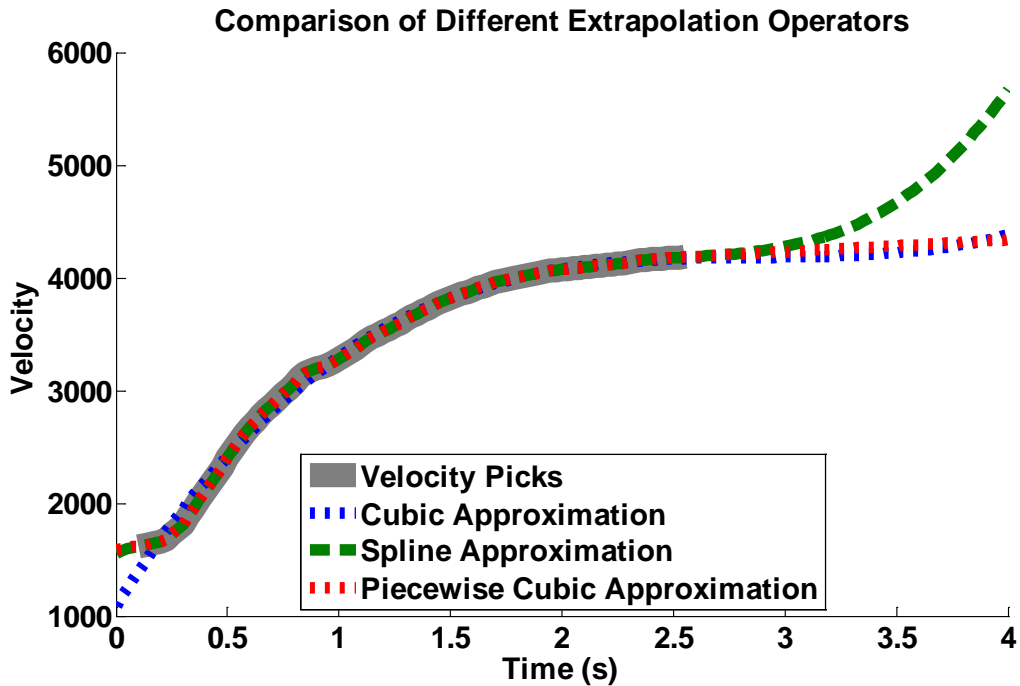


FIG 4: This shows the different interpolation methods available and their accuracy. The PCHIP approximation is the best choice as it follows the trend of the data in the lower times and does not overshoot at high times.

The next step in the process was to convert the stacking velocities to interval velocities. This was done using the standard Dix interval velocity calculation (e.g. Margrave (2002))

$$V_{int_k}^2 = \frac{V_{rms_{k+1}}^2(t_{k+1}-t_o) - V_{rms_k}^2(t_k - t_o)}{(t_{k+1} - t_k)} \quad (1)$$

where V_{rms} are the stacking velocities, V_{int} are the Dix interval velocities, t is the time and t_o is the starting time (zero in this case). Using this method the interval velocities can be seen in Figure 5. This figure also has the topography plotted at the top as there is a large anomaly in the center of the section that seems to be correlated to the topography. This may be a result of errors in the statics (Oldenburg et al., 1984), or possibly a bias from the topographic dip. Using equation 1 to calculate the interval velocities is the simplest way but better results may possibly be obtained from a more sophisticated method, such as the least squares method described in Oldenburg et al. (1984).

After the interval velocities have been calculated, densities can be calculated using Gardner's equation

$$\rho = 311 * V_{int}^{1/4} \quad (2)$$

where ρ are the densities and V_{int} are the interval velocities. These densities can be seen in Figure 6. The impedance section can then be simply calculated by multiplying the interval velocities by the densities, Figure 7.

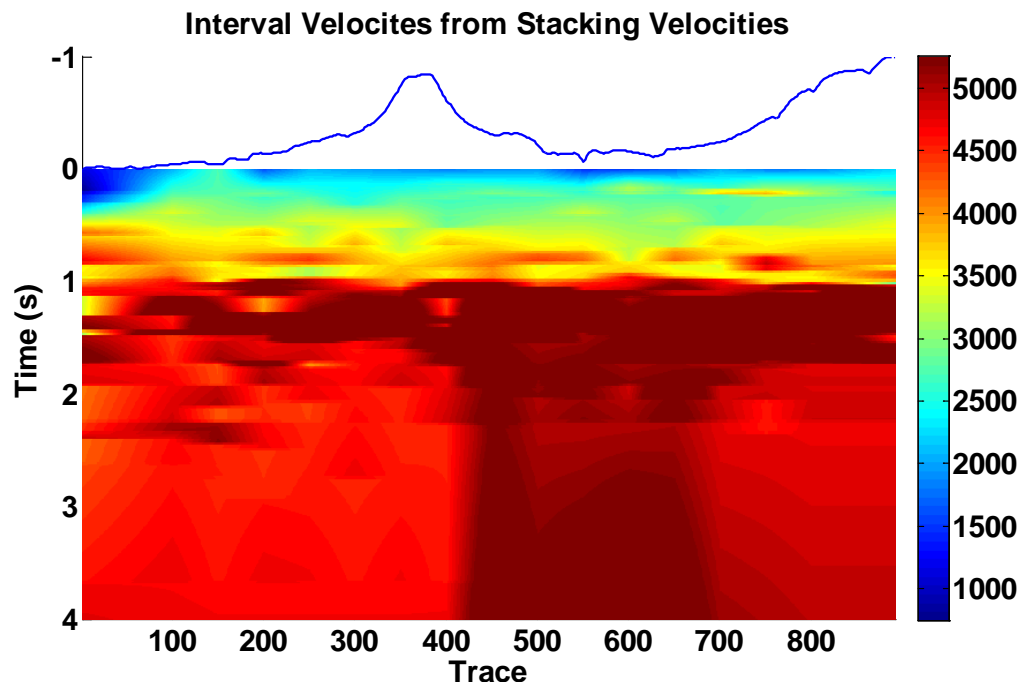


FIG 5: The interval velocities are shown with the topography as there is a very high anomaly between traces 400 and 700. The topography has been vertically exaggerated and the maximum difference between the high and low points is 83 meters

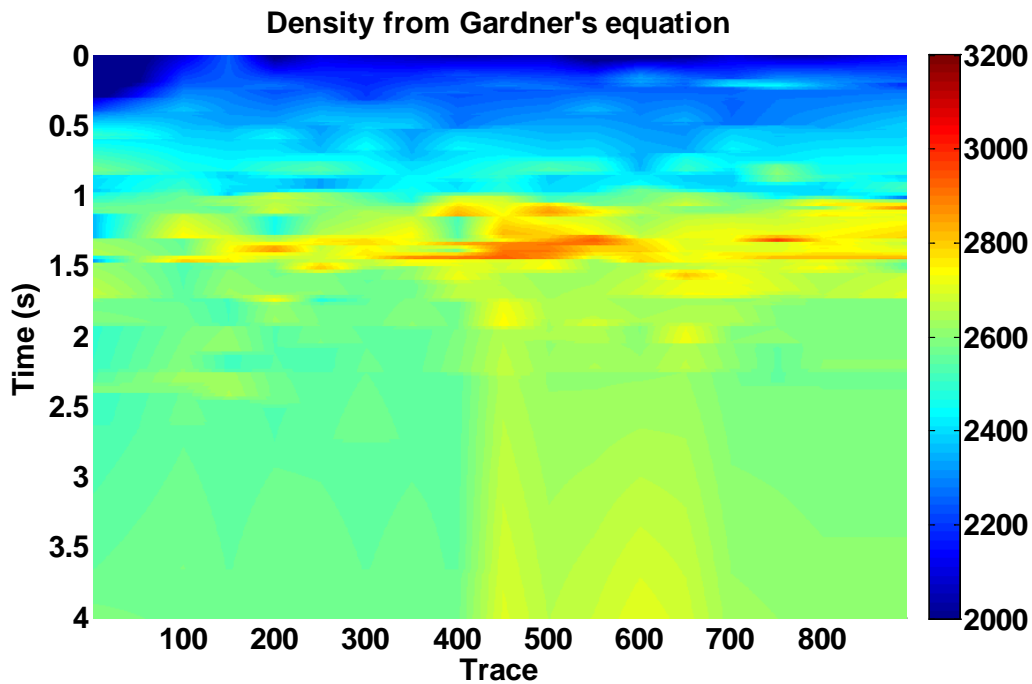


FIG 6: The densities were calculated from the interval velocities using Gardner's equation.

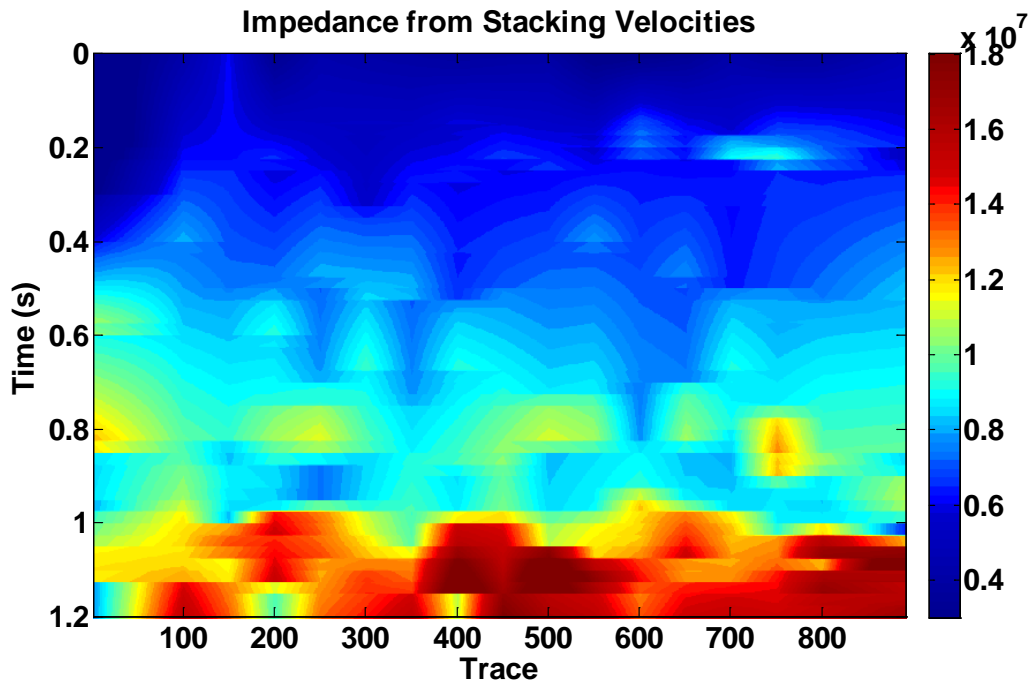


FIG 7: This figure shows the Impedance and is simply the product of the density and interval velocities. All impedance plots will be displayed using this color bar for ease of comparison.

The impedance section from stacking velocities is too low frequency bandwidth to use for rock property analysis as it is but we can use it as the low frequency component needed in the BLIMP method (Ferguson and Margrave, 1996). For the seismic data component, we will use the timevariant balanced seismic data described in Lloyd and

Margrave (2012). The low-frequency cutoff was selected as 2 Hz, meaning that 0 to 2 Hz is taken from the stacking velocity estimate and added to the trace spectra. The result of this can be seen in Figure 10. To visually compare this result to the well data a weighted well impedance section was prepared as described in Lloyd and Margrave (2012). This section is seen in Figure 9 and the filter shown in Figure 8 has been applied. Looking at Figures 9 and 10 we can see that the inversion using stacking velocities has higher impedances at 0.4 seconds, 0.65 seconds, 0.8 seconds and after 1 second. Even though the impedances are higher they do have similar trends as the event at 1 second is 3×10^6 $\text{kgm/s}^2\text{m}^3$ less than the event at 1.1 seconds in both cases. Figure 11 shows a comparison with the wells. A strong correlation can be seen between the two methods but it is far from a perfect match. The inversion using stacking velocities also shows a very high degree of spatial variability which is likely attributable to the high-sensitivity of Dix interval velocities to slight variations in the stacking velocities. While some variance is expected, there does appear to be an imprint from the low frequency contribution.

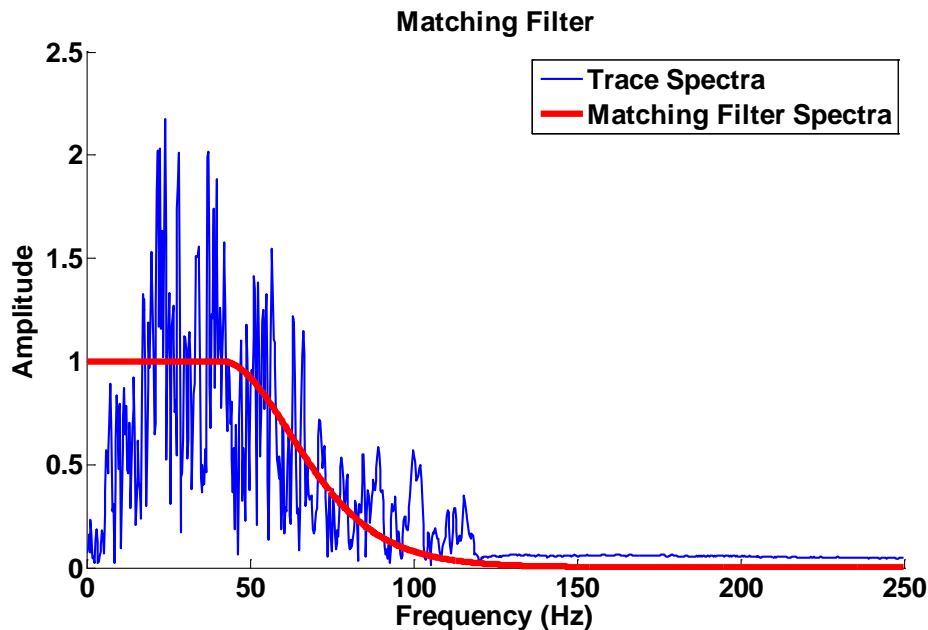


FIG 8: The matching filter used to make the well impedance more comparable to impedance inversions was derived from the shape of the trace spectra.

Interval velocities from stacking velocities tend to be very erroneous. To smooth the variability a Gaussian smoother is usually applied. For this example we will use an extreme smoother by averaging the interval velocities laterally. 2 Hz of low frequency information was used from the mean impedance section in BLIMP and the inversion shown in Figure 12 is the result. This section has much less horizontal variability and less low frequency imprinting can be seen. This section also is a better match with the reference section in Figure 9. Figure 13 shows the comparison between the inversion using mean stacking velocities and the well impedances. This inversion result is 1% more accurate than the previous result as shown in Figure 14. Each inversion result is subtracted from a filtered (matching filter) well impedance log.

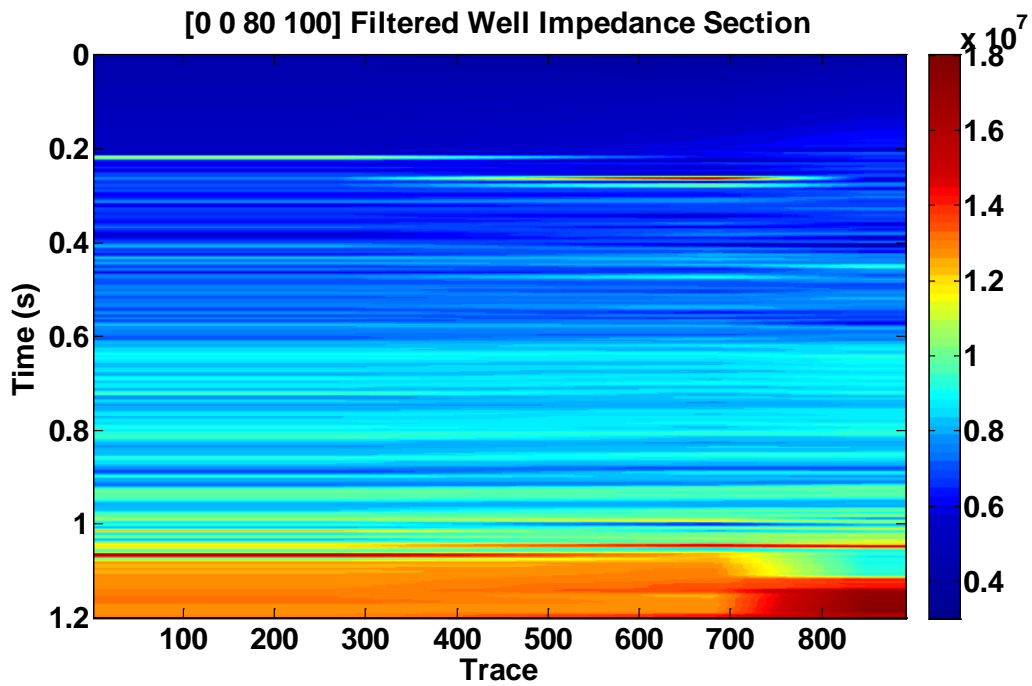


FIG 9: A reference section created from weighted average of the well logs. A [0 0 80 100] Gaussian taper filter has been applied to reduce the amount of low frequencies and ensure a better comparison with the inversion results.

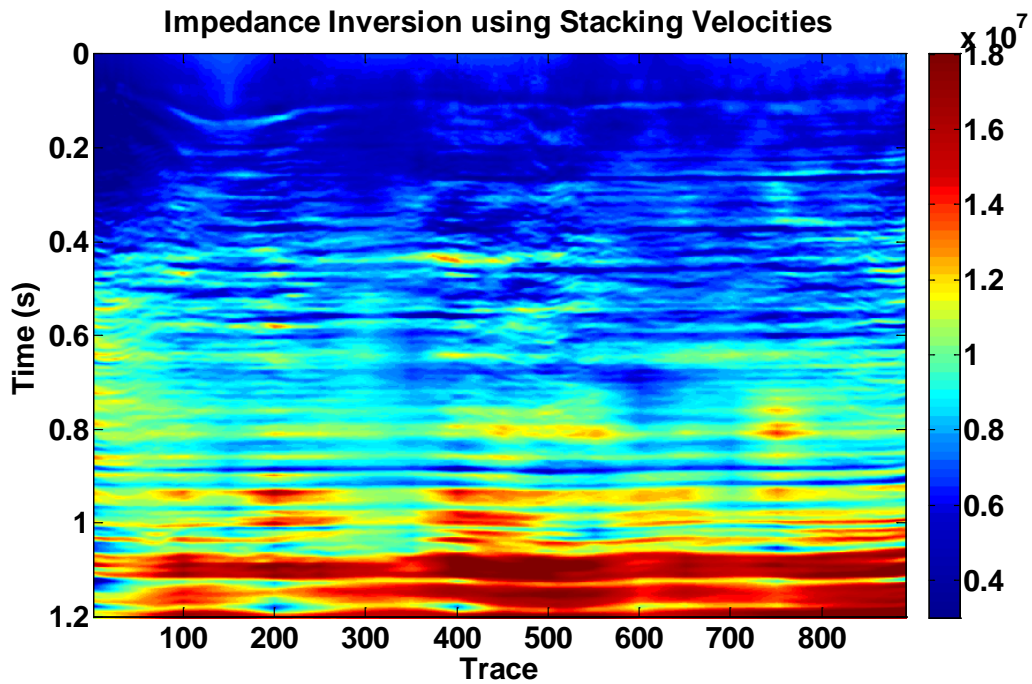


FIG 10: The BLIMP impedance result using 2 Hz of low frequencies from the stacking velocity impedance section.

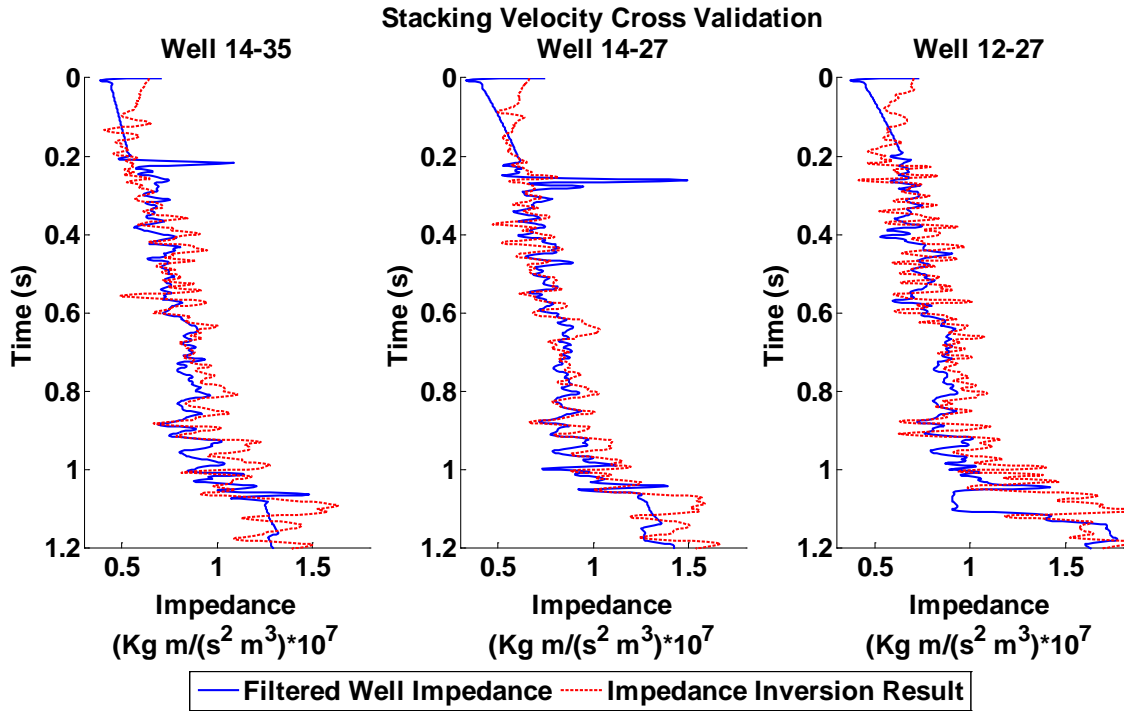


FIG 11: The 2Hz BLIMP impedance result from stacking velocities compared to filtered well impedance logs at well locations.

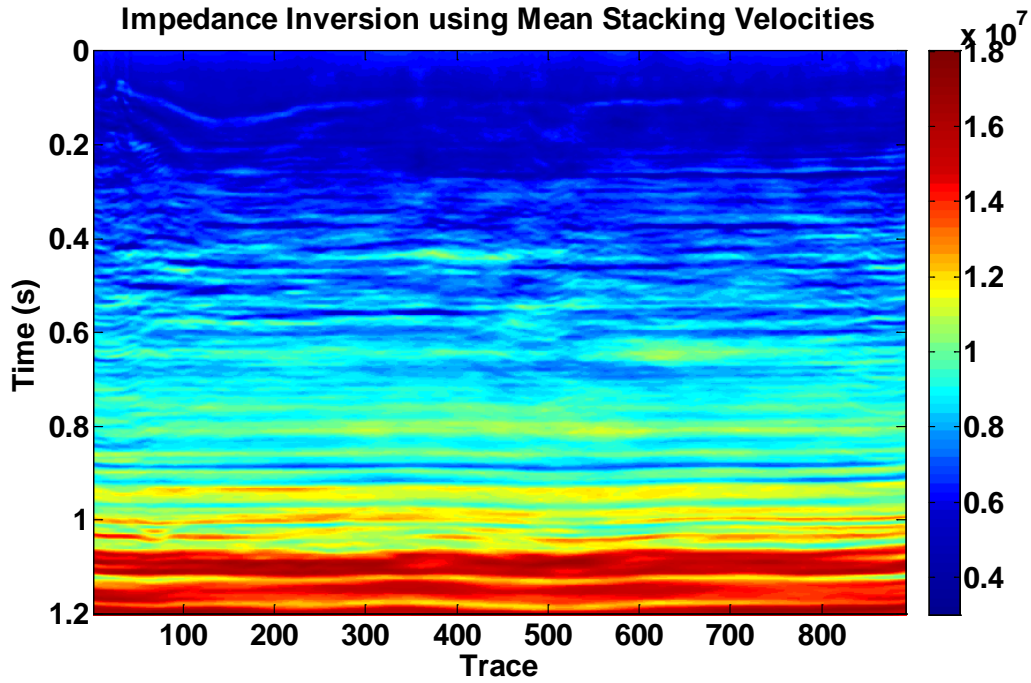


FIG 12: The BLIMP impedance result using 2 Hz of low frequencies from the mean stacking velocity impedance section.

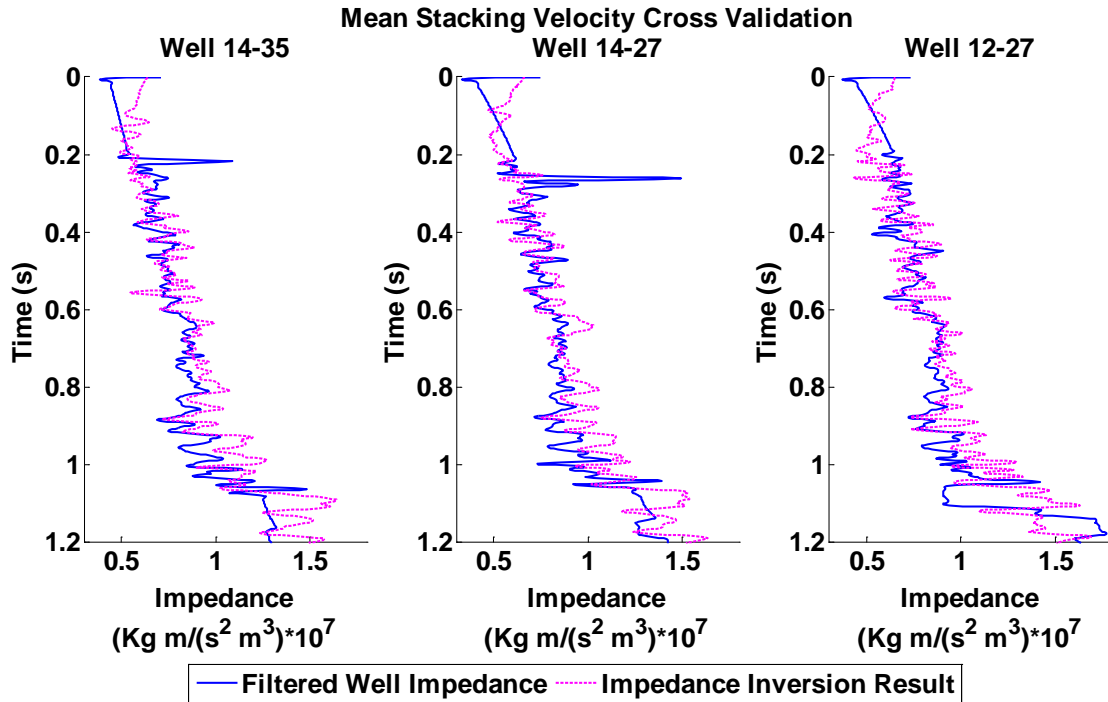


FIG 13: 2 Hz BLIMP impedance inversion using mean stacking velocities compared to well impedance logs at well locations.

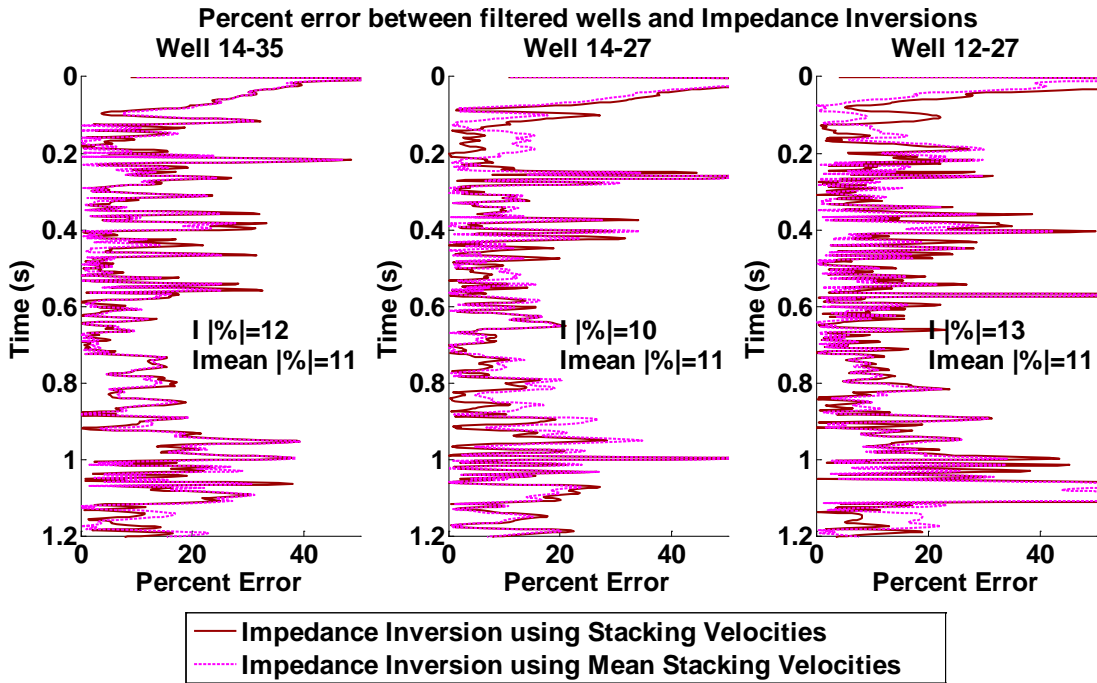


FIG 14: The percent difference between the filtered well and the inversion using impedance from stacking velocities (red) and the percent difference between the filtered well and the inversion using impedance from mean stacking velocities (purple). The average percent error values are calculated between .2 and 1.05 seconds.

CONCLUSIONS

This study demonstrates that it is possible to get a good impedance estimate using the stacking velocities to provide the low-frequency component. The result is actually quite remarkable when the amount of information (Figure 1) is considered. However, given good well control, it seems that using low-frequency information from wells may be preferred. When well control is absent or sparse, stacking velocities provide an interesting alternative. This method needs to be developed further before the impedance inversion can be used for any rock property analysis.

Since the inversion is mainly dependent on accurate stacking velocities picking them with the intent of using them for inversion would help the results greatly. In this study they were very sparse laterally so picking more locations would help constrain lateral variation. Picking more samples vertically would also help constrain any anomalies, however making picks too close together can create instabilities in the conversion to interval velocities. The statics should also be calculated carefully so they do not create imprints in the stacking velocity picks. In this study we used a very simple way of calculating interval velocities. There are more advanced methods of calculating interval velocities and they should be investigated. Oldenburg et al. (1984) discusses using weighted least squares methods to produce a smooth variation. They also discuss using known interval velocities as controls when converting the stacking velocities to interval velocities.

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