Well tying and trace balancing Hussar data using new MATLAB tools

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ABSTRACT

In September 2011, CREWES recorded a data set in southern Alberta near Hussar. The purpose of this survey was primarily to compare receiver types (four types of receivers) and source types (four types of sources) at very low frequencies. Data processing by CGGVeritas resulted in a final section for 10Hz vertical component geophones and dynamite source and this was used in this study. Three wells intersected this line, two near the south (12-27 and 14-27) and one towards the north (14-35).

An overburden and underburden, derived from the stacking velocities, was applied to the sonic logs. An overburden and underburden was also applied to the density log using the stacking velocities and Gardner's equation. The next step was to estimate a wavelet by fitting a fourth order polynomial to the decibel amplitude spectra of a seismic average trace.. Synthetic traces were then prepared at each well location. A rough tie of well 12-27 was completed and the seismic data was balanced with a time-variant scaling operator. To create a good tie between the seismic data and the synthetic traces the sonic logs of the wells were stretched until key events matched.

An average trace was prepared from averaging five traces located at each well location after the traces were aligned as a slight dip is evident in the seismic data. An average synthetic trace was prepared by aligning, balancing and averaging the synthetic seismograms at each well location. The reflectivity and Impedance for these wells were also aligned and averaged. It is helpful to have a reference impedance section which was created by a weighted average of the well impedance logs.

This study found that producing well ties that match the seismic data is not trivial and is very important for accurate inversions. StretchWell and WaveletEstimator were two programs created for this study with graphical user interfaces used in tying the wells. StretchWell is used to modify the sonic logs and WaveletEstimator is used to create wavelets. Each of these programs is explained at the end of this paper.

INTRODUCTION

For acoustic impedance inversion the impedance logs from wells are commonly needed to input the low frequencies. The well must be tied to the data to provide optimal results. This tying process includes adding an overburden and underburden to the well, converting the well to time, and finding a wavelet that matches the seismic data to be used to create the well synthetic. The next step is to align events on the synthetic and real traces and this can sometimes be managed with adding a static shift to the well in time. More commonly the sonic log needs to be stretched to correct for attenuation, errors in the overburden, and the difference in velocities between the high frequency sonic source used in well logging and the lower frequency source using in seismic acquisition.

To accomplish some of these tasks new graphical interface tools have been developed in MATLAB to make these processes easier and user friendly. This paper will use the Hussar data set as an example throughout this paper.

The Hussar data, acquired in September 2011, (Margrave et al., 2011) consists of a line that runs Southwest to Northeast shown in Figure 1. Four different sources: 3C 10 Hz geophones, 1C 4.5 Hz phones, 3C Vectorseis accelerometers and Nanometrics Trillium broadband seismometers were used at various spacing along the line. Four different sources were also used and include dynamite, low-dwell, low-frequency INOVA 364 Vibroseis, low-dwell regular Vibroseis and a linear 364 Vibroseis sweep. This paper will focus on the data associated with the dynamite source and vertical component of the 10 Hz geophones. Three wells are located along the line including well 1227, well 1427 and well 1435. Their positions are shown in Figure 1. The seismic line was processed by CGGVeritas. BLIMP the inversion algorithm used in this study requires stacked and migrated data so CREWES (Isaac et al., 2012) migrated the data using a Kirchhoff migration operator.

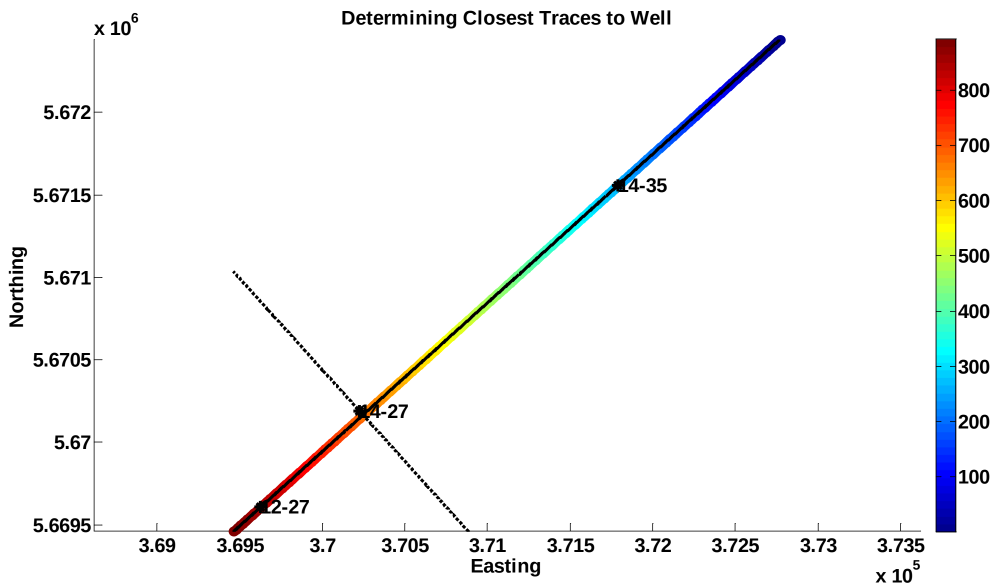

FIG 1: Well locations along the seismic line.

METHOD

All of the wells contain a sonic log and a density log, Figure 2, but are missing an overburden and an underburden. An artificial gradient was used to produce these quantities but better results were found when the stacking velocities were used to fill in the overburden and underburden. The stacking velocities were interpolated as described in Lloyd and Margrave (2012), converted to interval velocities and then translated into depth. They matched up fairly well with the velocity logs and inserted into the new logs, Figure 3. Densities were calculated using Gardner's equation (Gardner et al., 1974),

$$rho = 311 * v^{.25} \quad (1)$$

where rho is the density and v is the velocity. These densities were used to fill in the density log for the overburden and underburden.

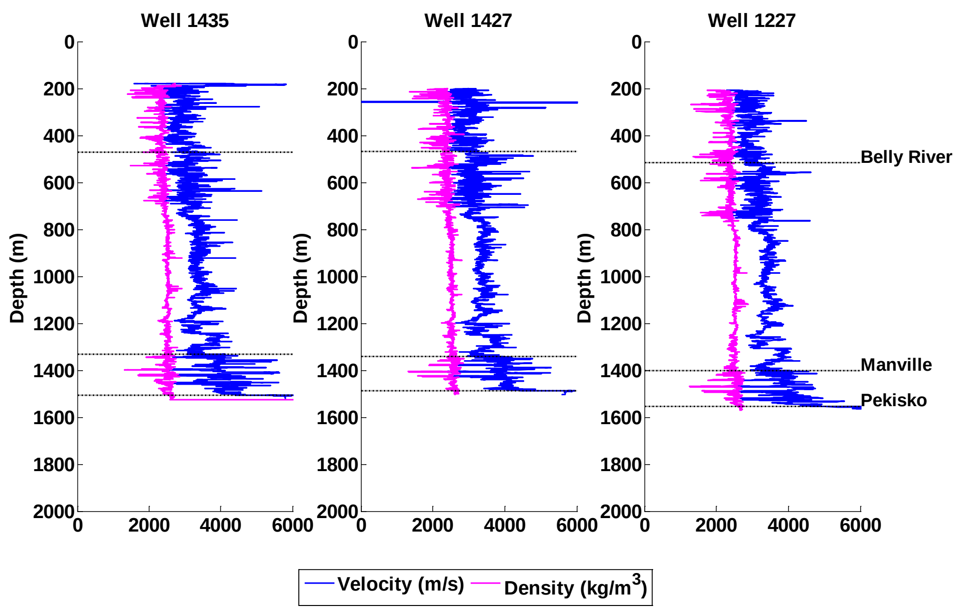

FIG 2: The velocity and density logs for each of well 14-35, 14-27 and 12-27, The pink curve indicates the density and the blue curve indicates the velocity log. Three tops have been plotted for reference

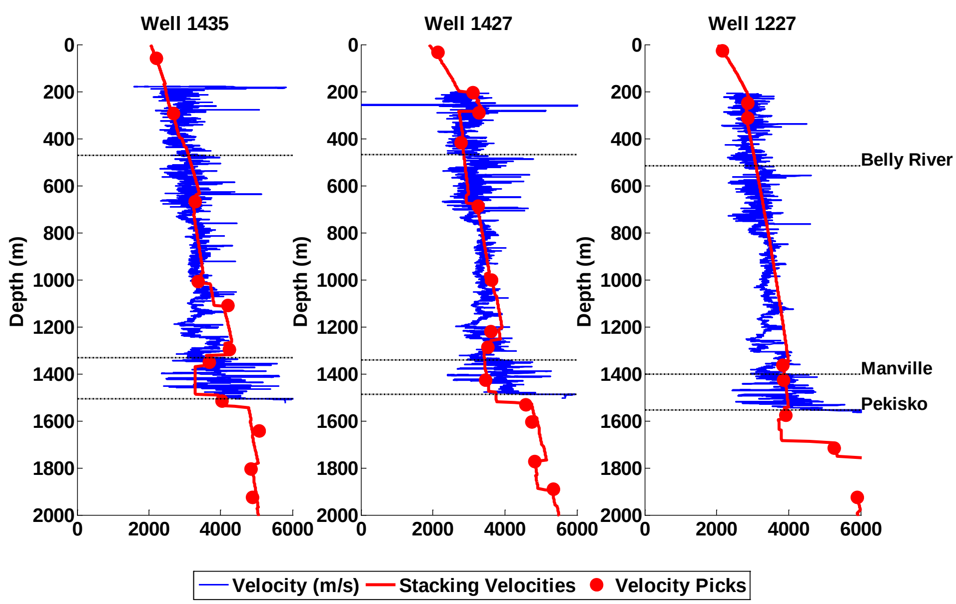

FIG 3: The velocity logs from the well , in blue, are compared with the stacking velocites from processing the stack,in red. The velocity pick locations are shown as a red star.

The next step was to create a synthetic seismogram using the new logs. A wavelet was needed and the new function WaveletEstimator was used. This function is described fully in the Product Description section of this paper. The wavelet was chosen to fit the seismic data from 0 to 1.1 seconds which represents the interval where the well log synthetics have reflection coefficients. A 4th order polynomial was chosen to fit to the amplitude spectrum in decibels. An option to make the wavelet estimate flat at the maximum root of the polynomial was selected and flattens any undulations at the end of the spectra. A Constant phase operator was used to determine that a phase rotation of 4 degrees was needed. Since this was such a small rotation a zero phase wavelet was used. The fit of the amplitude spectra and the wavelet in time can be seen in Figure 4.

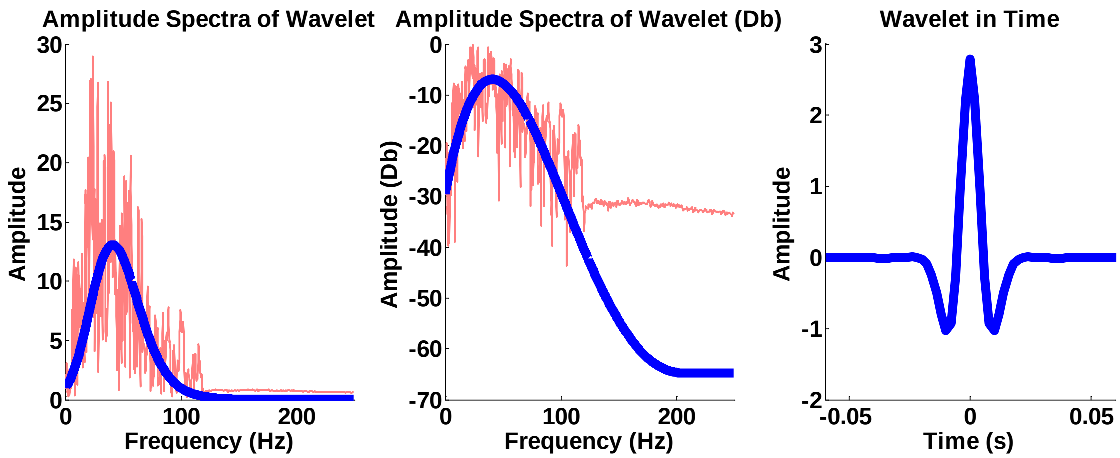

FIG 4: The wavelet used to create synthetic seismograms. The average trace spectra is shown in red where the wavelet estimate is shown in blue (bold). The wavelet was determined to be a zero phase fourth order polynomial approximation in decibels.

Synthetics were then produced for each well using this wavelet. Figure 5 shows the comparison of the seismic to the well synthetic for well 12-27. From this figure we can see that there is a shift needed in the well log. There is also an amplitude difference between the well log and the seismic. We can determine the problem to be in the seismic data as both the seismic and well synthetics have similar amplitudes after .9 seconds. To compensate for this difference a time variant balancing algorithm was applied to the seismic to match the amplitudes of the well. This function is called tvbalans and balances the trace using a series of Gaussian windows. For this data windows of 200 ms were chosen and the center of each window increments every 10 ms. It is important that the window is large enough so events are not artificially created. Figure 6 shows a selection of traces of the seismic after they have been trace balanced.

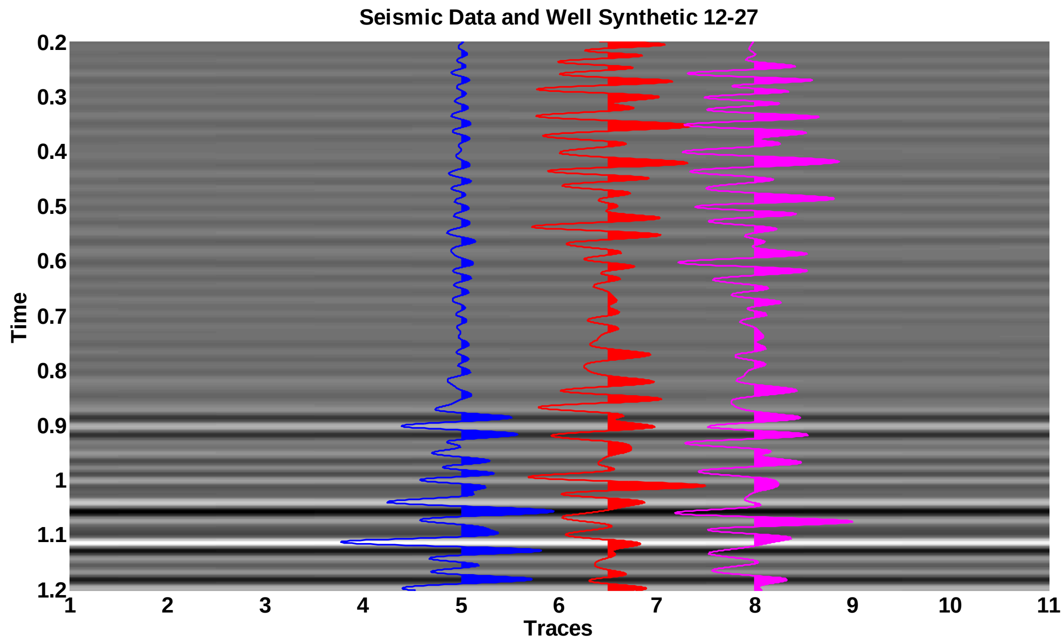

FIG 5 : Well tie for well 12-27. The trace located at the well location is shown in blue, the non static shifted synthetic trace is shown in red and the static shifted synthetic is shown in pink.

A static shift can produce a reasonable tie, but it does not match all the events. This is mostly due to attenuation in the seismic that the sonic tool cannot capture. It is then standard procedure to modify the sonic log to accommodate the static shift along with matching other events. Stretchwell, the program, is used to do this. It features a user interface where the user can see each change in the synthetic as well as changes in the sonic log. A more in depth description of Stretchwell can be found in the next section. Once the sonic log has been modified the final synthetic can then be tied to the seismic data, Figure 6.

Once the wells were tied it was useful to create an average trace and average well log. Five traces centered at the three well locations were chosen for the average trace. The traces needed to be static shifted to accommodate for a slight dip in the subsurface. Once they were all aligned they were then averaged to become the average trace. To create the average well log the three well synthetic seismograms were aligned, trace balanced and then averaged. The impedance and reflectivity logs were also aligned so that future analysis can take place. The average trace and average well-logs can be seen in Figure 7.

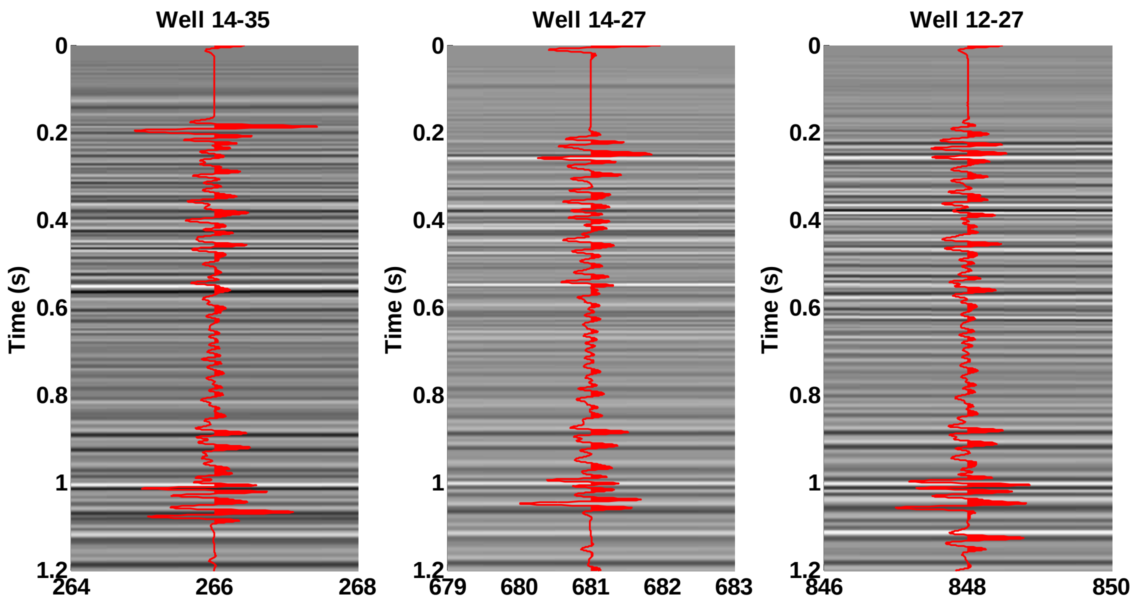

FIG 6: This figure shows the synthetic seismograms at the well tie location. The sonic logs have been modified such that the events match the seismic as closely as possible.

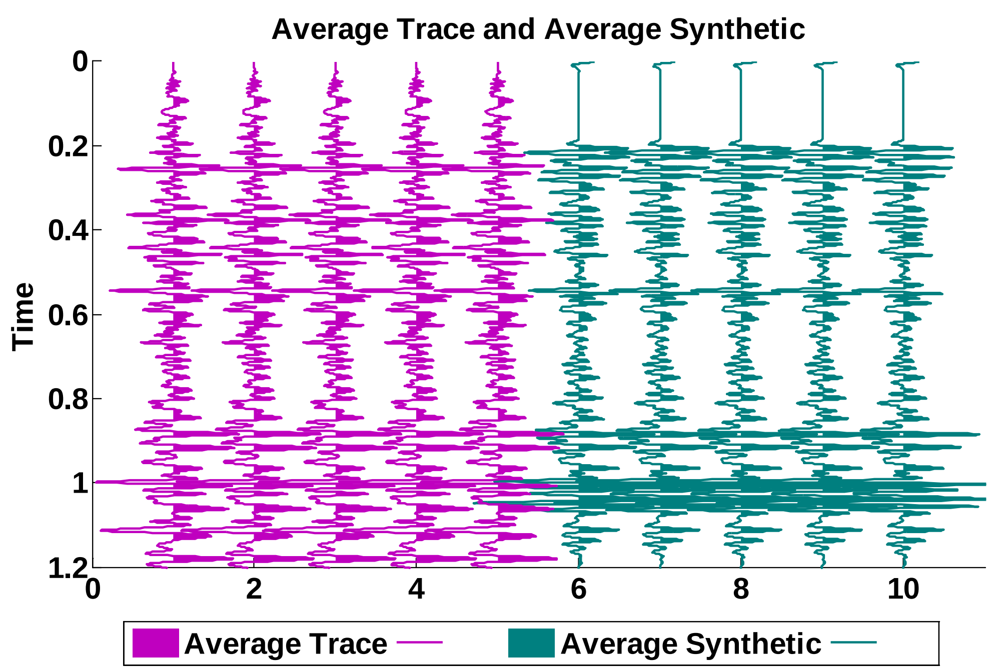

FIG 7: The average trace, which is an average of the seismic and the average synthetic, an average of the synthetic seismograms from the well logs are shown five times each for display purposes. These averages are useful for impedance analysis in additional chapters in this volume by the authors.

When computing an impedance inversion the whole section is displayed, however we can only compare the results with the actual impedance at the well locations. To be able to do a quick qualitative comparison between an inversion and the wells it is necessary to have a reference impedance section. This section was created by combining the two closest well impedance logs by weighting their distances. At the edges there is only one well that will contribute to the new traces. The equation used for this purpose is

$$tr_k = \frac{(d_2 w_1)+(d_1 w_2)}{(d_1+d_2)} \tag{2}$$

where tr_k is the new trace at location k, d is the distance between the well location and the trace location and w is the impedance log at the well location. The weighted average section can be seen in Figure 8.

One point to address is the high impedance values near the 12-27 well location. This is likely due to errors in the stacking velocities as it is in the underburden. We will ignore this for the time being as it is below the reservoir of interest.

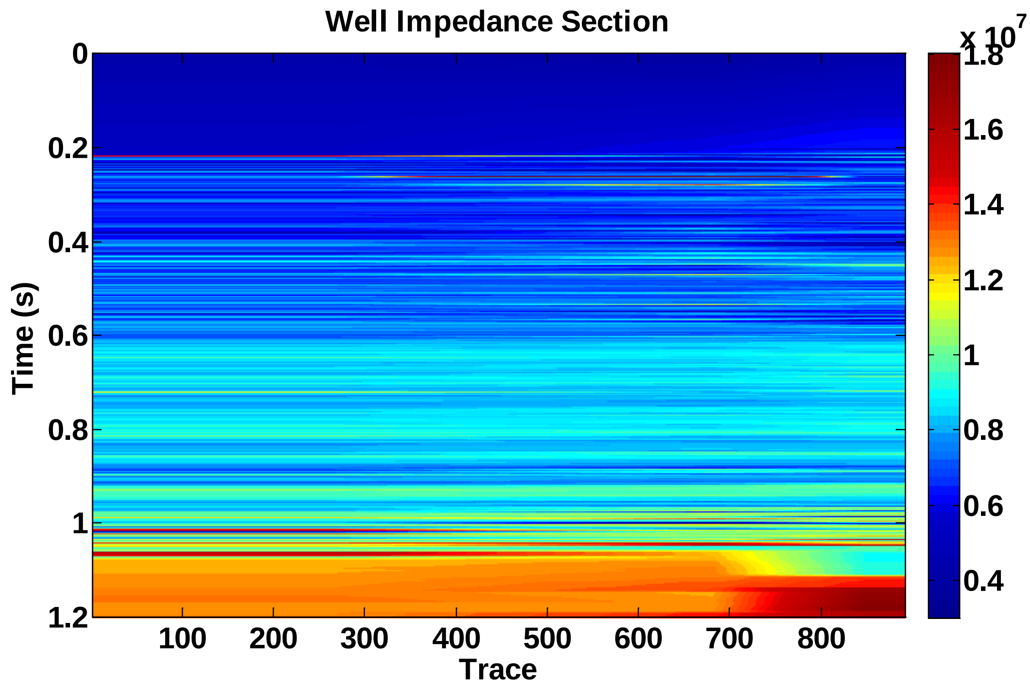

FIG 8: An impedance section calculated by the weighted average of well impedance logs. The anomaly on the right hand of the section is likely due to the inaccurate underburden from stacking velocities at this location.

PROGRAM DESCRIPTIONS

Two graphical user interface programs were designed to help with well ties. WaveletEstimator estimates a wavelet using the amplitude spectra of a trace. Where as Stretchwell stretches the sonic log until a good fit can be found.

WaveletEstimator

Finding a wavelet that fits the trace data can be difficult. WaveletEstimator, in Figure 9 uses polynominals to fit the amplitude spectrum of a trace. The program allows the user to select an interval to carry out the analysis on. The program allows the user to switch back and forth between three different wavelet types.

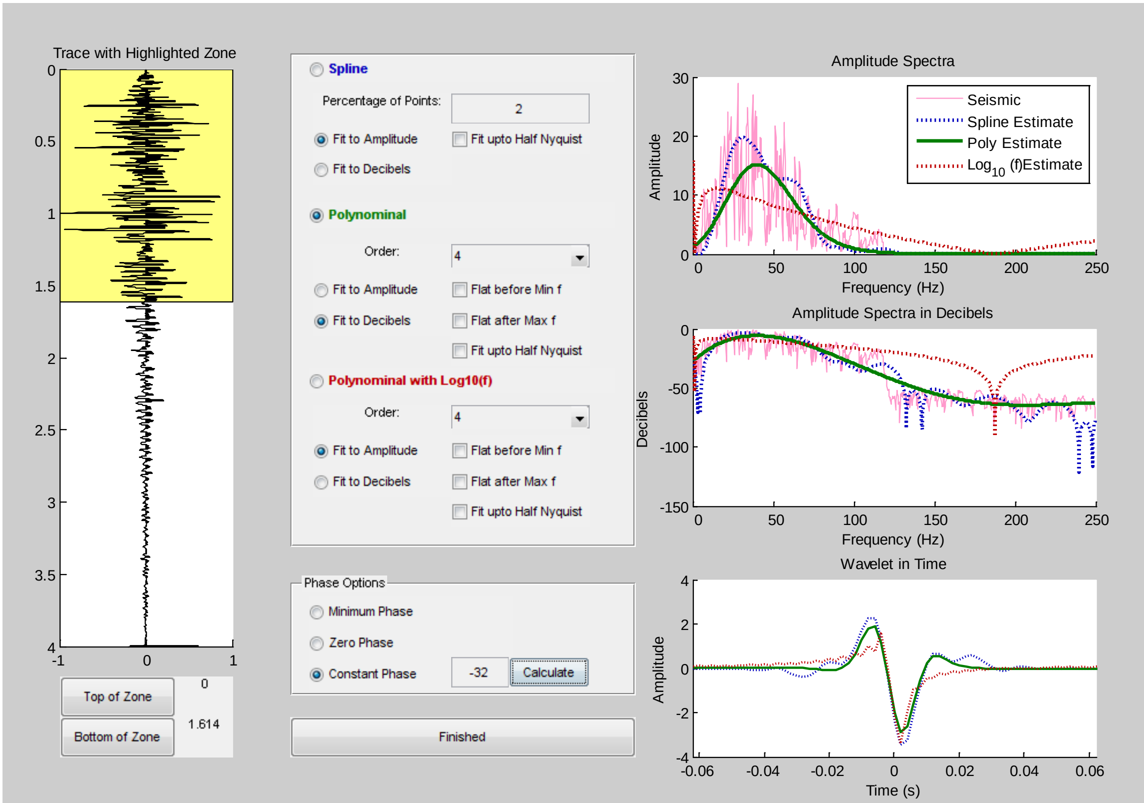

FIG 9: The interface for WaveletEstimator. The zone that is used in calculating the amplitude spectra from the trace is indicated in yellow on the left hand side. The amplitude spectra of the seismic trace and the estimated wavelet are shown in top right hand corner, and in decibels just below. The wavelet is shown in bottom hand corner in time. In the center are the wavelet options. Each wavelet type is identified by a separate color which can be seen in each of the displays.

The first is Spline which fits a series of cubic polynomials (de Boor, 1978) to the spectra. The sensitivity of this method is determined by the parameter Percentage of Points, where only that many points will be used to create the approximation. As this number increases the approximation gets closer and closer to the trace spectra. This method requires at least two points to provide an approximation. This method can be fit to the amplitude spectra or the amplitude spectra in decibels. Data points between 0 and half Nyquist can also be selected to avoid any imprint of the anti-alias filter that has been applied to the data. Approximations for this method are always shown in blue.

The second wavelet type is the polynomial. This method fits a polynomial, of the order specified by the user (orders 1-8) to the trace spectra. Again this method offers the option of fitting the polynomial to the trace amplitude spectra or the trace amplitude spectra in decibels. This method can take into consideration frequencies up to half Nyquist when calculating an ideal polynomial. To prevent trace spectra from taking off at very low frequencies the Flat before Min f button finds the lowest positive root of the function. From that point the value is copied for any frequencies that are less than that root. The Flat after Max f does a similar thing where it finds the largest positive root and copies the value for frequencies higher than that root. This provides a continuous wavelet estimate. These options are very handy when selecting the Fit up to half Nyquist.

The third method is similar to the polynomial method however it fits the wavelet to the amplitude spectra where instead of f the frequency is expressed as $\log_{10}$(f). This provides a very different fit of the spectra. It can be used to fit the reflectivity found in well logs. This method has the same options as the polynomial method including Flat before min, Flat after Max f, Fit up to Half Nyquist, and fitting the polynomial to the amplitude spectra and the amplitude spectra in decibels.

This program allows the user to select a zero phase wavelet, a minimum phase wavelet and a constant phase wavelet that the user can specify. The program will automatically calculate the constant phase rotation needed by pressing the calculate button next to the constant phase option.

Stretchwell

Sonic logs are used to produce time-depth curves which are then used to calculate a synthetic trace using well logs in time. The synthetic trace does not always match the seismic trace due to multiple reasons including:

- Non-ideal overburden
- Attenuation
- Sonic logs are not affected by Q in the same way seismic data are
- Source frequency differences
- $v(f) = v\left(1 + \frac{1}{\pi Q}\ln\left(\frac{f}{f_o}\right)\right)$, Where v is the velocity, Q is attenuation, f is the source frequency and f_o is the reference source frequency.
- Uncertain Wavelet

To compensate for these differences we have developed an algorithm that modifies the sonic log such that the events on the synthetic match the events on the seismic trace. Figure 10 shows the synthetic trace in blue and the seismic in red in the right hand panel. Ideally we would like to be able to match the events at about 0.85 seconds.

If we let the time that the records match be t_o and the event pick for the well be t_w and the event pick for the seismic be t_s then we can write the following expressions

$$t_w = \frac{1}{10^6}\int_{z_o}^{z} S(z')\,dz' \tag{3}$$

$$t_s = \frac{1}{10^6}\int_{z_o}^{z} (S(z') + \Delta S(z'))\ dz' \tag{4}$$

where z_o corresponds to the time at t_o, z corresponds to the time at t_w, S(z') is the sonic function and ΔS(z') is a perturbation of the sonic function.

If we let ΔS(z') = α, a constant we get the following

$$t_s = \frac{1}{10^6}\int_{z_o}^{z}(S(z')\,dz' + \frac{1}{10^6}\int_{z_o}^{z}\Delta S(z')\,dz' \tag{5}$$

$$t_s = t_w + \frac{1}{10^6}\int_{z_o}^{z}\alpha\,dz' \tag{6}$$

$$t_s = t_w + \frac{1}{10^6}\alpha z'|_{z_o}^{z} \tag{7}$$

$$\alpha = \frac{10^6(t_s - t_w)}{(z - z_o)} \tag{8}$$

where t_s and t_w must be in one way time. Since α is a constant it is added to the sonic function between z_o and z.

After the synthetic is recalculated using the new sonic curve the events should match up. Additional picks are then chosen until the synthetic is matched to the seismic. The program will then export the modified sonic log so that the user can create a better well tie.

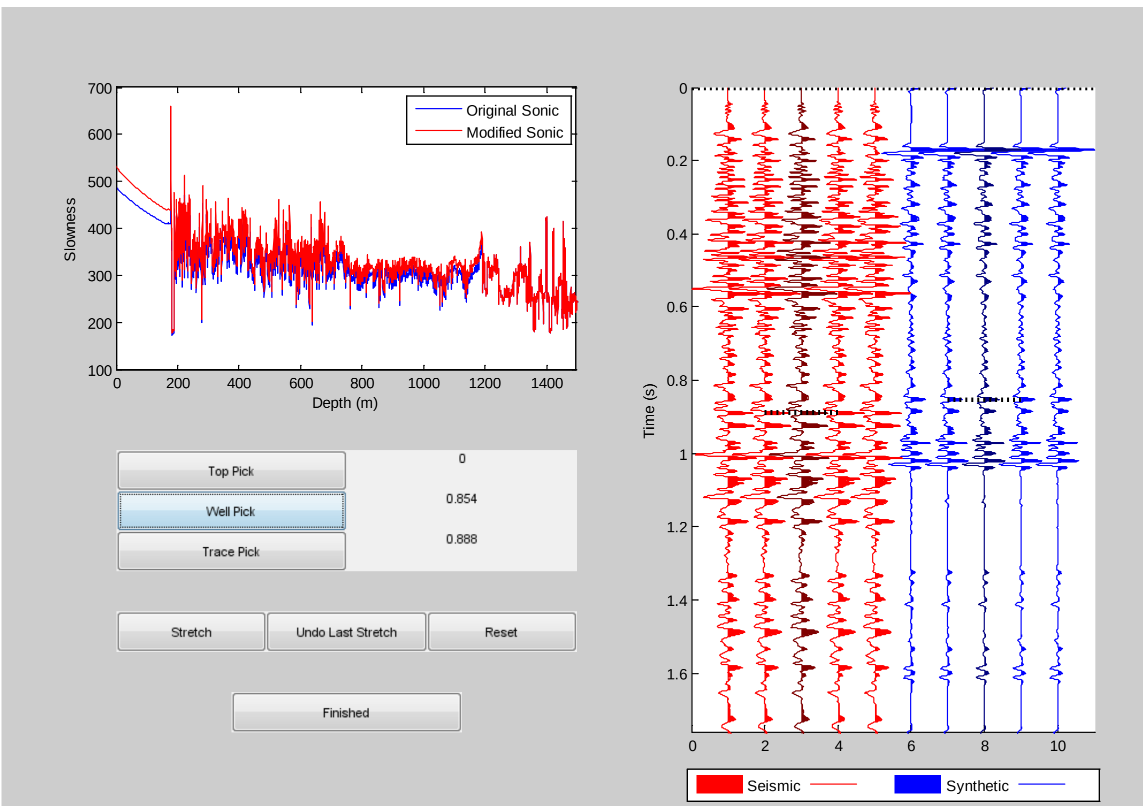

FIG 10: The interface of Stretchwell. The synthetic seismogram is shown in blue and the seismic data is shown in red. The two sonic curves are shown in the upper left hand corner of the display.

CONCLUSIONS

Preparing the data for inversion is very important and it is not trivial to create a good well tie. These steps were chosen as they demonstrate a better well tie than other options such as using a gradient for the overburden and underburden and using static shifts to accommodate for the sonic discrepancies. Throughout this study it was clear that new tools had to be made to make the well tying process simpler and easier, thus WaveletEstimator and Stretchwell are now available.

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