Comparison of deterministic wavelet estimation and statistic wavelet estimation through predictive deconvolution on the quality of well tie: application on synthetic and real data.

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Abstract

Well to seismic tie is used to correlate well log information to the seismic data. The main link between a primary reflection signal and the reflectivity from a well log is the seismic wavelet. In this paper we test two different methods to estimate the seismic wavelet for the well tie procedure: one based on both the well log and seismic data, the deterministic approach, and one based only on the real seismic trace, through the predictive deconvolution. Our tests with numerical data show the estimation of seismic wavelet with reasonable accuracy for both cases. The feasibility of this approach is also verified on a real seismic and well data from Viking Graben field, North Sea, Norway.

Introduction

Well-tie is an useful tool to relate recorded seismic waveforms to the stratigraphy and rock properties of the subsurface (WHITE; SIMM; XU, 1998). Accurate well-tie are essential to practical seismic lithological interpretation (WHITE, 2003). As long as the geology in the vicinity of the well is not unduly complex, the main factors controlling this accuracy are the processing of the seismic data and the construction of the seismic model from the well logs. The main link between a primary reflection signal and the reflectivity constructed from a well log is the seismic wavelet. In general, most of the studies on this subject states that methods to estimate the seismic wavelet are divided in two categories: deterministic and statistical. Deterministic methods require direct measurements of the source wavefield or the use of the well log data (OLDENBURG; LEVY; WHITTALL, 1981; YILMAZ, 2000). Statistical methods estimate the wavelet from the seismic trace itself and require assumptions about the characteristics of the wavelet (BULAND; OMRE, 2003; LUNDSGAARD; KLEMM; CHERRETT, 2015). In this study we compare the quality of the well to seismic tie based on two different methods to estimate the wavelet. The first one is the traditional deterministic method, which selects a segment of the reflection sequence and a segment of the seismic data. The best wavelet estimated is the one that leads to the best match between seismic and synthetic. The second one is statistical and is based on predictive deconvolution and on the classical assumptions concerning the convolutional model of the earth. Our algorithms, for both cases, introduce an semi-automatic approach that improves the correlation of the real seismic trace with the synthetic trace calculated from the well log data. We test our semi-automatic approach with synthetic numerical data and the results show the estimation of seismic wavelet with reasonable accuracy for both statistical and deterministical cases. Moreover, the feasibility of this approach is also verified on a real seismic and well data from Viking Graben field, North Sea, Norway.

Wavelet estimation and well to seismic tie

Well to seismic tie is used to correlate the well log information to the 3D seismic volume or 2D seismic lines. It is a important part of interpreter's trade once they provide means of: 1) correctly identifying horizons to pick and 2) estimating the wavelet for inverting seismic data to impedance (WHITE; SIMM, 2013). Borehole measurements such as sonic and density logs are recorded in depth while seismic measurements are in time. To convert the borehole measurements from depth to time, a time-depth relationship need to be established. In general, the creation of a synthetic include these steps:

1. Edit the sonic and density logs.
2. Generate a reflectivity series.
3. Apply a time-depth relationship.
4. Convolve the reflectivity series with a wavelet.
5. Compare the output of the convolution with the real seismic data.

If the seismic wavelet is not known, it is possible to estimate it from the seismic data alone (statistical), or from both seismic and well log data (deterministic). In this paper the both procedures were used: the deterministic estimation of the wavelet was through a filter and the statistical estimation was through the predictive deconvolution.

Our semi-automatic algorithm for the well to seismic tie performs a search for the best wavelet that produce the higher correlation coefficient between the synthetic trace and the real seismic trace. The first step needed to estimate the wavelet through the predictive deconvolution is select a range of traces in the vicinity of the well location. On a segment chosen of each trace, a predictive deconvolution will be performed. The predictive deconvolution is dependent on the prediction lag (α) and the operator length (N). The choice of the best values of prediction lag and operator length produce the best result on the predictive deconvolution. For that reason, on the segment chosen, the predictive deconvolution is applied using a range of prediction lag and operator length. Each combination α-N generates a wavelet for all the range of CMPs that will be convolved with the reflectivity calculated from the wells. The correlation coefficient between the real seismic trace and all the synthetic traces generated with all the different wavelets are estimate. The algorithm identify the highest correlation coefficient and the trace (or corresponding CMP), the prediction lag and the operator length that yields it and generates the best statistical wavelet among all. The other statistical alternative was to calculate the average wavelet. In this case, the procedure mentioned before is done with three or more different segments of the seismic trace. When the algorithm gives the best wavelet for each segment, an average wavelet is calculated. This average wavelet is the one that will be convolved with the reflectivity to generate the final synthetic seismic trace. As for the case of the deterministic estimative of the wavelet, the inputs of the algorithm are the real seismic traces in the vicinity of the well location and the reflectivity from the wells in a corresponding scale. In this case, a filter is built in a way that the convolution of the filter coefficients with the reflectivity, generates a synthetic trace that is as much as close to the real seismic trace as possible. This algorithm is dependent on the length of the filter (F) and a increment (Inc). Each combination of filter length and increment generates a wavelet for all the range of traces. Each wavelet will be convolved with the reflectivity calculated from the wells and then the correlation between the synthetic and the real trace is performed. The algorithm identify the highest correlation coefficient and the trace, the filter length and the increment that generated it and produce the best deterministic wavelet among all. The best wavelets calculated through the algorithms are the ones used to generate the synthetic traces of the well to seismic tie. The algorithm is not entirely automatic in the estimative of the best wavelet because on the statistical estimative, it is necessary to select a segment of the seismic trace in which the predictive deconvolution will be performed. It is recommended that this segment represents a reflectional signal from a interface so that the predictive deconvolution can separate the reflectivity component from the wavelet component. As for the deterministic estimative, the process is semi automatic because the seismic trace and the reflectivity in corresponding scales (the necessary inputs) are not made by the algorithm, it is made through the application of the time-depth relationship. The advantages of this method is that several wavelets are generated and have the correlation coefficient tested and only the ones that produce the best match are selected. It is not computationally expensive. Even when using a large range of traces, prediction lag, operator length, filter length and increment, the processing time is very low.

Application on synthetic data

In order to compare the feasibility of the well to seismic tie made with a wavelet estimated from a deterministic and statistical approaches, we test it first on a synthetic model. Our synthetic model consists of 6 layers and its logs are shown at Figure 1. The reflectivity was calculated and then resample to accordingly fit the time axis, which has a total length of 3 s and a sample rate of 0.004 s. Figure 2 shows the corresponding reflectivity of the model depicted at Figure 1. The wavelet used to compute the synthetic trace was a Ricker pulse with a peak frequency of 20 Hz. The seismic trace modeled is shown at Figure 3.

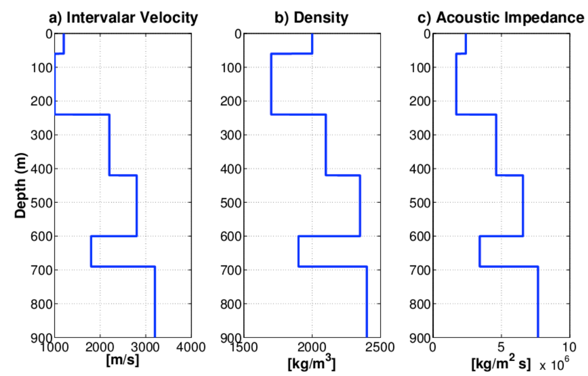

Figure 1 - P-wave, density and impedance logs related to a synthetic model with 6 layers.

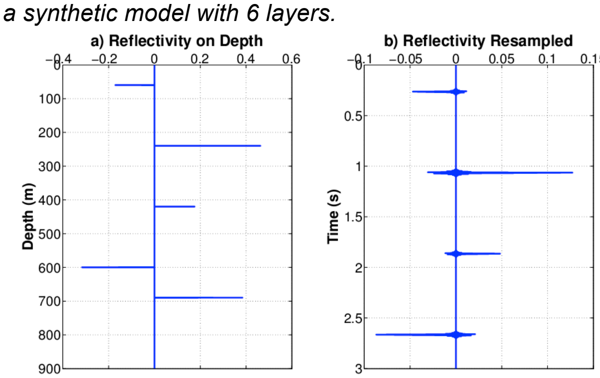

Figure 2 - Reflectivity on depth domain created through the acoustic impedance and the reflectivity resampled to fit the time axis.

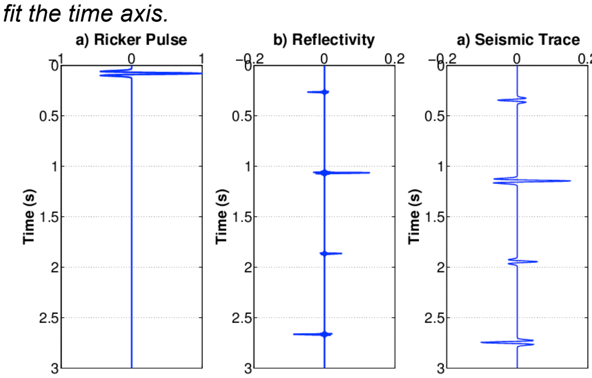

Figure 3 - Seismic trace produced by the convolution of the reflectivity with the Ricker pulse.

For the case of the deterministic estimative of the wavelet, we selected a range of filter length and increment in our algorithm to perform the extraction of the wavelet that gives the best match between the synthetic trace and the real trace. The correlation coefficient of 1 shows that it was very effective on estimate the wavelet for the synthetic layer model, it recovered the Ricker pulse.

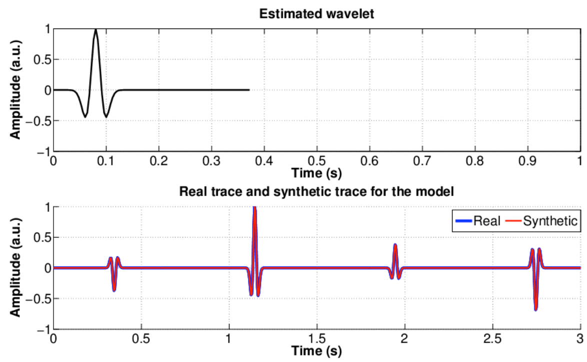

Figure 4 - Estimated deterministic wavelet for the modeled seismic trace without noise. The correlation coefficient between the synthetic trace and the real trace is 1.

For the case of the statistical estimative through the predictive deconvolution, we selected 136ms of the complete trace, from 280ms to 416ms and on that segment we perform the predictive deconvolution in a range of operator length and prediction lag. After we know the best operator length and prediction lag, we can calculate the estimated wavelet. Figure 5 shows the comparison between the real and the synthetic trace using a statistical estimative of the wavelet. The correlation between them was 0.962.

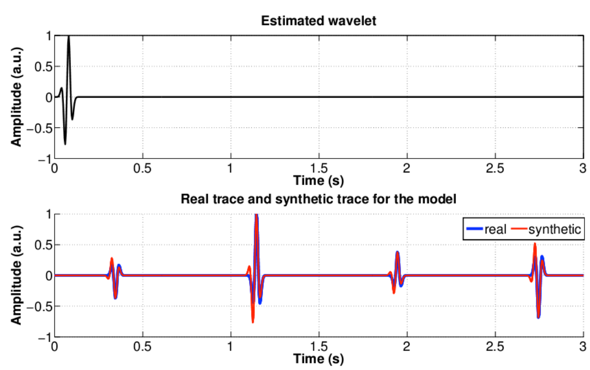

Figure 5 - The estimated wavelet by the predictive deconvolution for the modeled seismic trace and the comparison between the real trace and the synthetic trace. The correlation coefficient between the traces is 0.962.

It is possible to observe that the deterministic method produces a more accurate wavelet than the statistical method by the predictive deconvolution. It happens because the deterministic method uses both data, from the well log and from the seismic. The statistical method to estimate the wavelet is based on assumptions made about the characteristic of the wavelet (minimum-phase) and the reflectivity of the earth (random process), generating a statistical model for it purely based on mathematical tools. Therefore, this difference of accuracy of the wavelets is also expected when applying the algorithms to the real data set.

Application on real data set - Viking Graben

The real data used in this study comes from the northern North Sea basin, Viking Graben. It is a north-south trending linear trough straddling the boundary between the Norwegian and UK sectors of the northern North Sea (MADIBA; MCMECHAN, 2003). The seismic line consists of 1001 shot records, each shot recorded on 120 channels for six seconds. The sample rate is of 4ms. An air gun provided the seismic source. The source and receivers are separated by 25m. The seismic data has 2142 CMPs with 1501 samples each. The well log information is from a well designed as Well A located on the CMP 808 on the seismic line. Due to unregistered points or noises in the density and sonic data, it was necessary to edit these logs in order to do not deal with wrong values. Because of that, a despike process was applied on well A (Figure 6). Three-component zero-offset vertical seismic profile were recorded in well A (KEYS, 1998). In this case, the Vertical Seismic Profiles (VSP) are useful in the well tie process once they provide a link between wells and seismic at the correct scale. With the measurement of the arrival time for the direct wave arrival, at each level in depth, it is possible to establish a time-depth relationship. The time-depth relationship in this study was generated by time picks of the VSP direct arrivals. Figure 7 shows the time-depth relationship for the well A.

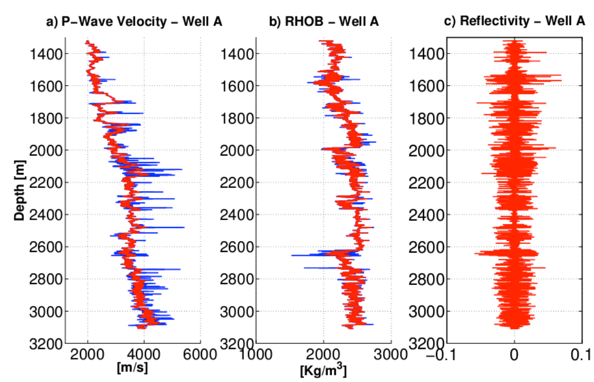

Figure 6 - The logs used to construct the synthetic seismogram at well A.From left to right: sonic log (P-wave velocity), density log and reflectivity log. The red lines are the output logs from the despiking process.

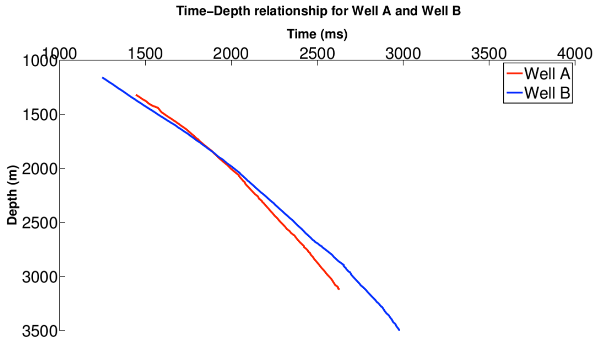

Figure 7 - Time picks of the VSP direct arrivals that constitute the time-depth relationship for the wells of the Viking Graben data set. The well A was the one used in this study.

The first analysis consists to compare the results of the statistical and deterministical wavelet estimation and the respective well to seismic tie on a migrated seismic section concerning the location and information of the well A. The procedure to estimate the wavelet through the predictive deconvolution was the same as the one applied on the synthetic model: a segment of the seismic trace is selected and on that segment the predictive deconvolution is performed with the proposal to separate the signal related to the seismic source and the signal related to the reflectivity of the earth. The algorithm gives the best pair prediction lag (α) and operator length (N) that produces the best wavelet for the synthetic trace. To measure the quality of synthetic trace, we correlate it with the real trace. We followed the recommendation of White (2003), and we selected traces on the vicinity of the posted well location (CMP 808) to find the best match, once it is common for the best match to do not be located on the well location. Figure 8a shows that the best well to seismic tie location with the highest correlation relying on CMP 809 instead CMP 808, as mentioned in Keys (1998). Figure 8b shows the prediction lag versus correlation coefficient. As can be noted the highest correlation corresponds to the prediction lag of 13ms. Finally, the Figure 8c shows the operator length versus correlation coefficient. In this case the highest correlation yielded was with a operator length of N=118ms. Figure 9a shows the estimated wavelet based on the statistical method. Figure 9b shows the synthetic seismogram (red) aligned to the seismic trace (blue), with a correlation of 0.658. In order to have a frequency content on the synthetic trace similar to that on the real seismic trace, the second approach concerning to the predictive deconvolution was to compute a average wavelet. It was selected four different segments along the seismic trace to perform the predictive deconvolution and consequently four wavelets were estimated. These wavelets as well as the average wavelet is shown in Figure 10. The wavelet used to compute the synthetic trace was an average among all the four estimated wavelets. Figure 11 illustrates the average wavelet and the convolution of it with the reflectivity of Figure 6. The average estimated wavelet method yield better results on the quality of the tie. The correlation coefficient increased from 0.658 (using the predictive deconvolution of one segment alone - see Figure 9) to 0.674 when using the average statistical wavelet as shown at Figure 11.

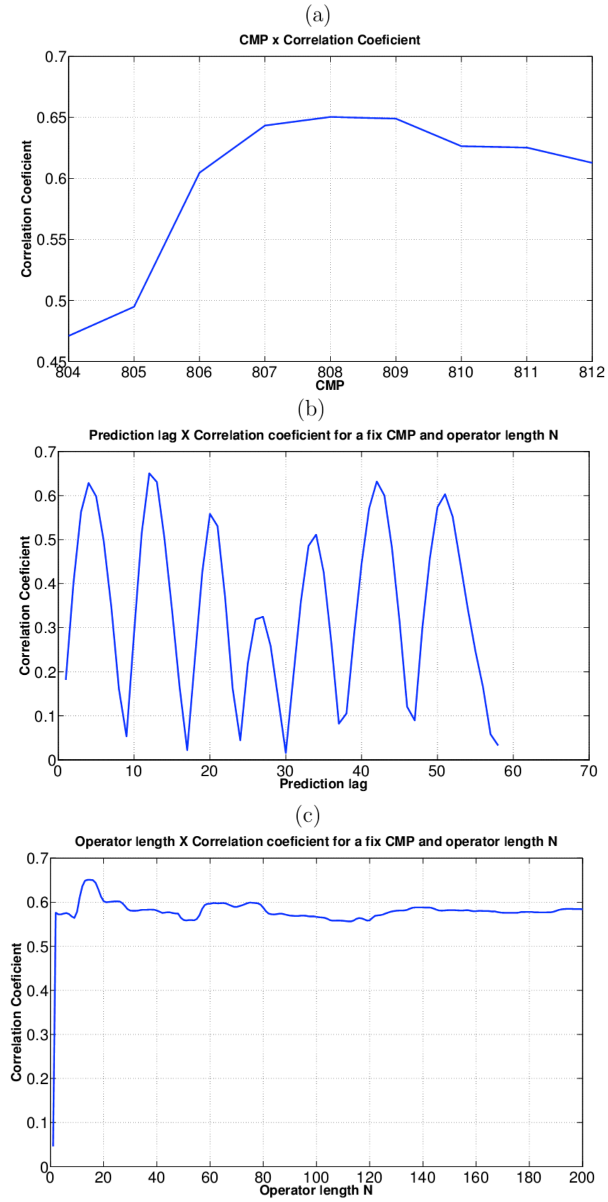

Figure 8 - (a) Correlation Coefficient x CMPs for the Well A with the migrated seismic section and the predictive deconvolution to estimate the seismic wavelet. The best match location is on CMP 809, with a correlation of 0.658. (b) Prediction lag x Correlation Coefficient for the CMP 809. (c) Operator length x Correlation Coefficient for the CMP 809.

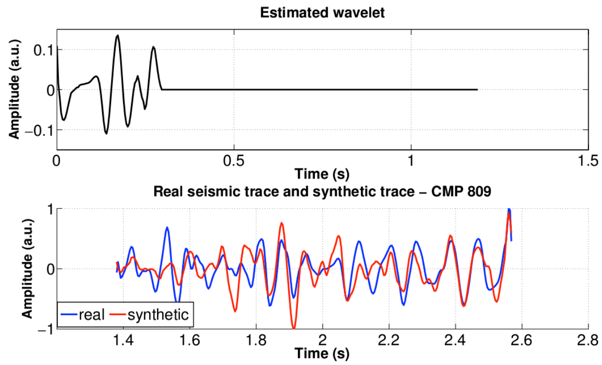

Figure 9 - The wavelet estimated through the statistical predictive deconvolution method and the synthetic and real migrated seismic trace on CMP 809. The correlation coefficient is 0.658.

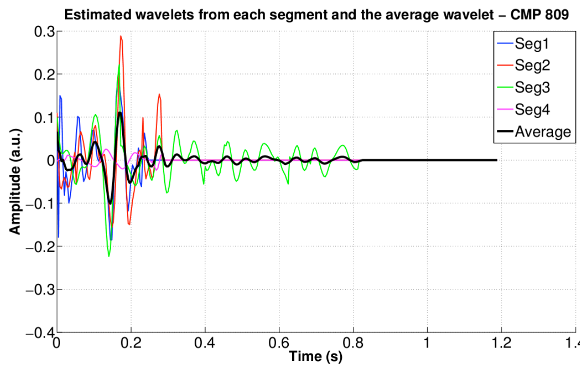

Figure 10 - The wavelets estimated through the predictive deconvolution from each segment of the migrated seismic trace and the average wavelet used to compute the synthetic trace.

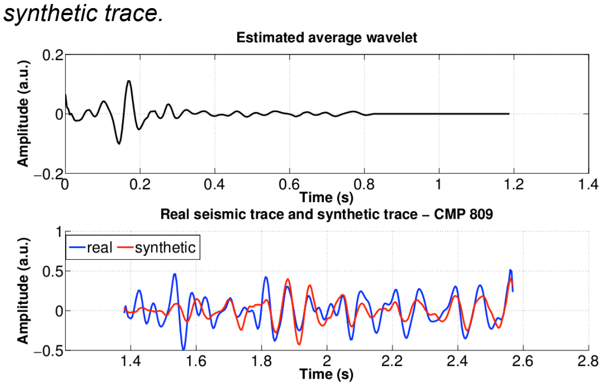

Figure 11 - The average statistical wavelet estimated and the synthetic and real migrated seismic traces for the CMP 809. The correlation coefficient is 0.674.

Finally, the last procedure made was the deterministic estimative of the wavelet. It uses both the seismic data and the well logs to estimate the wavelet that leads to the best match of the synthetic to the real seismic trace. As shown at Figure 12 the best match also relies on CMP 809. Figure 13 shows the deterministic estimative of the wavelet as well the comparison between the real and estimated trace. Through this method there was a improvement of the well to seismic tie, with a correlation of 0.712.

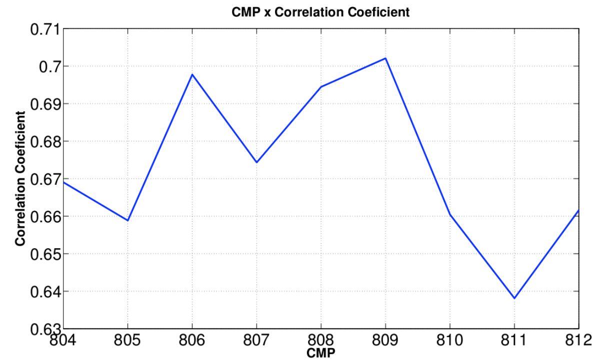

Figure 12 - Correlation Coefficient x CMPs for the Well A with the migrated seismic section through the deterministic method to estimate the wavelet. The best match location is also on CMP 809, but the correlation coefficient using the deterministic approach is higher than that of the statistical approach, it is 0.712.

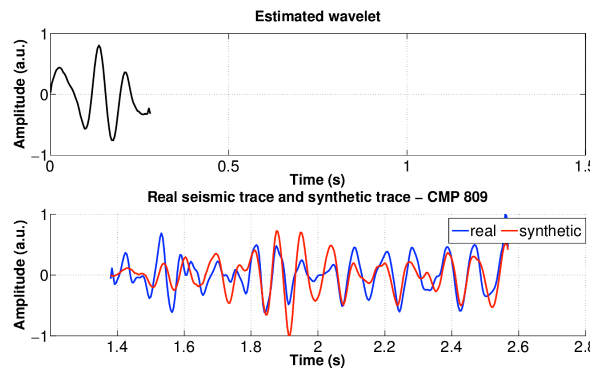

Figure 13 - The wavelet estimated through the deterministic method and the synthetic and real migrated seismic trace on CMP 809. The correlation coefficient is 0.712.

Discussion and Conclusions

In this study we compare the quality of the well to seismic tie made from different algorithms to estimate the wavelet (the semi automatic deterministic and statistical estimative). The application on the synthetic data shows that both methods were satisfactory on the seismic wavelet estimative. In the case of the synthetic examples, this is confirmed by high values of correlation coefficient which reached values higher than 0.90.

On the real Viking Graben data set, the predictive estimation, based on the classical assumptions of the convolutional model produced a good estimative on the well to seismic tie. All of them with a correlation above 0.60. It is expected that the average wavelet from the predictive deconvolution produces better results because it was computed from wavelets estimated from different segments of the seismic trace, therefore, its frequency content tends to be similar to that of the real seismic trace. The results on well A confirmed this supposing. The correlation coefficient increased from 0.658 to 0.674 when using the average wavelet on the migrated seismic section.

The deterministic estimative of the wavelet tends to produce better results on the tie, once it is based on the well log data and on the seismic data. However, the need to use both well logs and seismic data in corresponding scales, makes it more sensitive to errors on the time-depth relationship. The deterministic estimation of the wavelet produced the best result with a correlation of 0.712.

As different methods to estimate the wavelet leads to different wavelets, it is not uncommon for the best match location to be different with different approaches, although on our application on the real data set the best match location was the same for all methods, on CMP 809.

Acknowledgments

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