Well to seismic calibration: a multiwell analysis to extract one single wavelet

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Summary

This paper focusses on the well to seismic calibration for wavelet extraction. We describe a methodology where the results at all wells are analyzed simultaneously to derive if possible one single wavelet. Two field cases are presented, one where no particular problem was encountered during the process and the other where the calibration step highlighted serious processing problems.

Introduction

The increasing use of 3D seismic data for quantitative reservoir characterization arises the crucial importance of a reliable well to seismic calibration. The single link existing between hard well data and soft seismic data is the wavelet; as a consequence, it should be carefully estimated. From a general point of view, two main approaches are used to estimate wavelets. The first one consists in estimating a wavelet at each well location, and somehow deriving a wavelet field covering the seismic data field. The second one tries to globally conciliate the seismic data and the well data to derive one unique wavelet valid on the whole field. That "multiwell" approach ensures the consistency of the data everywhere - it can even be used as a QC of the data - and reduces uncertainties attached with the wavelet.

We will first describe the"multiwell" calibration methodology; we will next apply it to two data sets, one where the results were satisfactory and the other where the well to seismic calibration revealed some important processing issues, preventing from using the seismic data for a quantitative interpretation.

Methodology

The well to seismic calibration process is divided into two main stages; the first one uses seismic data only and is aimed at evaluating a preliminary zero-phase wavelet whose amplitude spectrum is representative of the seismic data. The MC (MultiCoherence) analysis permits the extraction of both signal and amplitude spectra from the seismic data; it is based on correlation theory (Dash and Obaidullah, 1970) where the main assumption is that the signal correlates from trace to trace whereas the noise components do not correlate with any other component on any trace.

The second main stage uses both well and seismic data to analyze the correlation between a synthetic trace computed from impedance log and portions of seismic traces in a minicube surrounding the well (Déquirez et al., 1995). The process is divided into four steps. The first step is independant of the signal spectrum; the zero-phase signal computed from MC analysis is used to build a synthetic trace and its autocorrelation. The time shifts between the synthetic trace and the seismic traces are computed at each trace of the minicubes from the maximum of the envelope of the crosscorrelation between synthetic trace and the surrounding seismic traces. From this step 1, it is then possible (1) to detect a global time shift that could be globally applied to all logs, and (2) to have a first look at the quality of the data and detect anomalies or particularities of a minicube dataset (noisy data, strong dip...).

The result of the second step is the optimum phase value of the wavelet, which is valid for all the wells. The procedure consists in computing a set of synthetic traces where the phase varies from 0 to 360. The correlations beetween each seismic trace and the set of synthetic traces are computed and only the best one - in terms of correlation coefficient - corresponding to the best phase angle, is kept. This procedure is run for all seismic traces around each well and the resulting phase values are displayed in the form of an histogram where an "optimum" phase value, i.e an unimodal peak with good enough correlation coefficients, should emerge. This phase value is a consensus value, roughly satisfying all the well neighbourings.

Now that the phase value is fixed, the energy of the extracted wavelet at each seismic trace is taken into account to choose the "optimal location" of the impedance log in the minicube around its initial location (step 3). The time shift to apply to the log, the ratio of the amplitude of the real trace to the amplitude of the synthetic trace - related to the energy of the extracted wavelet - and the corresponding time shift are calculated for each seismic trace. Once again an histogram view of the amplitude ratios should present an unimodal peak corresponding to a satisfying ratio value for all the wells. The optimal location of the log is chosen from a mini location map around the well, color-coded with the amplitude ratio value (or any other relevant information such as correlation coefficient).

In the step 4, optimal wavelets are extracted at each optimal locations; they are compared, but should look very much alike since they have the same phase, and almost the same amplitude. The final wavelet can be an average of these optimal wavelets, or can be slightly modified through another step where the phase can be readjusted.

Examples

We applied this methodology on a small field (2km x 5km, 77 lines and 200 CDPs) where log data were available at

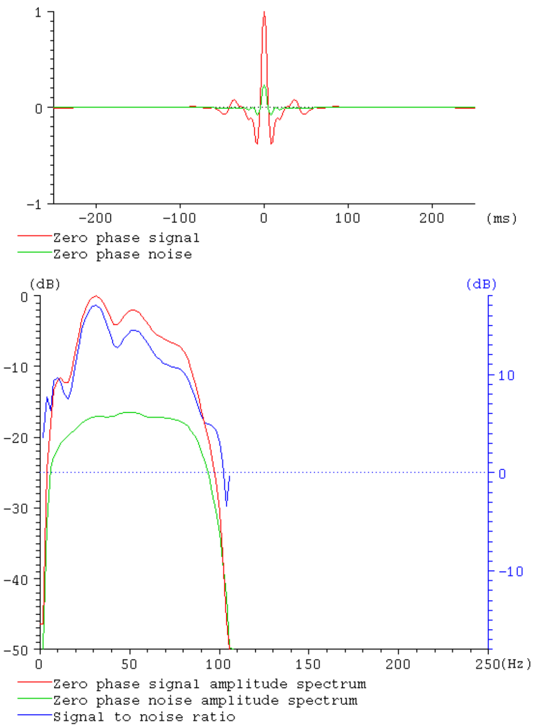

Fig. 1: MC analysis

4 wells. We feel that an important part of the calibration work is to check carefully the quality of the log data and especially the depth to time conversion (use of checkshots, Nyquist filtering before resampling,..); in our case we could trust the quality of the impedance logs in time sampled at the seismic sampling rate (1ms). We run the first stage of the study, i.e. the MC analysis. The resulting zero phase wavelet is plotted in red on the top of 1. The bottom part of the figure shows the resulting signal and noise spectra. The signal to noise ratio is good and the seismic bandwidth is approximately 20 to 70Hz.

The log data is now used to run the four steps of the multiwell calibration. Results of the step 1 show that a global shift of -8ms can be applied to all impedance logs before running the next step. The step 2 results are presented on Figure 2. The upper right part of the figure shows a crossplot of correlation coefficients vs. optimum phases. Each square corresponds to a seismic trace and is color-coded according to the well it is related to. Two modes can be detected in the histogram of the correlation coefficients; the lower mode corresponds to the blue and yellow wells that do not correlate as well as the two others, even if many detected phases - especially for the yellow well - belong to the nice unimodal peak of the histogram of the phases. An optimum phase of 215 degrees can be chosen for the 4 wells with a rather good correlation coefficient, in particular for green and red wells. The left lower part of the figure shows a mini location map around well 3 (in green in the crossplot), where it appears that the detected phases are very homogeneous in this zone.

We can now go on to the step 3 with the phase fixed at 215 degrees. In this step, we recall that we are looking for the best location of the log in the mini seismic cube, considering the ratio of the amplitude of the real trace to the amplitude of the synthetic trace, which is called normalisation coefficient on the Figure 3. The corresponding histogram shows two modes, but a compromise can be found with sufficiently good correlation coefficients for a ratio around 0.67. The mini location map, color-coded with the ratio values is presented for well 1 (in red in the crossplots). The optimal location for the log is automatically detected at the position of the star, but the user can impose his own choice.

The final result is presented on Figure 4 for the green well, where the synthetic trace computed with the optimal wavelet on the side of the figure is included in the seismic line at the optimal location. The calibration at this well is very satisfying, with a good correlation coefficient (0.85), but the extracted wavelet leads also to good correlations at the other wells.

The results of the step 2 on another case are presented on Figure 5. From the histogram of the phases, it appears impossible to fix a phase value that could be valid for all the wells. We have carefully checked the edition and processing of the log data and their quality could not be questionned. Going back to the seismic data processing, it appears that there were important difficulties to remove residuals in the seismic; this could explain the poor quality of the seismic data, and as a consequence of the seismic to well calibration. In this kind of case, we are reluctant to go on in deriving any quantitative geophysical interpretation from the data, since the wavelet cannot be controlled.

Conclusion

We have presented a methodology for wavelet extraction from seismic data. Compared to other works, our methodology provides a single wavelet, which represents the best compromise for the whole field. This multiwell calibration is also a required step to ensure data consistency and data quality, especially when the seismic amplitudes are to be used for any quantitative reservoir characterization method (stratigraphic inversion, seismic attributes, constraints for stochastic reservoir model...).

References

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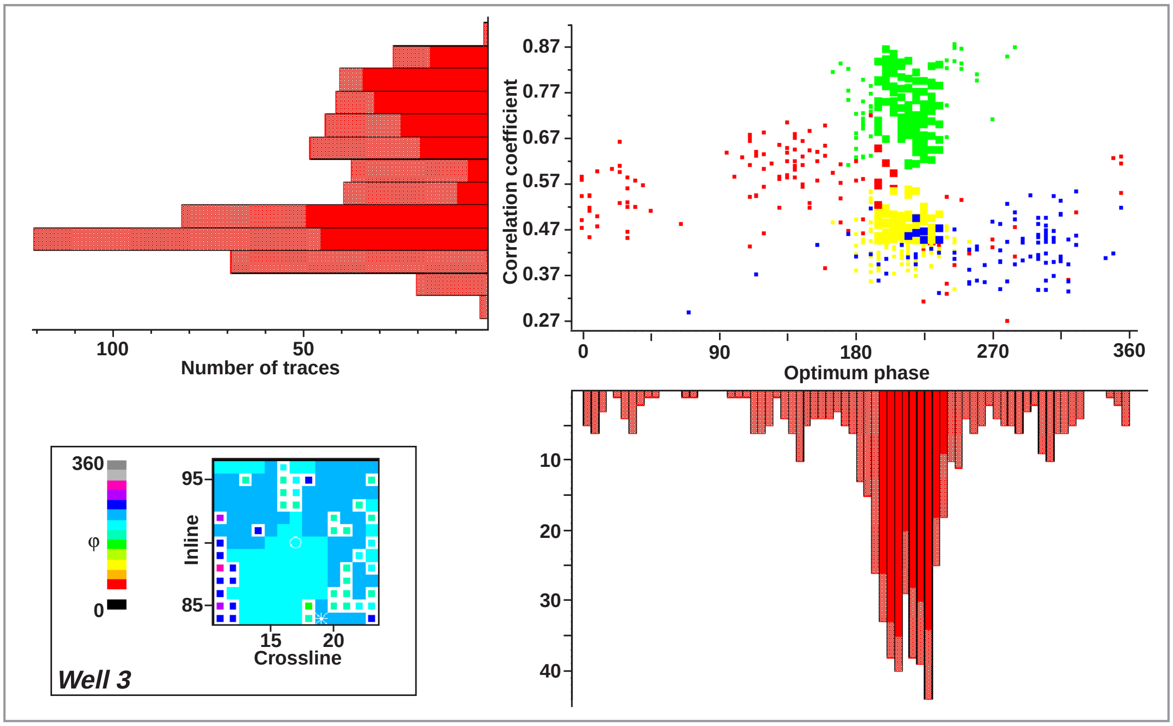

Fig. 2 Common phase detection (step2)

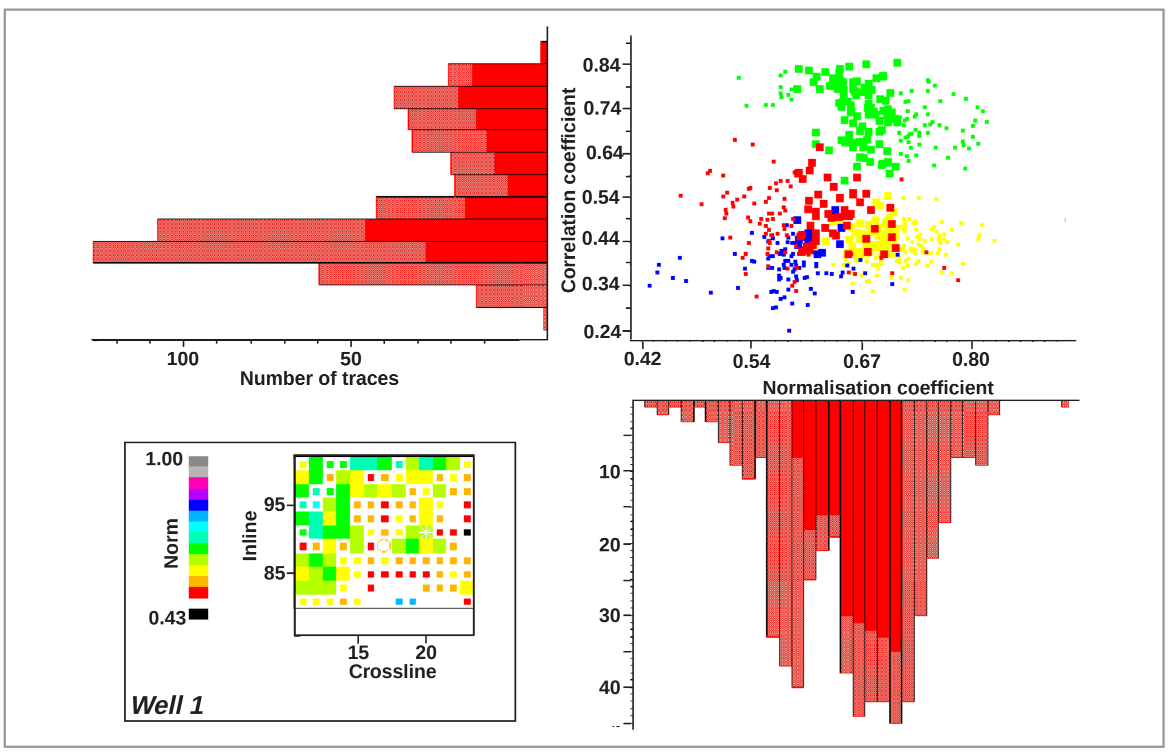

Fig. 3 Energy detection and optimal location choice (step 3)

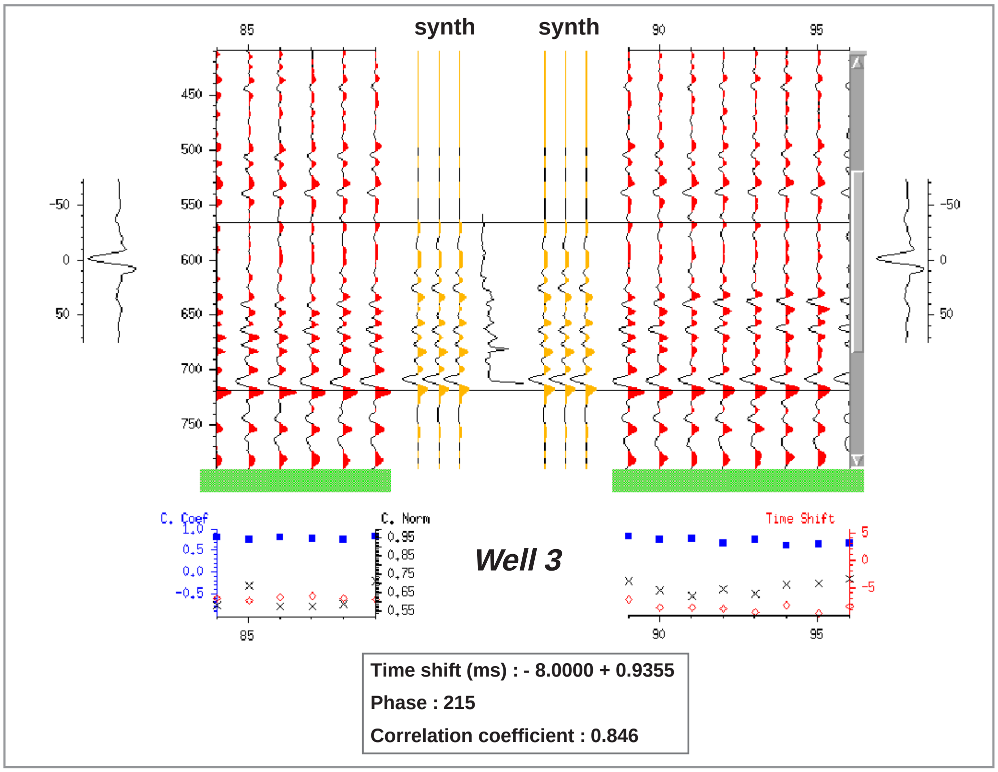

Fig. 4 Final calibration at well 3

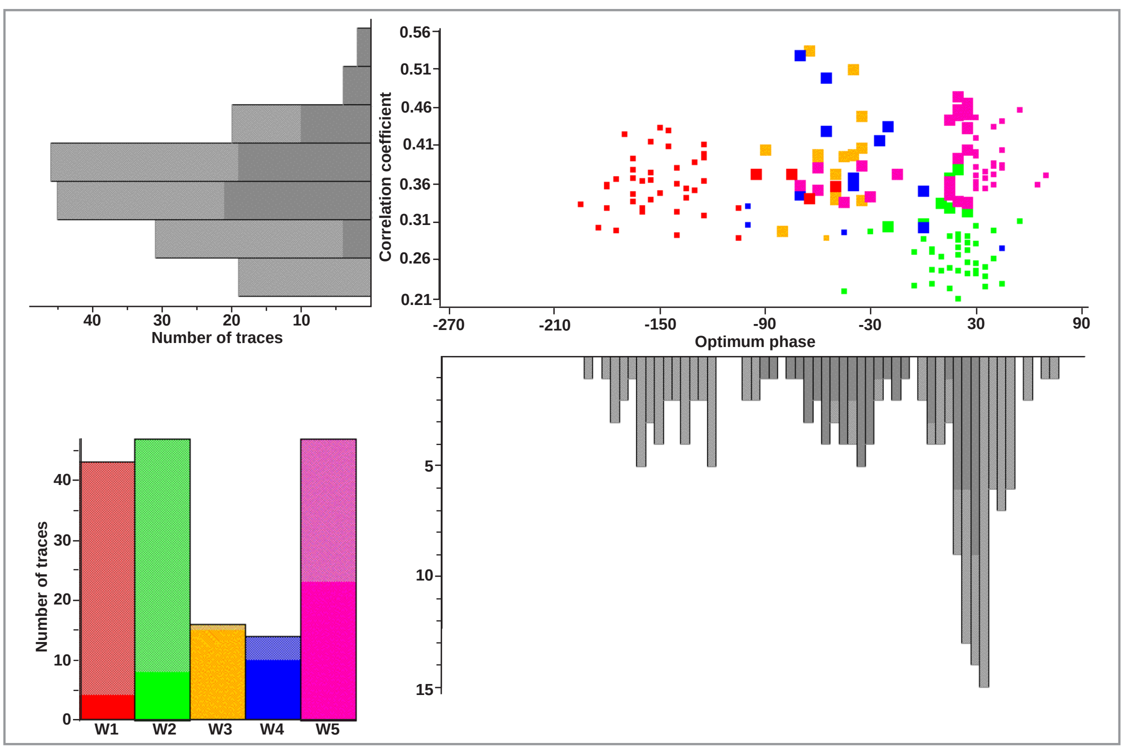

Fig. 5 Another case : example of calibration problem