High Resolution Processing for Time-lapse Seismic

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Abstract :

Time-lapse seismic technology is moving from measurement of qualitative variations to quantitative analysis of fluid saturation and pressure variations. Increasing the resolution of time-lapse seismic data relative to the reservoir body scale offers the possibility of even more accurate measurements. The resolution improvement is directly dependent on the capacity to recover the high frequency content of the seismic measurement. In this paper, we investigate a data processing methodology that provides a 4D seismic signature with an extended frequency bandwidth. We pay particular attention to the seismic data preconditioning in order to remove random noise and spatial correlated noise, such as the acquisition footprint, which can contaminate the seismic high frequency content. Using a geostatistical technique, we apply the concept of common seismic cube derived from two adjacent seismic angle stacks. The common seismic cube does not include the acquisition imprint and has an improved signal to noise ratio, especially for the high frequencies. The concept of common spectrum is used to design two symmetric matching operators in order to increase the repeatability of the high frequencies. Once the data have been preconditioned, we use an innovative technology exploiting the spatial coherence of the seismic information with predefined reflector constraints to solve a sparse reflectivity distribution. A North-Sea example shows the benefits of the new high-resolution time lapse processing workflow.

Introduction

Today, time-lapse seismic technology has become an effective reservoir management tool. Time-lapse seismic is used to monitor fluid flow and detect undrained reservoir compartments. Geophysicists have taken the challenge of merging the information available from time-lapse seismic with the output of reservoir simulation models and the available reservoir knowledge. Optimizing information across the disciplines faces a major problem of scales and uncertainties. Improving the vertical seismic resolution is a key factor in this overall reconciliation.

Time-lapse studies show seismic variations below the "resolvable limit"[1] defined with the Raleigh criteria of ¼ of the dominant wavelength. Figure 1 illustrates the benefit of increasing the high frequency content of the signal to improve the resolution of the 4D signature. The high frequency signal presents a better resolving power for small time variations of the reflector and reduces the tuning effect.

Whatever the methodology used to extend the seismic signal bandwidth, the high frequency recovery process requires an efficient noise removal filter for data preconditioning. Random noise is obviously an important source of disturbance for 3D seismic data, but 4-D seismic repeatability forces us to consider noise with a second order of magnitude such as acquisition patterns.

To tackle spatially correlated noise like acquisition footprint (commonly visible as stripes) we use a spatial 2D geostatistical operator, which is frequency dependant [2]. Working with a larger bandwidth in the time-lapse context forces us to revisit the conventional frequency matching procedure as well. We propose an approach using symmetric matching operators in order to increase signal repeatability at high frequencies.

Acquisition footprint and random noise removal with seismic angle stacks

We make use of the redundancy of information between two consecutive angle stacks to compute a common seismic cube, which is free of acquisition imprint. The common seismic cube is computed in the frequency domain. A spatial 2D factorial co-kriging operator is designed from variograms and cross-variograms for each frequency. The acquisition imprints, which are uncorrelated but spatially organized, and the random noise can thus be removed at each frequency. A 3D common seismic cube is constructed from the spatially correlated information. This common seismic cube is considered as an intermediate angle stack. It exhibits an improved signal to noise ratio as well as better lateral continuity, especially at high frequencies. This process works as an efficient noise attenuator and destriper. Figure 2 illustrates the high frequency recovery process.

Matching the high frequencies

The conventional matching approach is no longer valid for the extended bandwidth time-lapse seismic data. As the high frequency content of the initial seismic data has a poor signal to noise ratio compared to the dominant frequency, matching one dataset to the other one tends to decrease the repeatability of the high frequencies. In minimizing the difference in a least square sense, the standard matching operator is built from cross and auto-correlated estimated signals. Consequently, the matching operator has an intrinsic noise reduction effect (as the noise is uncorrelated). The fact that the filter is applied only to one dataset unbalances the signal to noise ratio for the high frequencies of the two vintages. To avoid the asymmetry of the usual matching filter, two complementary matching operators are designed for each input in order to minimize their differences with a common spectrum. This common spectrum contains a better signal to

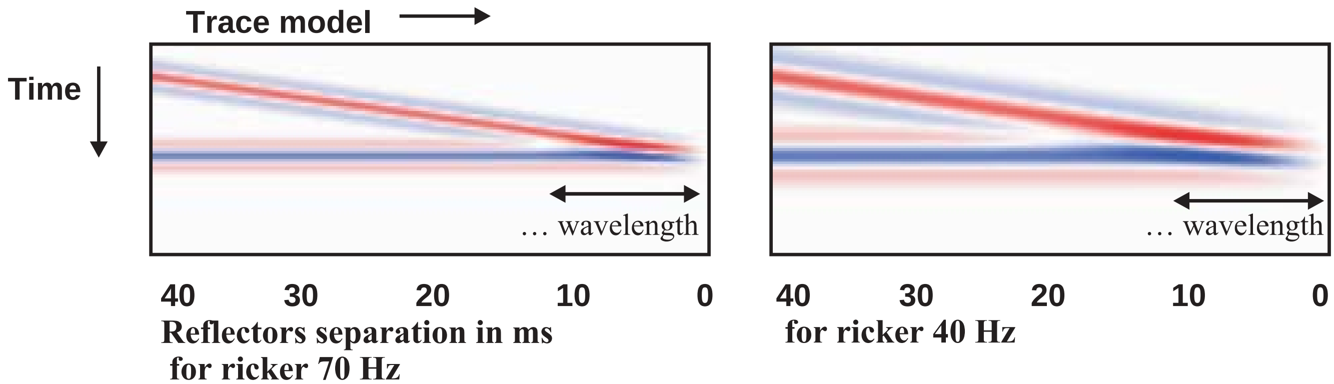


Fig. 1: The panels represent a 1D seismic difference model with a gradual decreasing distance/time between two reflectors (same reflection coefficient). The reflector separation varies from 40 to 0 msec with a step of 0.4 msec. The tuning effect is reduced for the high frequencies.

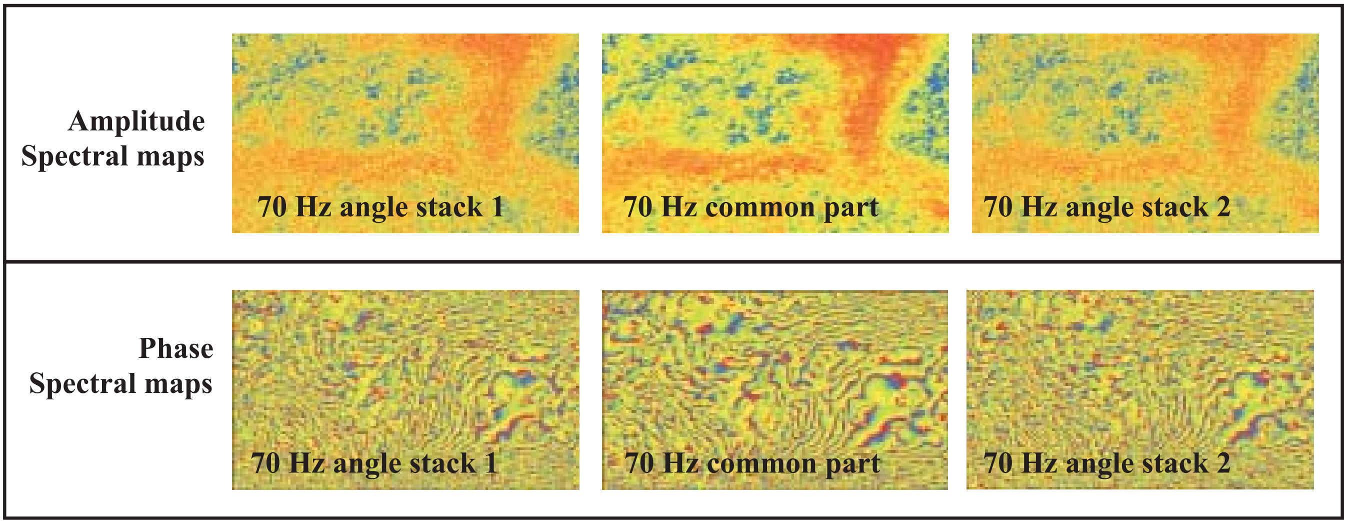


Fig. 2: High frequency recovery after a factorial co-kriging operator applied on phase and amplitude spectral maps. The frequencies of the common part, corresponding to an intermediate partial stack, are constructed from the coherent information.

noise ratio per construction and it leads to an increase of signal repeatability at high frequencies.

4D high frequency broadening

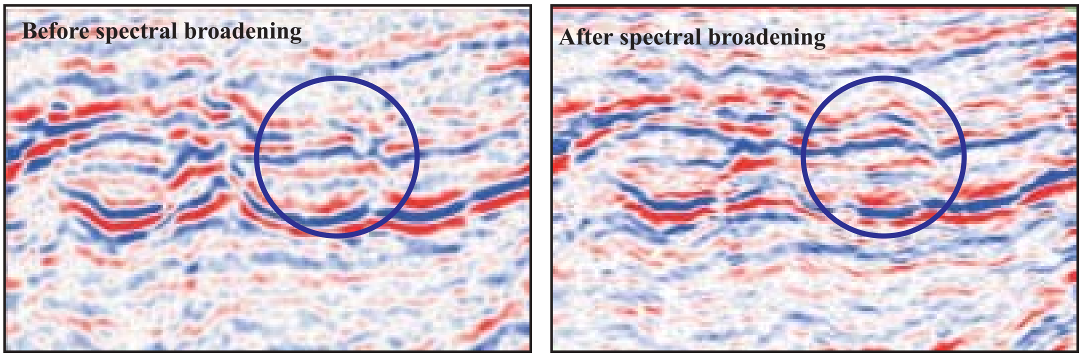
CGG has developed an innovative technology to allow identification of underlying reflectivity and thus to control the high-frequency operator required for maximum bandwidth. The algorithm is based on constrained sparse deconvolution with a predefined number of reflectors and a known wavelet. Using a 3D inversion engine, the time-position and the amplitude of the reflection coefficients are optimized regardless of the seismic sample rate consequently allowing the frequency enhancement process. This technology has been extended in a time-lapse context using two phases: the first phase is designed to solve the statistically common/invariant part of the time-lapse seismic data. The result is given as the input model of the second phase, which focuses on the determination of the residual part of the two vintages.

Example with Time-lapse North-Sea dataset

The pre-processing sequence and the high frequency broadening process have been applied on timelapse seismic data acquired on the Gryphon Field (North Sea). Starting with the different seismic angle stacks of the two vintages, the principal processing stages can be summarized as follows:

1. Remove the random and correlated noise using coherent information of adjacent angle stacks.
2. Apply two local symmetric matching filters converging to a common spectrum.
3. Compute the reflectivity model of the common/invariant seismic cube between the two vintages, (one for each pair of intermediate angle stacks computed in Step 1).
4. Compute the high resolution seismic for the two vintages by perturbing the common model calculated in Step 3. The difference is calculated for each resulting angle stack.

Figure 3 shows the vertical seismic sections of the common/invariant seismic cube between the far angle stacks of the two vintages. Poorly separated events in the input seismic data appear more clearly on the processed output data. The resolution improvement of the 4D signature is illustrated in Figure 4. The oil-water contact (OWC) and the gas-water contact (GWC) are better defined after the high frequency



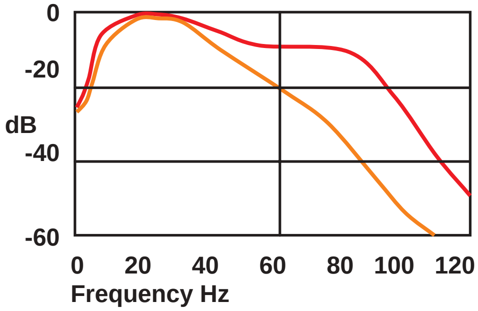


Fig. 3 : Seismic section before and after spectral broadening and their corresponding amplitude spectra (before orange line, after red line). The bandwidth enhancement corresponds to 20-30 Hz gained by 20 dB. Note the ability to identify some reflector and the resolution improvement.

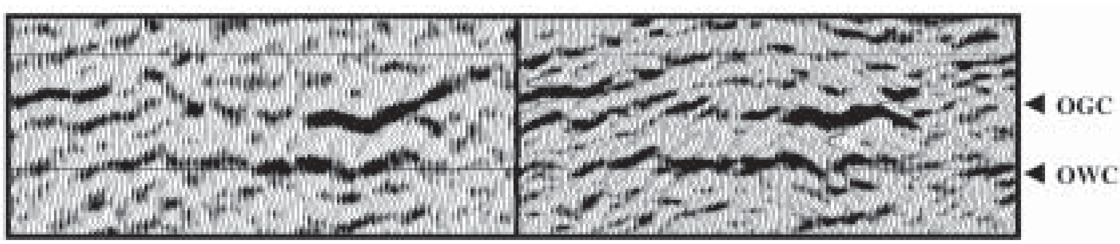


Fig. 4 : 4D signature before and after high frequency broadening. The resolution of the variation of the oil-water contact and the oil-gas contact are improved after the high frequency enhancement. Some lateral continuity ambiguities of the 4D signature can be clarified.

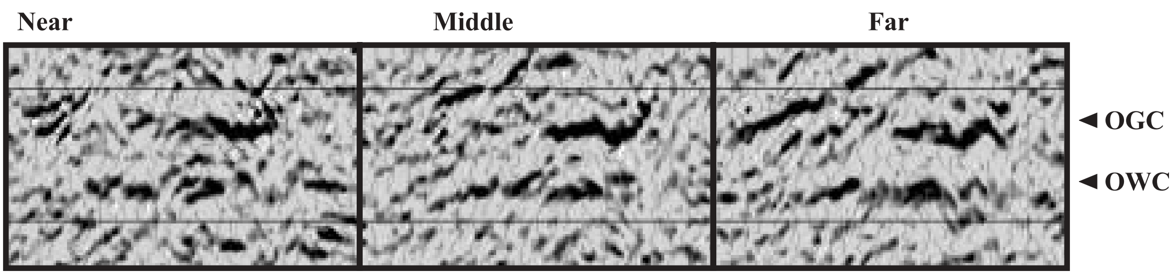


Fig. 5: High-resolution 4D signatures on different angle stacks. Near, Mid, Far

enhancement and some lateral continuity ambiguities of the 4D signatures have been clarified. Figure 5 displays the 4D signature within the angle of incidence (Near, Middle and Far angle). As each angle has been processed independently, it shows the consistency of the results. The resolution improvement facilitates the quantitative 4D analysis of this dataset.

Conclusions

Controlled spectral broadening methods show a significant potential to increase the resolution for time-lapse seismic datasets. However, high frequency enhancement needs to be monitored carefully, as extending the bandwidth beyond certain limits may create potentially erroneous events. To avoid this problem, we propose a specific seismic data preconditioning methodology in order to remove random and spatially correlated noise impacting the high frequencies. The repeatability issue is tackled with an adapted matching procedure calibrating each dataset equally. Improved 4-D vertical resolution opens the door to an easier integration of time-lapse seismic information with reservoir models and production data.

References

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