4-D denoising and spectrum broadening: application to a deep-water GOM reservoir

Ed Mozer, Samson Lone Star, Igor Popovic, Anthony Vassiliou, Lionel Woog, GeoEnergy, Inc.*

SUMMARY

Multidimensional denoising was applied to 3D PSDM data to enhance the seismic evaluation of stacked subsalt reservoirs in the deepwater Gulf of Mexico (GoM). The principal objective of the evaluation was to delineate the aerial extent of the reservoirs and obtain seismic attribute-based pay thickness estimates. The target reservoirs, which were the objective of an exploration and appraisal program, had many of the imaging challenges common to subsalt reservoir evaluations. In particular, interpretation of the subsalt events were compromised by multiples associated with the top and base salt interface and migration swings below the salt canopy edge. The program economics and drilling timeline would not support a costly and lengthy reprocessing effort to address the noise problem. Cost and time conscientious technologies were needed to produce accurate reservoir interpretations without sacrificing data integrity. To achieve this objective two technologies were applied: 4-D adaptive denoising and 3-D spectrum broadening. Four-dimensional denoising was applied to the pre-stack depth migrated angle gathers available for the area. Subsequently the resulting denoised full-angle stack volume was spectrally broadened. In this case study we demonstrate the robustness and effectiveness of 4-D Denoising and 3-D spectrum broadening in attenuating coherent noise, delineating the reservoir, and obtaining accurate pay thickness estimates.

INTRODUCTION

There are several advantages of multidimensional denoising with adapted waveforms, when compared to traditional coherent noise attenuation. First, the method employs adapted waveforms and not a fixed mathematical basis. Second, the method estimates iteratively a model of the signal and of the noise, thus allowing for a gradual separation of signal and noise. Third, adapted waveform denoising works in all spatial dimensions simultaneously, for example, for PSDM gathers on angle, inline, crossline, and depth. The added dimension provides an additional degree of flexibility to the iterative estimation of signal and noise.

During the last few years there have been substantial developments as well in the area of spectrum broadening (Little, et. al., 2005). Spectrum broadening increases the seismic bandwidth, generating only geologically meaningful results. The generation of the geologically meaningful results was also confirmed in one case study carried out by spectral inversion, in which the same layering solution was generated before and after spectrum broadening (Partyka, 2005). When inverted the spectrum broadening results yield high resolution acoustic impedance estimates.

MULTIDIMENSIONAL ADAPTIVE WAVEFORM DENOISING

Denoising with wavelet packets is achieved by picking a wavelet packet basis or collection of waveforms in which the desired components of the signal are well represented and the undesired components of the signal are poorly represented. Well represented components offer easily separable large wavelet packet coefficients relative to the undesired or noise components small wavelet packet coefficients. Using an appropriate thresholding function, the small noise coefficients can be set to zero, and a clean signal can be rebuilt from the remaining large coefficients. This approach is suitable for the attenuation of incoherent noise as that components energy will be distributed across many small terms, and an entropy cost-function will provide a straightforward best-basis search criterion (Averbuch et al, 2001, Coifman, 1997)

In seismic data processing practice, however, where the noise is often highly coherent, such a simple approach will not yield satisfactory results. There simply may not exist a basis that can appropriately model the desired features of the signal without also modeling some of the undesired ones. In particular, where energetic coherent noise may be obscuring low-amplitude signal detail, thresholding is likely to cause damage to those signal components one wishes to preserve. In order to deal with such difficult scenarios we perform an iterative denoising process, effectively deriving and optimizing the signal and noise analyses simultaneously. We perform a first analysis to obtain an approximate signal model, possibly at the cost of suffering some loss of signal energy and/or some noise still lingering in the signal. Upon reconstruction we perform another analysis on the residual of the first analysis to obtain as signal-free a noise model as possible, even at the cost of not capturing all the noise energy in it, and/or allowing some signal to remain in the noise. The process is iterated as many times as needed to achieve a satisfactory separation of the two models, as shown schematically in Figure 1 (Woog, et al. 2005). In very difficult situations a complete separation may not be possible. In the hands of a capable operator, however, the process still allows for fine-grain parametric control to obtain a result that may not be achievable with other denoising methods.

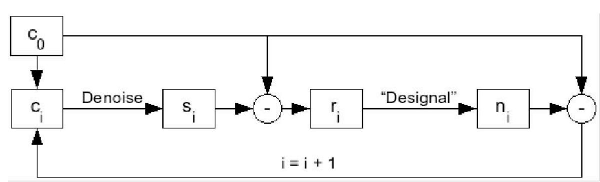

Figure 1: Iterative signal and noise modeling with adapted waveforms (c_0 = noisy data, c_i = data at iteration I, s_i = signal model, r_i = residual, n_i = noise model.

SPECTRUM BROADENING METHOD

The spectrum broadening technology has been applied over the last few years in very diverse areas of the world extending the temporal bandwidth of the 3-D seismic data. The method uses the low and medium frequency amplitudes to estimate the high frequency amplitudes by virtue of small 3-D spatio-temporal windows in which the transfer functions between the low/medium frequency and the high frequency amplitudes are developed. The spectrum broadening technology has some very important features:

1. no time shifts of zero-phase reflection events are shifted,
2. the original dynamic range is preserved
3. low-pass band-pass filtering of spectrum broadened data to the original data seismic bandwidth does not generate erroneous events that do not exist in the original data,
4. the relative amplitudes within a volume or between multiple angle volumes are preserved,
5. the layering information, as it is extracted from a subsequent to spectrum broadening product, called singularity volume, matches the layering from the well log information.

INTERPRETATION

Preliminary interpretations of subsalt reservoirs A and B were completed on speculative full-stack 3-D prestack depth migrated seismic (PSDM). The objective of the seismic evaluation was to provide in-place reserve estimates in support of a potential development program.

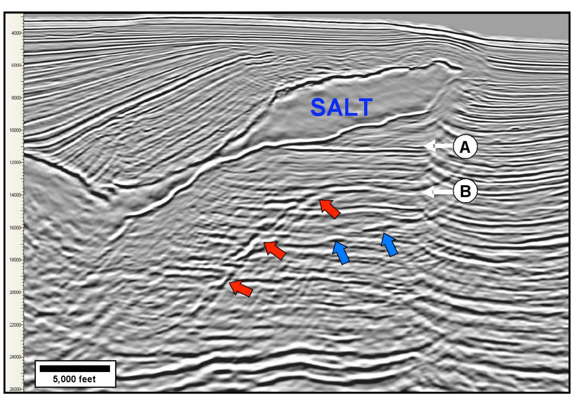

Figure 2: PSDM Inline through reservoirs A and B before 4-D denoising showing salt canopyand base salt multiples (red arrows) and base salt multiples (blue arrows). Migration swings are also noticeable below the salt edge.

Both reservoirs A and B drape across a broad gently plunging faulted-anticline, that truncate up-dip against a salt keel. Amplitude maps and well log analysis clearly supports that the two reservoirs were deposited as channel-levee sands. Top and base salt multiple energy caused disruptions to amplitude continuity, thereby leaving uncertainties in the connectivity of the reservoirs (Figure 2). The severity of the interference varied based on reservoir depth below the salt canopy. Reservoir A, just beneath the salt canopy, did not have appreciable interference from multiples. Interference was more apparent in Reservoir B, which is approximately 2,000 to 3,500 feet below the salt canopy. Common to both reservoirs was the disruption of amplitudes beneath the salt canopy edge caused by migration swings (a common processing artifact).

Following the application of 4-D adaptive denoising, reservoirs A and B were re-evaluated using the denoised full-stack and angle stack (near, mid, and fars) reflectivity data. Example seismic lines with Denoising applied are presented in Figure 3. Although the structural elements of the reservoirs did not change significantly, the interpreter was more confident in the position and extent of the faults on the denoised seismic.

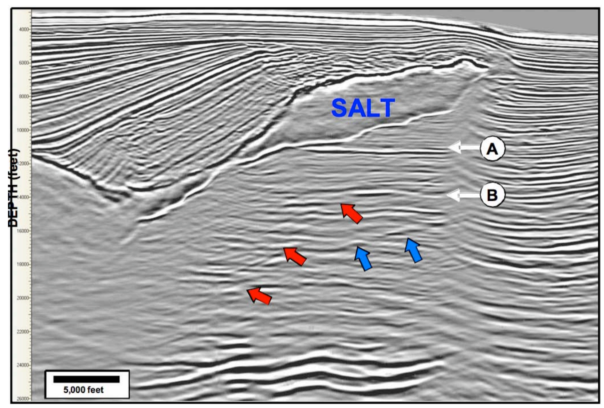

Figure 3: Same PSDM Inline presented in Figure 2 but with 4-D denoising applied demonstrating attenuation of top/base salt multiples.

Spectral broadening was applied to the denoised data in an attempt to improve the calibration of net pay to seismic amplitude. Using the spectral broadened seismic, RMS amplitudes were extracted from the full wavelet (trough onset to peak offset) of the reflectivity data for each the reservoir. Amplitude values at each well take-point were plotted against the net pay counts derived from petrophysical analysis. Figure 4 is a cross-plot of net pay versus amplitude for Reservoir B which had four well penetrations for control. The linear equation displayed in Figure 4 was used to produce a net pay prediction map for Reservoir B. Net pay in a subsequent appraisal well for this reservoir was within 80% of the predicted net pay. Reservoir A had seven subsalt well penetrations for net pay calibration. Calibration results for Reservoir A showed a similar degree of accuracy.

CONCLUSION

Adaptive waveform senoising applied in this case study affectively attenuated coherent noise while maintaining amplitude integrity. From the interpreters perspective, a critical element to the success of this workflow was the timely delivery of final denoised and spectral broadened outputs. Adhering to a strict 30-day turn-around requirement, from delivery of the PSDM gathers to receipt of the final processed data, the interpreter was able to complete detailed reservoir evaluations and provided time-critical direction to a pending development program. This case study also demonstrates that 4-D denoising can be affectively applied to PSDM data, and does not require pre-migration time gathers as input.

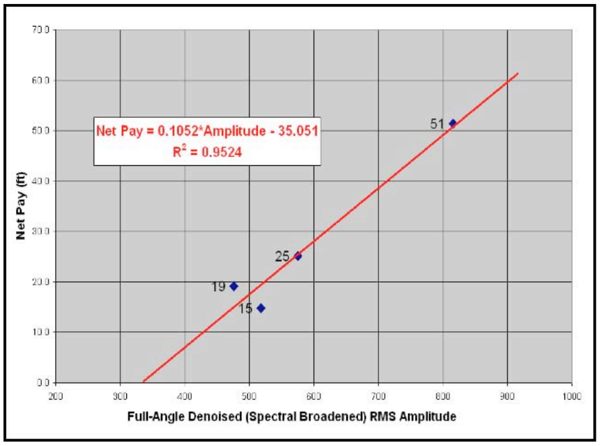

Figure 4: Cross-plot of net pay versus RMS amplitude for Reservoir B using spectral broadened seismic.

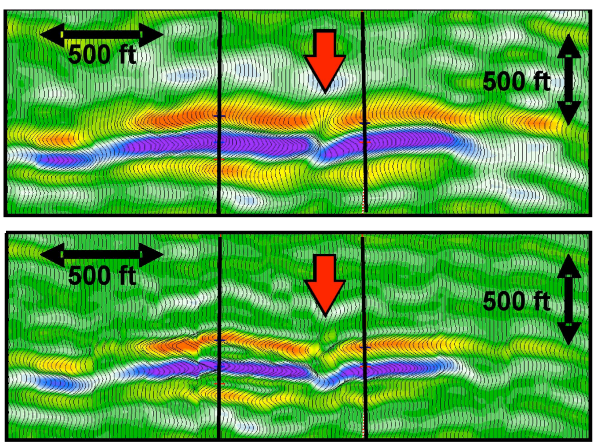

Figure 5: Close-up comparison of Reservoir A before denoising (Top) and after denoising and spectral broadening. Red arrow indicates position of shale-filled channel. Black vertical lines are well penetrations.