Seismic data conditioning is an essential step for facies prediction.

Denis Alexeenko, Ikon Science; Russell Exley, Summit Exploration and Production Limited*

Summary

Advanced seismic techniques such as EEI inversion, simultaneous inversion and so called facies based inversion are now routinely adopted for quantitative reservoir characterization of rock properties. Rock physics provides the crucial link between the quantitative geophysical measurements derived from inversion and geological parameters. However, in order to ensure that rock physics parameters, as encountered in well data, are accurately determined from spatially equivalent seismic data requires specialist processing beyond conventional image orientated workflows. Seismic data conditioning is specifically designed to provide a calibrated and conditioned AVO signal. In this regard reservoir specific processing routines are developed to mitigate multiple, random and coherent noise, over or under-corrected seismic velocities, frequency distortions and other undesirable effects. Synthetics generated at well locations are crucial for quality control at each step of the seismic data conditioning workflow. This paper demonstrates the advantages of performing seismic data conditioning, on a regional (multi-survey) North Sea seismic dataset, prior to reservoir characterization using a facies based inversion.

Introduction

To take full advantage of AVO (amplitude versus offset) inversion techniques seismic data needs to be carefully conditioned so that any variation in amplitude is solely the result of reflection-coefficient changes and not seismic processing artefacts (Chopra and Castagna 2014). AVO gradient in particular is highly influenced by far offset amplitudes, yet provides a key control on the output of Vp/Vs and thereby significantly influences fluid and lithology prediction. Data conditioning routines are therefore focussed on the preservation of the AVO gradient, with each seismic dataset and each specific reservoir interval typically requiring a unique optimisation approach. Over-corrected and under-corrected seismic velocities, incorrect multiple removal parameters, improper migration and poor angle stack range selection can all cause significant distortion of AVO signatures on pre-stack seismic gathers. However, with a targeted seismic data conditioning (SDC) workflow these undesirable effects can be minimised and corrected allowing noise to be subtracted without impacting primary AVO signals. Post-stack noise that has not been removed by pre-stack SDC techniques must also be subtracted by routines that do not damage AVO signatures. In this paper, we summarise the specific SDC steps required for marine seismic data and demonstrate them on a regional, multi-survey, North Sea, seismic dataset via the application of facies based inversion (Kemper and Gunning 2014).

Method

Each seismic survey consists of specific acquisition / processing parameters and also likely contains various individual reservoir intervals of interest, all of which require a unique approach to designing the optimum SDC workflow. In this paper we focus on a typical marine, multi-survey, SDC workflow designed for the UK North Sea. Marine seismic typically suffers from extensive coherent multiple energy. The addition of random noise when combined with multiples significantly corrupts any AVO analyses or other interpretation techniques. Radon transforms are widely used and help separate out multiples from primary reflections using differences in linear, hyperbolic, and parabolic curvatures after NMO. However, this requires good quality velocity data. Too often the velocity differences for specific intervals of focus are not considered when carrying out image processing of large, regional, multi-survey datasets. Therefore, demultiple at the image processing stage, especially for regional seismic datasets, is usually insufficient to remove all multiple energy resulting in a corrupted AVO signal. A more targeted, higher resolution, Radon based approach is usually required and represents the first step in the described SDC workflow. The second step in the workflow is the application of trim statics. Trim statics are designed to align reflection data, in order to improve signal to noise ratios before stacking and in turn stabilise the seismic gradient. However, trim statics need to be applied with careful supervision of observed and expected AVO classes due to variations in near and far amplitude and phase, especially when considering Class 2P AVO signals (Rutherford and Williams 1989). Seismic stacking is a widely used, powerful, noise removal procedure and represents the third SDC step. The summing of traces at common depth points (CDP) assumes the reflection data is aligned and the amplitudes of coherent events will increase according to the fold or the number of traces in the gather. Thus, it may be assumed that a high fold will give a stable inversion product. However, when the reflection data is misaligned or unsuitable offsets/angles are incorporated an unstable seismic gradient will result. To prevent this specific angle ranges for the stack should be predefined by AVO blocky modelling or by analysing 1D convolutional / FWF (Forward Wave Field) synthetics to enable an optimised stack that captures the true AVO gradient. The fourth SDC step involves post-stack conditioning and is designed to tackle high frequency noise via structurally orientated filtering (SOF). SOF relies on averaging seismic samples, but only along continuous seismic events according to their structural dips. Remaining random, high frequency, noise is consequently supressed by SOF offering significant uplift in signal to noise ratios. Trace alignment of angle stacks is the fifth step and can be considered as a second pass of trim statics, but this time post-stack. This process ensures that AVO events are optimally aligned between near and far angle stacks, but again requires careful pre-consideration of the expected AVO behaviour at wells in order to ensure phase changes between near and far angles of incidence are not removed or induced. The penultimate step in the SDC workflow aims to specifically reduce low frequency noise by frequency slice filtering (FSF). FSF targets selected parts of the low frequency spectrum by running a 2-D smoothing filter in the complex X-Y-frequency domain. The final step is spectral balancing (SB) to address differences in frequency content across each angle stack, which may have been introduced by the trace alignment, trim statics or FSF. This process also corrects for the natural shift towards low frequencies at far offsets caused by move-out corrections and high frequency attenuation, through the application of a single operator function to each partial angle stack. Only after the correct application of all these steps can seismic data be considered as suitable input to inversion routines.

Examples

To demonstrate the benefits of a correctly optimised SDC workflow we apply the described steps to a regional, multi-survey, seismic dataset that covers a 2800 sq km area within the North Sea's East Central Graben. Geological variability is combined with a typical, regional processing workflow that only considers seismic velocities for seismic imaging on a relatively coarse 1km grid. Therefore, the pre-SDC demultiple routines applied are insufficient in preserving an adequate AVO signal, thus requiring a second pass higher resolution radon demultiple (Figure 1). Pre-stack SDC steps were optimised by correlation to suitable well data (Figure 2). The Forties Member when saturated with hydrocarbons in the East Central Graben typically exhibits a Class 2P AVO response and therefore requires particular care to ensure preservation of phase and amplitude variations with increasing offset. Well data is again crucial to enable calibration of seismic in the intercept and gradient domain (Figure 3a). Deterministic wavelet estimation is also used before and after SDC to provide an additional QC (Figure 3b). Post-stack conditioning likewise ideally requires well synthetics. However, in places where well data is unavailable quality control can be performed using only intercept / gradient cross-plots (Figure 3a). The impact of the SDC is obvious

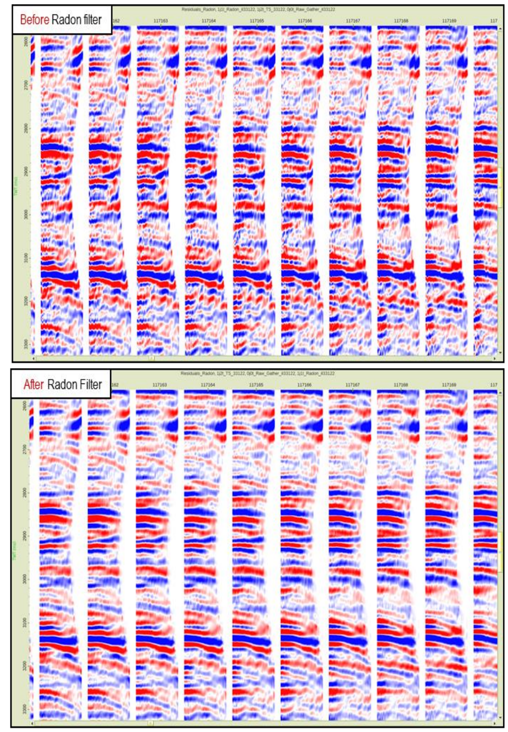

Figure 1: High resolution Radon demultiple applied to a North Sea seismic dataset.

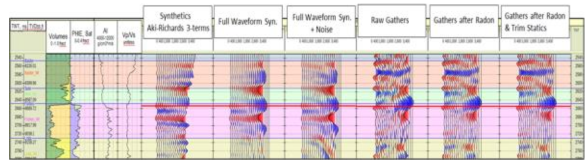

Figure 2: Well synthetic gathers compared with seismic gathers after the application of high resolution Radon and Trim Statics.

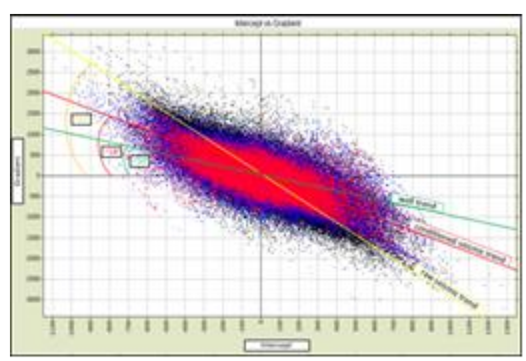

Figure 3a: X-plot of seismic AVO intercept and gradient before and after SDC compared to equivalent well data

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from the interval marked in Figure 2. The data after SDC provides a clear rotation in X/Intercept and Y/Gradient domain, a more linear response with less scatter and is closer to the well trend. Where, Black dots are the original seismic dataset, Blue dots are after pre-stack SDC and Red dots are after the post-stack SDC

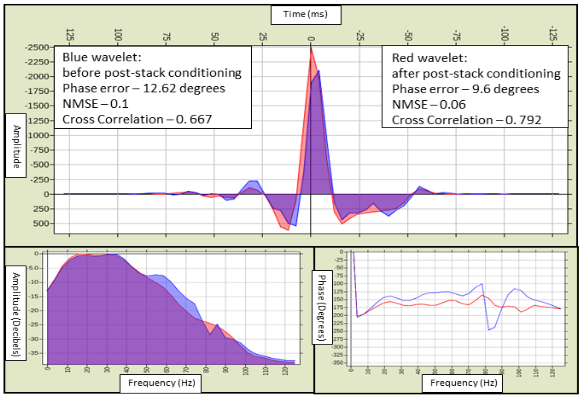

Figure 3b: Wavelet comparison using the ´Roy White method´ before and after post-stack SDC where the wavelet has smaller side lobes, reduced phase error, decreased NMSE (Normalised Mean Square Error) and a higher cross-correlation coefficient when compared to well synthetics and seismic data.

after the application of facies based inversion (Figures 4 and 5). SDC when combined with facies based inversion allows for increased fluid prediction accuracy over existing discoveries and provides a powerful exploration tool.

Conclusions

Pre and post-stack SDC is an essential step in quantitative interpretation. The improvement visible in inversion products, when using facies based inversion, across existing discoveries such as the Everest Field demonstrates the importance of using well synthetics in both pre and post-stack workflows. SDC is considered compulsory particular when using large, vintage, multi-survey, seismic datasets in mature basins, such as the North Sea where a large number of well calibration points are available. In conclusion, this study has demonstrated how careful rock physics analyses combined with SDC, prior to inversion, can vastly reduce hydrocarbon exploration, appraisal and development uncertainty.

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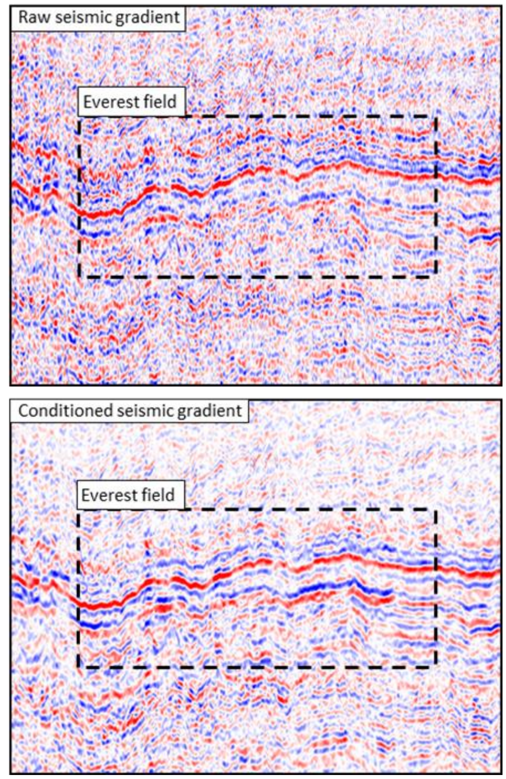

Figure 4: The AVO gradient across the Everest Field is absent on seismic data without the benefit of SDC (left) when compared to an equivalent section with the application of SDC (right).

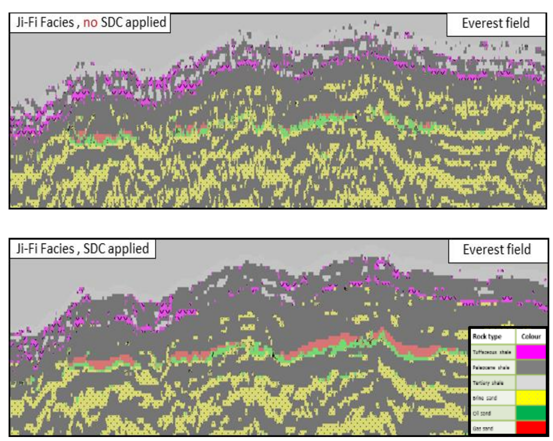

Figure 5: Facies inversion without (top) and with (bottom) the application of SDC. The output signal across the Everest Field is significantly enhanced allowing clear definition of facies especially in the presence of hydrocarbons.

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