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Implementing New Technology to Revitalize Central North Sea Seismic Via Evolutionary Processing

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Summary

The Central North Sea is a mature basin containing a large number of fields, some of which have been in production for decades. Advances in seismic acquisition and data processing over the life of these fields have brought about improvements in seismic image quality and therefore the understanding of the reservoirs. Here we apply some of the latest processing and imaging techniques in a challenging geological setting to help overcome some prevalent subsurface issues and identify opportunities to add significant potential reserves. These include improving the bandwidth of the data, the multiple attenuation and addressing the imaging problems introduced by shallow channels and gas. The processing sequence was established via an evolution style workflow, whereby fully imaged seismic volumes were created at stages during the life of the project. These products provide the opportunity for end user feedback, based upon detailed, reservoir focussed QC.

Introduction

The Montrose and Arbroath Fields lie on the Forties-Montrose High (FMH) on the same play fairway as the Forties and Nelson Fields, discovered in 1971, with first oil in 1976. The recent seismic re-processing exercise was designed to address the subsurface uncertainties associated with the limited bandwidth, multiple content and imaging distortions which characterise the legacy seismic data.

The Montrose Top Reservoir event is characterised by a Class II-P AVO response. The interrogation of fully imaged seismic volumes and AVO attribute derivatives was key to constructing a successful and robust processing sequence. Legacy pre-processing and imaging flows have tended to be linear, employing sequential testing to identify the processing sequence and parameters. Here, an evolution style approach has been utilised. All steps of the pre-processing testing were run in parallel; with fully 3D imaged interpretation ready volumes and reservoir attributes being repeatedly produced during the project. Although highly intensive compared to a conventional project, this approach enables the key parts of the processing flow to be identified and critical feedback from end-users to be incorporated at each evolution. Interpretive based assumptions were removed from the velocity model build and replaced with entirely data driven methodologies, such as joint tomography of reflection and first break picks, followed by Full Waveform Inversion (FWI), to update velocity, anisotropy and attenuation (Q).

Below we describe the impact of the technologies applied to the dataset. The improvements to bandwidth, resolution, multiple content, AVO and signal-to-noise met the project objectives with regards to the signal processing. The velocity updates have supplied a model with a high level of definition, whilst also removing the interpretation based assumptions used in the legacy model building flow.

Signal Processing

Broadband pre-processing incorporating de-ghosting on both the source and receiver sides has now become standard. In the first evolution the source wave field was modelled from the source array design parameters. In subsequent evolutions the near-field hydrophone recordings, originally regarded as an acquisition QC product, have been used. These produce an improved estimation of the emitted source wave field which subsequently improves accuracy of bubble attenuation and zero phasing (Ziolkowski et al, 1982).

The peak frequency at reservoir level of the legacy processed data is around 30 Hz. This is a result of the constructive interference of the source and receiver ghost wave fields, leading to a 6 dB amplitude boost at around 30 Hz. Attenuation of the ghost wave fields and improvements to the low frequency content has resulted in a re-processed dataset with a peak frequency around 5 Hz at reservoir (Figure 1a). A wavelet extraction QC (Figure 1b) illustrates the reduction of the side lobe energy. Ties to available well data have confirmed the improvement in the stability of the phase response.

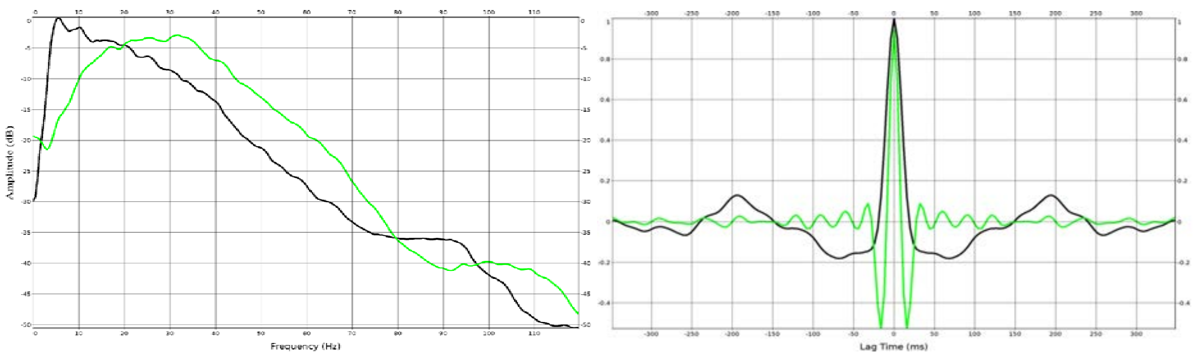

Figure 1: *(a) Amplitude spectra of the legacy (green) and reprocessed (black) seismic data shows the shift in peak frequency from 30 Hz to 5 Hz. (b) Wavelet extraction shows the sharper wavelet with reduced side lobe energy.*

Multiple Attenuation

The legacy processing used predictive deconvolution in the shot and receiver Tau-P domains to attenuate water layer related multiples. These techniques result in significant damage to low frequency primary events, along with any signal with a period similar to the targeted multiples. This damage results in a significant reduction in signal to noise ratio in the low frequency band, critical for robust AVO inversion and attribute work.

Model-based water-layer demultiple (MWD) (Wang et al. 2011) uses a Green's function of the water bottom primary to estimate a multiple model which can then be adaptively subtracted from the input data. Early evolutions used a 2D MWD modelling process, resulting in a level of residual multiple energy considered unacceptable. Progressing to a 3D modelling in later evolutions provided significant improvements in terms of kinematics, amplitude, timing and phase. Following extensive testing of this and other de-multiple processes, a 3D Recursive MWD modelling (Cooper et al, 2015) was implemented. The recursive approach correctly predicts the magnitude of the higher order multiples, overcoming a shortcoming of standard MWD. Also, an emerging inversion based, fully data driven modelling solution using multi-sailline 3D deconvolution imaging (Pica et al., 2005) was used to complement the 3D MWD. This combination of advanced modelling techniques produced a set of multiple models requiring minimal adaption across the bandwidth of the data prior to subtraction. Figure 2 shows an example line comparing the reprocessing to the legacy volume, which shows a clear improvement in event continuity, resolution and multiple suppression.

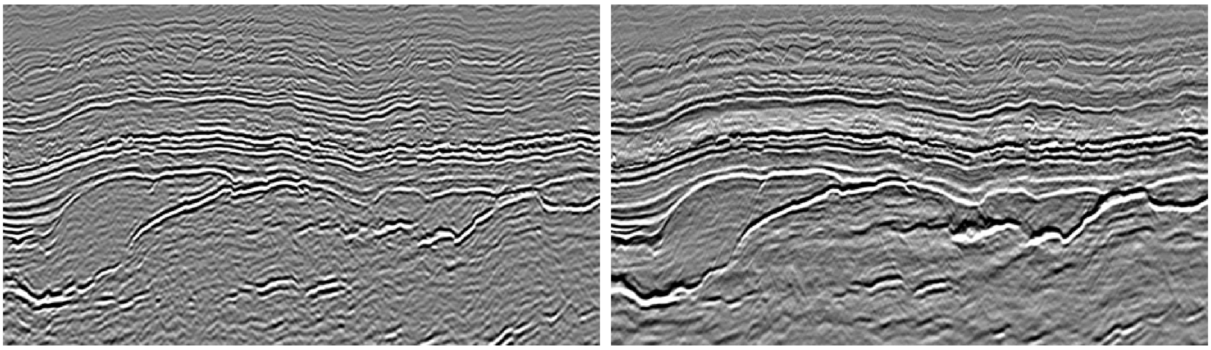

Figure 2: *Example inline display for legacy (left) and reprocessing (right) showing the improvements in bandwidth, primary preservation and multiple content.*

Velocity model update

Glacial channels in the Quaternary (with a velocity fill slower than the background velocity) and furrows at the Base Pliocene (with a fast velocity fill) present two key challenges of the velocity model construction. Each of these features cause significant depth distortions deeper in the section. Shallow gas bodies present a further challenge since they are characterised by a low velocity and high attenuation (Q). Including Q in the update avoids the risk of cross talk between velocity and Q which would result in erroneous velocities in the model, as well as amplitude dimming. A good level of understanding of anisotropy is critical to an accurate Earth model, especially in the near surface where it is often difficult to attain, since there is often little or no well log data. Also, given the limited number of useable near offset traces at very shallow depths, a conventional reflection tomography update often struggles to produce a reliable update to either velocity or anisotropy.

The legacy velocity model relied upon an interpretation-based model update utilising dip constrained tomography (Guillaume et al, 2013) to capture the Quaternary channels and Pliocene furrow features in the shallow overburden. A conventional layer stripping approach then followed to complete the model build, locking in any unresolved errors from the shallower layers, which typically manifest as wave-fronting and push-downs or pull-ups deeper in the section. Here, those prior interpretation assumptions were discarded and the overburden model was updated by implementing fully data driven technologies.

Following the construction of an initial model using available well data and legacy models, a joint reflection-refraction tomography technique was used, with both reflection and refraction picks being utilised in a joint update of velocity and anisotropy (Allemande et al., 2017). The first break picks from the raw shot records provide additional stability along with producing a velocity and anisotropy model which honours the diving waves whilst also producing flat gathers. Full waveform inversion updating both velocity and Q (Xiao et al., 2018) was then used in order to produce a high-resolution model of the near surface that yields improvements in imaging and resolving distortions at deeper intervals. The inclusion of Q in the FWI helped to identify shallow gas pockets, which if left unaccounted for, result in anomalous velocity updates due to cross talk between Q and velocity terms. The calculation of a Q model, compensating for phase and amplitude effects, also enables the use of Q imaging to overcome issues introduced by trapped gas on both large and small scales across the survey. Figure 3 shows examples of a near surface depth slice of the legacy velocity model, joint reflection and refraction tomography and FWI models, which shows a significant improvement in the resolution of the quaternary channels compared to the legacy.

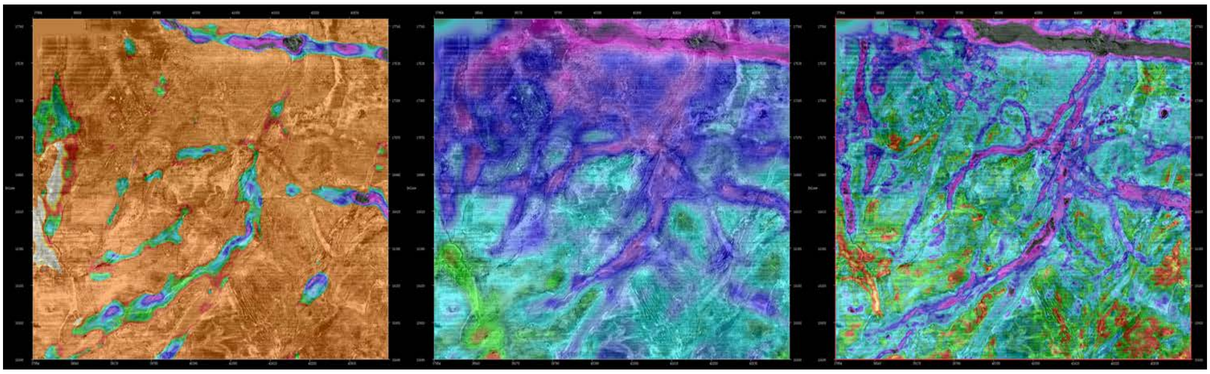

Figure 3: *Depth slices through the near surface (240m) of the legacy processing velocity model (left), joint reflection/refraction tomography (middle), Q-FWI (right)*

The improved velocity model provided imaging improvements, resolving the pull-up and push-down anomalies observed in the legacy seismic. It also provides a realisation of the top reservoir interpretation in depth, which is important as the wells do not sample the velocity anomalies in the overburden which affect the top reservoir horizon.

Amplitude versus Offset (AVO) QC Products

Reservoir focussed quantitative interpretation (QI) attributes confirm the benefits of the reprocessing compared to the legacy volume. At each evolution, P and S impedance estimates were generated using a linearized Bayesian pre-stack inversion (JafarGandomi et al., 2015). A VP/VS ratio volume was used for lithology discrimination of Forties reservoir sands from the overlying shales, the Lambda Rho attribute volume acted as a fluid indicator. Both VP/VS and Lambda Rho attributes show a good uplift compared to the legacy. Figure 4 illustrates a VP/VS ratio attribute extraction over the Arbroath field demonstrating the improved standout of the reservoir.

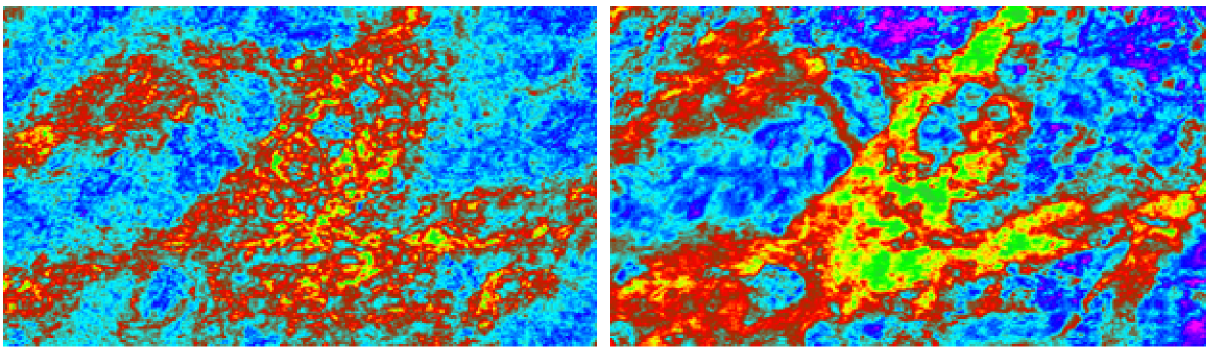

Figure 4: *VP/VS ratio over the Arbroath field: Legacy (left) and reprocessing (right). The reprocessing shows a clear step-change improvement in the definition of lithology compared to the legacy processing around the Forties formation.*

Conclusions

Re-processing of this challenging and complex area of the Central North Sea has yielded improvements in the bandwidth and seismic resolution. The improvements to the demultiple modelling and subtraction schemes provided a good level of multiple attenuation whilst preserving the low frequency primary energy, which was damaged previously in the legacy data through the application of predictive deconvolution.

The velocity model building flow has resulted in a model which captures the channel features in the near subsurface, of both large and small scale. The inclusion of Q in the FWI has ensured that the shallow velocity model does not suffer from cross talk between velocity and attenuation fields.

The utilisation of an evolution, rather than a sequential based, testing and production flow meant that many evolutions of the seismic data could be produced during the project. The generation of the full 3D volumes enabled the QC of reservoir properties whilst the processing was ongoing, rather than at the end of the processing when it is too late to make changes to the sequence or parameters. This ensured that valuable end user feedback could be incorporated into subsequent volumes to focus the processing to ensure it met the expectation of the asset team.

Comparisons to legacy data benchmarks reveal significant improvements in data quality in this mature, but also complex and challenging region of the Central North Sea.

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