LEVERAGING LEGACY DATA

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Recent years have seen many rapid developments in subsurface imaging, especially in velocity model building. This means that not only can many older data sets be reprocessed to a standard approaching that of modern data sets, as a result of advances in areas such as deghosting and designature, but even data sets acquired relatively recently can benefit from reprocessing. As technology continually evolves, there is often value in reprocessing seismic data multiple times, ensuring it remains a valuable asset.

Many thousands of square kilometres of seismic data around the world are suitable for reprocessing. Many of these data sets provide patchwork coverage, with different orientations and parameters, which would benefit from being combined and reprocessed as contiguous volumes. In many cases, they may be improved by infilling gaps with new acquisition. In more challenging areas, the data may be enhanced by over-shooting with new seismic acquired at a different azimuth, which can then be processed with the older data to deliver the benefits in

illumination and multiple attenuation that multi-azimuth data provides.

Cornerstone Evolution

The Cornerstone Evolution reprocessing project in the Central North Sea demonstrates the value achieved by reprocessing a large number of existing data sets in conjunction with newer acquisition. The Cornerstone data set consists of several phases of acquisition, covering over 35 000 km² (Figure 1), built up over more than a decade. These surveys are not a random patchwork (like some reprocessing programmes), but rather were intentionally acquired in stages as a regular grid of multi-client projects, incorporating the latest advances in acquisition technologies as they were developed. The earlier surveys were all acquired with an approximate north-south orientation, while the most recent were acquired east-west, in some places overlying the previous surveys to provide dual-azimuth (DAZ) data.

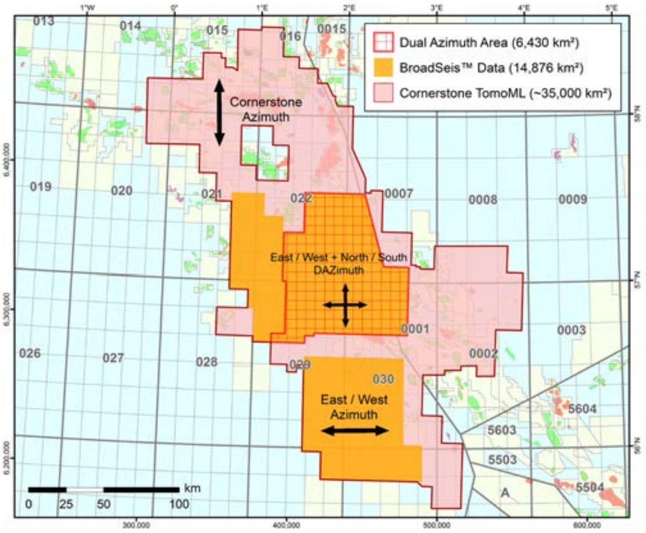

Figure 1. *Map showing the Cornerstone area, showing the areas of BroadSeis and dual-azimuth data.*

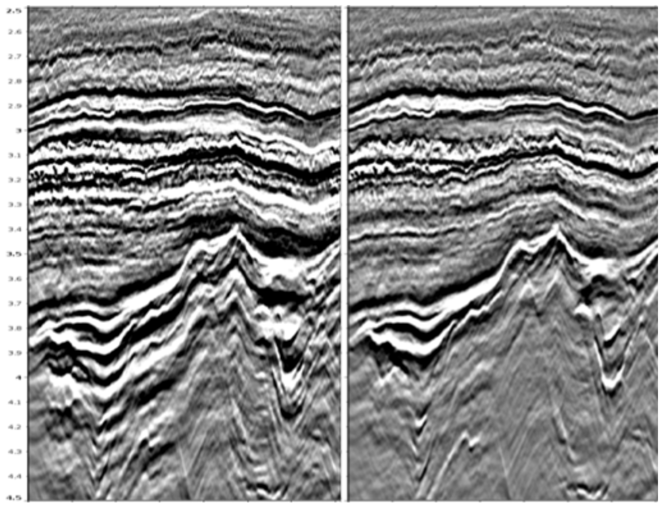

Figure 2. *Data before (left) and after (right) the new demultiple (recursive 3D MWD with 3DSRME).*

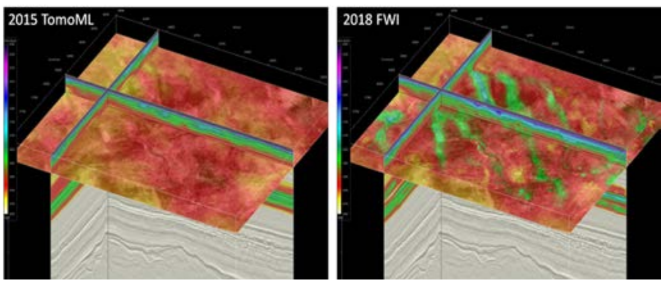

Figure 3. *Comparison of the 2015 velocity model (left), which used multi-layer tomography, and the 2018 model (right), derived from Q-FWI, showing the improvements in resolution achieved (image courtesy of CGG Multi-Client & New Ventures).*

The Central North Sea is a mature basin, yet still rich in opportunities for the discovery and development of new fields. There are many prospective intervals, with hydrocarbons encountered within three main sequences: Upper Jurassic sandstones, Cretaceous chalks (on the Norwegian side of the Central Graben) and Lower Tertiary submarine fan systems. Advances in technology have continued to allow new play models to be explored and new discoveries to be made. The development of broadband technology has enabled new stratigraphic traps and subtle structural closures to be delineated, and reservoir development and hydrocarbon recovery have been enhanced by more information about local facies variations and reservoir compartmentalisation. The higher frequencies in broadband data push the limits of amplitude tuning effects and help to resolve thin beds and pinch-outs that have previously been problematic to image. The low frequencies also play an important role by reducing sidelobe interference and helping in the interpretation of subtle facies transitions.

The Central North Sea suffers from a number of geophysical challenges, including shallow anomalies, heavy multiple contamination and sharp velocity contrasts, all of which may be resolved by modern processing techniques. Although the surveys that make up Cornerstone have already been recently reprocessed in depth (2015), the advances made in full-waveform inversion (FWI) for modelling velocity, visco-elasticity (Q) and anisotropy mean that considerable improvements can already be achieved by reprocessing again. The previous reprocessing started from archived pre-processed data, but the new Evolution project is reprocessing the data completely, starting from the field tapes, to gain the maximum advantage from improvements in signal processing such as 3D designature and deghosting. The project also benefits from advances in demultiple, especially the move from predictive to model-based techniques. Two areas of Cornerstone have been reprocessed as a priority, one of which is in the DAZ area and is the example discussed here.

Designature and deghosting

3D designature was applied to all the data sets using wavelets generated from recorded near-field hydrophone (NFH) data, with advanced Ghost Wavefield Elimination (GWE) 3D deghosting to extend the bandwidth as much as possible. In the most recently acquired surveys, the NFH measurements were used on a shot-by-shot basis to provide an accurate estimate of the source response to improve debubbling and zero phasing. For the older surveys, the quality of the NFH recordings was not suitable for shot-by-shot use, so global wavelets were generated for each survey.

The bandwidth that GWE can achieve depends on the signal-to-noise ratio in the recorded data, and so the ultra-low frequencies of BroadSeis™ true broadband data could not be obtained for all surveys. Nevertheless, considerable extension to the original bandwidth has been achieved, providing sharper wavelets and improved visibility of impedance contrasts for enhanced interpretation.

Demultiple

Predictive deconvolution in the tau-p domain has been the standard demultiple tool in shallow-water areas for many years, but in some cases has recently been found to harm primary reflections, especially at low frequencies and at near offsets. Using model- and inversion-based methods avoids this effect. A combination of the latest demultiple techniques is being used in the Evolution reprocessing, including 3D recursive model-based water-layer demultiple (MWD), for the waterbottom and short-period peg-leg multiples, and 3D surface-related multiple elimination (SRME) for longer-period, surface-related multiples (Figure 2).

Reservoir-oriented processing sequence

Modern multi-client data from CGG is processed in such a way as to be 'reservoir-ready'. Quantitative amplitude-versus-offset (AVO) QC attributes, generated after each key processing stage, can be used to ensure that the seismic data will be compliant with any requirements for later reservoir characterisation work. One of the benefits of the reprocessing has been the increase in the usable angle range of the data. The improvements in the signal processing and demultiple, combined with the reservoir-focused reprocessing workflow and creation of AVO QC products at intermediate stages in the sequence, have contributed to a significant uplift in image quality, reliable reservoir properties and Quantitative Interpretation (QI) attributes.

Full-Waveform Inversion

One of the most significant advances in model building of the last few years has been the evolution of FWI from a research project to a large-scale production tool. FWI is now used routinely to determine a number of different parameters, from velocity and anisotropy to Q.

The near-surface of the Central North Sea features large-scale Quaternary channels that strongly influence the imaging of deeper data. Accurate modeling of these shallow features was one of the main aims of the Evolution project to reprocess the Cornerstone surveys, as inaccuracies in the shallow section cause distortions in the imaging of the deeper structures. FWI uses recorded and modelled waveforms to derive a high-velocity model of the near-surface, which frequently has enough detail for use in shallow hazard identification (Figure 3). It does not rely on assumptions regarding structure or require residual moveout picks and is therefore an effective and reliable tool.

In addition to the velocity anomalies caused by these channels, there are also areas of gas leakage that cause absorption effects, resulting in amplitude dimming, a serious impediment to the accurate amplitudes required for AVO. Q-FWI is an important new tool for identifying these anomalies, whose effects can then be compensated by Q-migration. Jointly inverting for Q phase and amplitude effects alongside velocity reduces the likelihood of erroneous velocities being derived from FWI due to the cross-talk between Q and velocity.

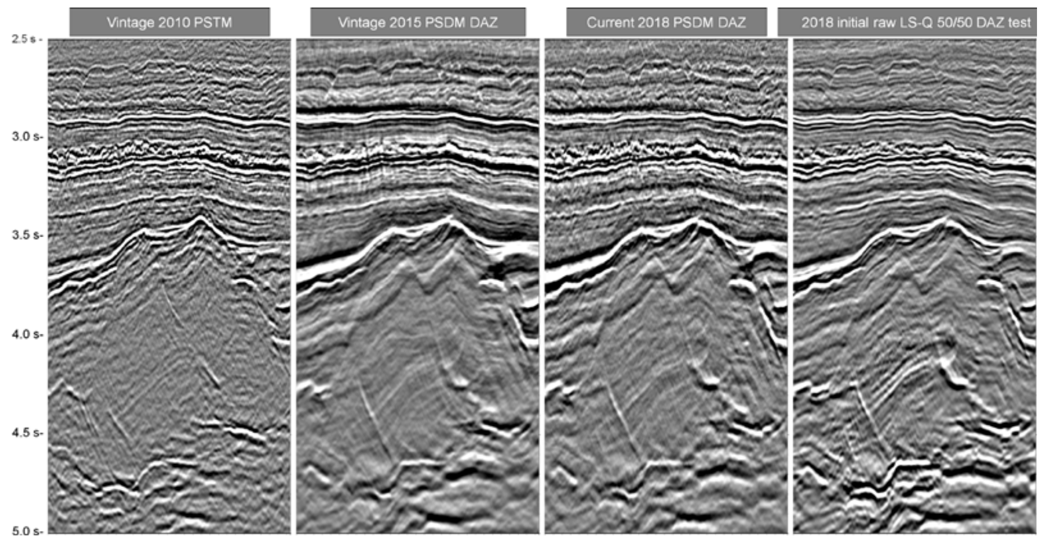

Figure 5. *Evolution of image quality from the 2010 processing, through 2015 to today's version. Note that the LS-Q data is an initial test, and the processing of this data is not yet finalised (image courtesy of CGG Multi-Client & New Ventures).*

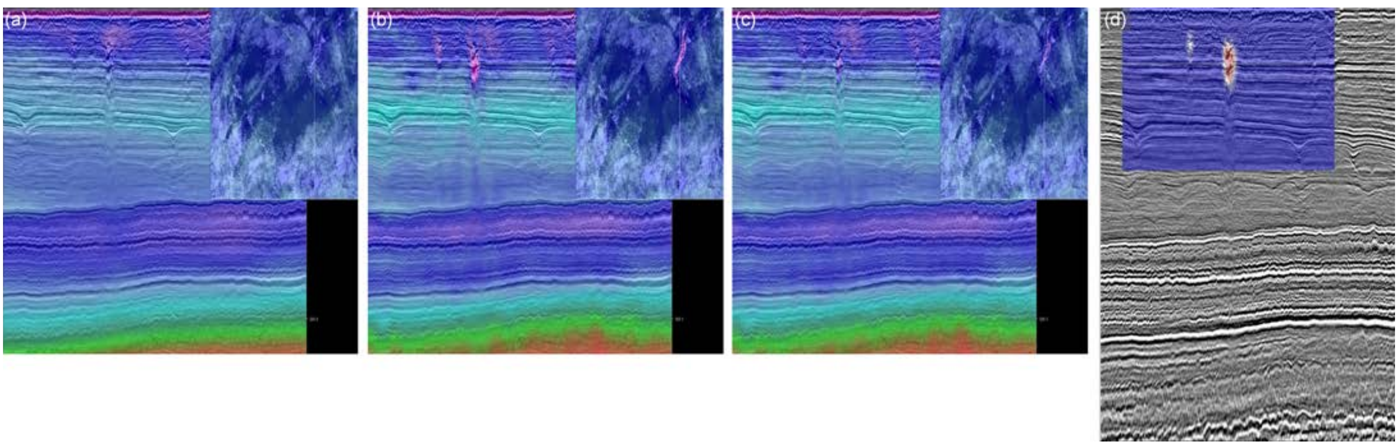

Figure 4. *Figure 4. (a) Input velocity model from the 2015 reprocessing, derived using TomoML multi-layer tomography; (b) FWI velocity model derived using constant background Q. Due to the Q anomaly not being included, the velocity beneath the channel is too low; (c) Q-FWI velocity model derived by joint inversion for Q and velocity; (d) Q-migration with Q model overlay. The absorption anomaly in the Q model delivers stable velocities beneath, so that local pull-up is reduced and amplitude is recovered (all images courtesy of CGG Multi-Client & New Ventures).*

Q-FWI results show good conformance with geology and seismic structures. The Q-FWI successfully identifies the shallow glacial channels and their associated velocity and absorption anomalies, to deliver a more stable velocity field beneath them (Figure 4). The reprocessed data shows much sharper features than the legacy processing results, with better well ties and therefore more reliable depth imaging.

Conclusion

The Cornerstone Evolution project clearly demonstrates the value that even legacy data can contribute when reprocessed. For the priority area discussed here, the older data was processed in combination with newer acquisitions to deliver DAZ coverage. In other areas of the full project there is only single-azimuth data, some of which was acquired with broadband technology and is only a couple of years old, and some of which is conventionally acquired data. Figure 5 shows the evolution of data quality from the initial 2010 processing to today's DAZ Least-Squares Q-PSDM. The Least-Squares Q-PSDM panel is only an initial test. Unlike the other DAZ panels, which have been processed through a full DAZ sequence, each azimuth has been processed individually and then been stacked together with 50% weights. Further improvements are expected when this has been processed through a proper DAZ sequence.

The entire 35 000 km² Cornerstone project is being combined and reprocessed through the new sequence. This will deliver a seamless, contiguous volume of the highest-quality reservoir-ready data. An early-out volume will be available during the third quarter of 2019.

CGG has recently reprocessed several of its older seismic data sets around the world, in some cases combining them with new acquisition, to deliver large contiguous volumes of modern, broadband, pre-stack depth-migrated seismic data. These large-scale projects include over 100 000 km² of data in the Santos and Campos Basins, 38 000 km² in the Perdido fold belt in the Mexican Gulf of Mexico, and 11 000 km² of data offshore south-east Australia, where new, complementary acquisition is planned. Larger surveys deliver a better overall understanding of a basin by providing a regional view. By processing these surveys using the latest advanced FWI imaging sequences, they also have the fine resolution necessary to make the best-informed decisions.

The rapid improvement in subsurface imaging technology is continuing, meaning that reprocessing is becoming more necessary – today's highest-quality data will be next year's baseline for improvement. Nevertheless, improvements tend to progress by incremental stages with occasional quantum leaps. Recent step-changes have been the introduction of broadband data, followed some years later by the industrialisation of FWI. The next big improvement is likely to come from extending the improvements in azimuthal sampling, delivered by wide- and full-azimuth surveys, from the Gulf of Mexico to more areas of the world, even those without salt. Rich- and multi-azimuth surveys not only benefit from improved illumination but also from the denser fold coverage, which significantly improves signal-to-noise ratios and attenuation of multiples. CGG is already acquiring a rich-azimuth survey over the North Rona Ridge, Northwest of Shetland, and various node surveys are being planned around the world for the coming years. With this trend, ownership of legacy data to overshoot at a different azimuth will be an even more valuable asset than it is already. Seismic data is always as good as the day it was acquired; it does not perish, even though the media that it is stored on may. Newer, more advanced data may deliver improved imaging, but older data remains a valuable commodity.