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Seimic Processing and Imaging in Central North Sea Area - Recents Advances and Remaining Challenges

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SUMMARY

The Central North Sea area (CNS) is a very mature area. While still an active exploration area, most of the standard prospects have been already drilled and new discoveries can only been obtained today with the help of improved seismic acquisitions and using the latest techniques in seismic processing and imaging. We will review and illustrate improvements in processing and imaging that have a significant impact for the CNS.
However, the best seismic images obtained today are still far from perfect. Parameters having a negative impact on the seismic quality are numerous: multiples, structural model complexity, formations with very different velocities, strong anisotropies, overburden glacier channels, shallow marine section... As a result, seismic images below the base cretaceous unconformity remain often of poor quality. We will review the main problems encountered today.
Hopefully, we have not reached the limits of seismic acquisition and processing technology. Emerging approach and methodologies should help in improving the seismic imagery quality. We will propose and illustrate some directions that we believe should help to improve CNS seismic images.

Introduction

The Central North Sea (CNS) area is a very mature zone with more than 40 years of exploration history. While still an active exploration area, most of the standard prospects have been already drilled and new discoveries can only been obtained today with the help of improved seismic acquisitions and using the latest techniques in seismic processing and imaging. However, seismic acquisition and processing is a very rapidly evolving domain. Active R&D in this field allows new technologies to rapidly emerge and allow to constantly improving the quality of seismic images. We will review and illustrate, in the first part of this paper, improvements in processing and imaging that have a significant impact for the CNS.

However, the best seismic images obtained today are still far from perfect under the cretaceous levels where, we believe, most of the remaining prospectivity lies. The so-called Base Cretaceous Unconformity (BCU) is often characterised by a huge velocity inversion after the strong velocities encountered in the chalk layer. Parameters having a negative impact on the seismic quality are numerous: multiples, structural model complexity, formations with very different velocities (Tertiary, Cretaceous, Jurassic, Triassic, Zechstein, Permian, ...), strong anisotropies, overburden glacier channels, shallow marine section... As a result, seismic images below the BCU remain often of poor quality. We will review the main problems encountered today.

Hopefully, we have not reached the limits of seismic acquisition and processing technology. Emerging approach and methodologies should help in improving the seismic imagery quality. We will propose and illustrate some directions that we believe should help to improve CNS seismic images.

Significant improvement in processing techniques for CNS area

Multiple attenuation techniques:
The first main difficulty is the strong presence of multiples both short period (mostly multiple reflection on the seabed which is often shallow with typical depth encountered being 70 to 100m) and long period (internal multiples often generated in the chalk layer which represent strong impedance contrasts). Several techniques are today available from the Surface Related Multiple Elimination (SRME) family. Shallow water environment requires a specific approach from the Shallow Water Multiple attenuation family, which has been widely developed during the last years. The best result is often achieved by combining several multiple modelling tools (Shallow water demutiple type, Tau-P deconvolution, SRME and Radon) and an optimised adaptative subtraction workflow (sequential or simultaneous). During the presentation we will illustrate the impact of these multiple attenuation processes.

Multiple Attenuation within Migration methods:
While strong improvements have been achieved through surface related multiples elimination, internal multiples remain a real problem in CNS. Usually these internal multiples still contaminates processed data sub-BCU. Compared to water layer multiples, move-out is difficult to differentiate from the primary move-out since the internal multiples have complex ray path.
Beam migration technology has emerged over the last decade and allows migrating coherent local events, rather than seismic samples as classical other approaches do. Local coherent events (which can be either primary or multiple reflections) provide travel-time and slope information that can help, when unfolded after the depth migration process, to better discriminate primary and multiple reflections. Migrated coherent events identified (through several criteria) as multiple energy will not contribute to the final image reconstruction. Figure 1 compares a Kirchhoff migrated images where a harsh Radon has been applied post migration and a Beam PSDM image using several criteria for rejection of migrated local events.

Model Building and parameterisation:
CNS is characterised by strong velocity contrasts associated with main geological formations. Clear velocity contrasts are observable on well sonic at the limits of these units. However some velocity variations are also seen within these units. Accurate depth imaging can only be obtained by a model parameterisation and update that will account for the different scales in velocity variations.

Tomographic tools have evolved over the years to achieve these requirements. In addition the seismic quality is not always sufficient (reflectivity loss in shaly and in carbonateous layers) and layer thickness too small in some areas to obtain a robust velocity update. Regularisation techniques need therefore to be included with sufficient flexibility and has been an important evolution of model building techniques over the last few years. We will show during the presentation a comparison of model update with different strategies and show how we can obtain more geological model while still preserving the image focussing.

Shallow channel determination:
CNS reveals strong presence of shallow channels which can have significant imprint on seismic images. Determination of the velocity anomalies associated with these channels cannot be obtained easily from the seismic gathers themselves because of the lack of information in the recorded data. Until recently models needed a strong interpretative input and simplifications in the update techniques (trial and error or simplified 1D update). Thanks to High Performance Computing improvements, Full Wave Form Inversion (FWI) has become tractable in 3D today. This technique can make use of refraction energy which brings important information on the velocity model in the first hundreds of meters. Often described as a fully automatic method, the method needs however a good starting model to avoid falling into local minima. Getting a suitable initial model is therefore the main challenge and often involves manual testing. It also implies to derive correct anisotropic parameter (not updated by FWI today) to reconcile mostly horizontal propagation from refraction energy and mostly vertical propagation from reflection energy. Constraints on the initial model can be mitigated by the use of low frequency that recent broadband acquisition can provide. We will show during the presentation successful application of FWI using broadband data to solve shallow channel anomalies.

Remaining problems impacting the imagery sub-BCU

Despite recent improvements, sub-BCU imaging remains difficult. The main limitations that we observe today are:

Presence of multiples that contaminate the imagery sub-BCU:
Multiples have a strong imprint on the final images and we often need to use targeted multiple attenuation techniques post migration and post stack to remove them. It is a severe limitation for Kirchhoff and Wave Equation migration algorithms. Internal multiples also contaminate the model building phase. Indeed, as mentioned in the first part, due to their complex move-out, they are difficult to discriminate from the primary move-out and often introduce bias in the model update.

Illumination and reflection angle limitations:
The Chalk layer acts as a seismic screen in addition to being a good generator of internal multiples. As a result, illumination below BCU is impacted as well as the limited reflection angles. Model updates below the BCU can therefore only retrieve long wavelengths of the model when not corrupted by the multiples.

Sub-BCU model update:
Due to the above limitations, the most popular method to derive sub-BCU velocities is the scan approach. Since the velocity picking criteria is mostly on the stack images and remains interpretative, it allows picking the most focused image and often avoiding the pitfall of focussing multiples energy. However, it is difficult to obtain a geologically consistent model at the end of the process. It relies implicitly on 1D assumption (in classical implementations) and strongly relies on the initial model used in the scan process. Indeed the different images are associated with constant perturbation on the initial model used. After the picking, the optimal combined image is not associated to a 3D migration and the 3D migration with the rebuild model (using 1D approximation) will be different.

Well information is insufficient to constrain the model:
Well information does not provide velocity information in the shallow part of the subsurface. We often overcome these limitations by building an equivalent model in this area. For FWI, this lack of information becomes a limiting factor for reconciliation of horizontal and vertical velocities. Below BCU, well penetration is often insufficient to allow the construction of a good initial model in 3D and

to constrain its update. Corridor stack from VSP could bring valuable information for identifying multiples but are too rarely acquired. It is even worse for walk-away acquisitions that could however be used to determine the anisotropic parameters around well locations.

Way forward

In terms of multiple attenuation, active R&D is still ongoing (Weglein et al., 2011) and new internal multiple attenuation approaches start to emerge. Success in this domain may have a strong impact in CNS. Focussed R&D effort on CNS specificities could help to solve this difficult problem.

With the current towed streamer acquisitions, model building below BCU needs more interpretation driven approach to overcome the limitations of the seismic information. Moreover structural model below the BCU are frequently very complex involving several tectonic phases with salt movement which are very challenging for PSDM. Figure 2 compares (in vertical time) the results obtained from tomography and velocity scans with a purely interpretation driven model building approach. In the latter result well information and interpretation have been used to build plausible models including velocity contrasts. In this process the seismic data are used as QC to discriminate between the models. The structural image obtained seems better while the focussing seems comparable. Moreover, this image ties perfectly to the well. Uncertainty analysis on velocity models is required for a better evaluation of the prospect (volume, geometry, ...). Using this approach we can initiate the process with a set of realistic models.

Improvement in illumination and usable reflection angles can be achieved by improved acquisition such as Wide Azimuth Towed Streamer (WATS) or Ocean Bottom Seismic (OBS). There are numerous real data examples from Gulf of Mexico or Gulf of Guinea (for WATS acquisitions) and in CNS (for OBS acquisitions) showing the benefits of such Techniques. For CNS, exploration prospect and its associated risk cannot always justify such expensive acquisitions technologies**.** In this context acquisition feasibility study becomes an important process to prove the added value and optimize its cost. Building representative models and synthetic data remains a challenge. We illustrate in Figure 3, results obtained from finite difference modelling that we compare to real data. Special care has been paid to construct a representative model using 2D modelling/migration approaches. Namely, the thin Kimmeridge clay layer below BCU was a key factor in this area impacting strongly multiples generation and illuminations problems. Such feasibility approach needs to correctly model geophysical problems encountered on real data, such as multiple contamination, and Finite Difference technique seems the most adapted tool to achieve this goal. We have chosen, rather than applying a costly multiple attenuation processing step to the modelled data, to attenuate their strength in the modelling itself (by incorporating a fictive layer above sea level) without impact on the numerical cost of the modelling.

Conclusions

Seismic processing techniques have made tremendous improvements. As illustrated, some new techniques already have a significant impact for seismic imaging of the CNS. As a result reprocessing of vintage data has always shown significant uplift on all our blocks.

However, today, most of our prospects are located sub-BCU, where seismic image quality is often poor. Major factors are the presence of multiples, the lack of illumination and maximum available reflection angles. Available well information is often insufficient to compensate the seismic limitations. As a consequence, the methodology used (tomography and/or velocity scan) to derived the model sub-BCU is far from being optimal.

There are hopefully possible ways of improvements. Emerging techniques for internal multiples attenuation may have a strong impact in CNS. With current streamer acquisitions, we illustrated how sub-BCU model building could be more driven by interpretation, where seismic information is only used to discriminate between plausible models. Improvement in terms of acquisition is surely a promising route. For CNS, remaining exploration prospect and its associated risk cannot always justify such acquisitions. The expected improvement in terms of quality cost ratio must therefore be carefully estimated by use of acquisition feasibility study. As illustrated, representative seismic response can be obtained by building realistic models and using appropriate modelling tools. As frequently for a complex problem the answer is not unique and it is a set of solutions which would help to overcome the seismic limitations below the BCU in CNS area: Part of them are very sophisticated, and rely on R&D breakthrough, others are more pragmatic, integrating previous information and geological knowledge in the velocity models.

Acknowledgements

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References

Weglein A., S. Hsu, P. Terenghi and R. Stolt, 2011, Multiple attenuation: Recent advances and the road ahead. The Leading Edge (2011), 30(8):864.

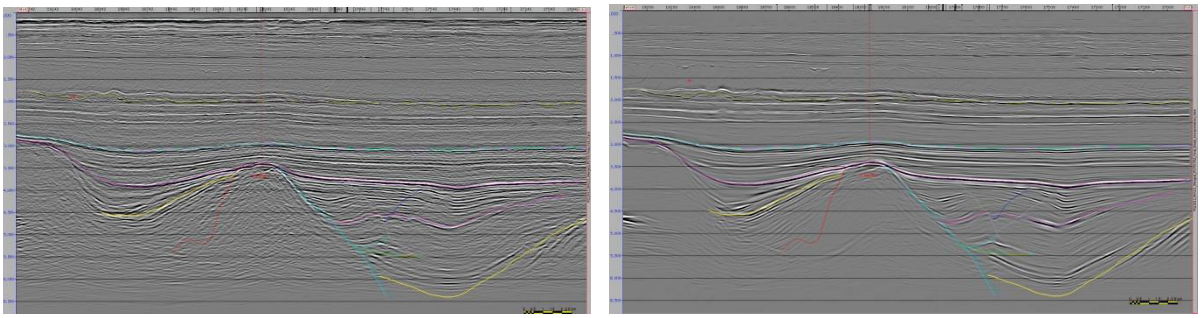

Figure 1 *Comparisons between Kirchhoff migration using harsh Radon demultiple (left) and Beam migration using several criteria for rejection of migrated local events (right).Courtesy of PGS.*

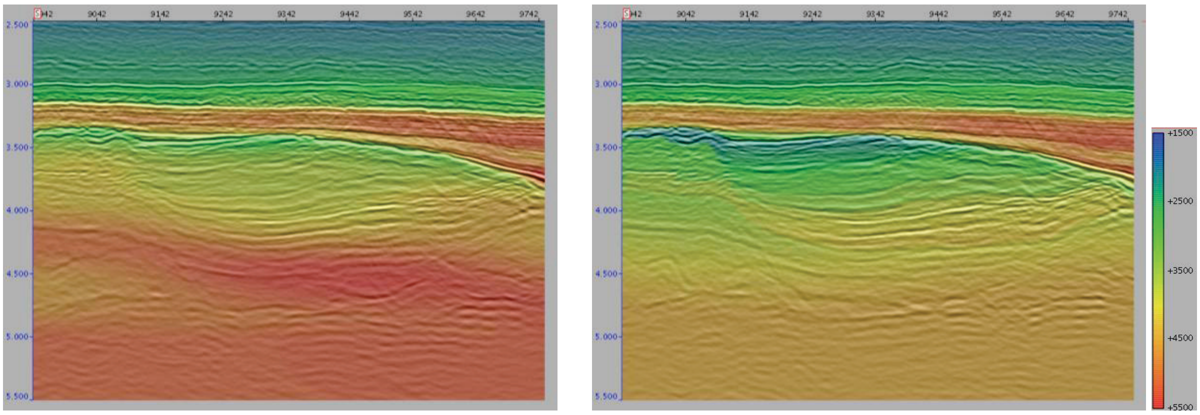

Figure 2 *Comparisons between migrated images obtained after sub-BCU tomography and velocity scan (left) and interpretation driven sub-BCU model building (right).Courtesy of CGGV.*

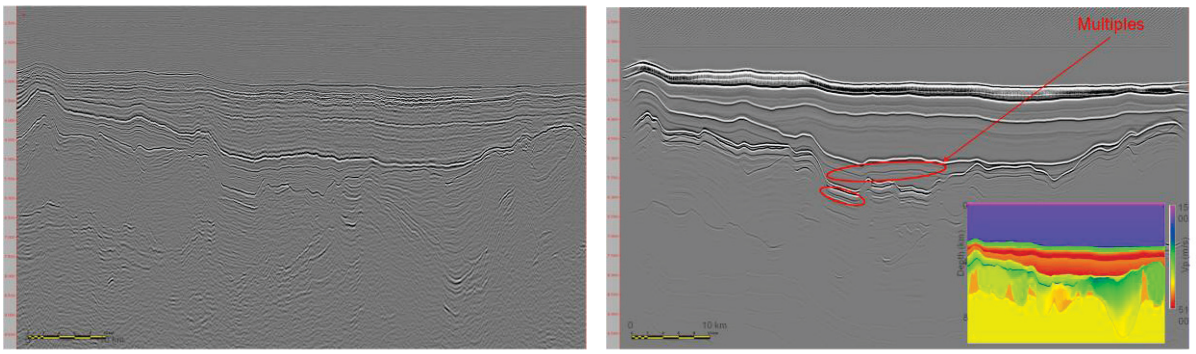

Figure 3 *Comparisons between migrated image obtained from real data (left) and image obtained after finite difference modelling/migration using a synthetic model (right).Courtesy of CGGV.*