How broadband can unlock the remaining hydrocarbon potential of the North Sea

Gregor Duval\(^1\) provides some graphic evidence of how broadband seismic data can unmask the hidden potential of the UK Continental Shelf.

Broadband variable-depth towed-streamer solutions are proving able to deliver wide-bandwidth seismic data (Soubaras and Dowle, 2010) of up to six octaves, sometimes doubling the bandwidth provided by legacy data in the same area. In a mature basin such as the North Sea, data from a proprietary broadband variable-depth towed-streamer solution is providing E&P companies with a competitive edge by providing significant enhancements in a range of environments: the ability to explore new stratigraphic traps and delineate subtle structural closures, and enhance reservoir development and hydrocarbon recovery with more information about local facies variations and reservoir compartmentalization. We take here a step-by-step approach through the North Sea stratigraphy, demonstrating the benefits of broadband seismic data from shallow to deep, illustrated with examples from two 3D surveys from the North Sea, one in the region of the UK Continental Shelf (UKCS) Quadrant 20 and the other in the east of Quadrant 22 (Figure 1).

Need for a broad bandwidth

It is easy for seismic interpreters to understand the need for higher frequencies in seismic data since they provide more detail about the geology, such as thin stratigraphic features and subtle rock structures. However, low frequencies are just as important. They suppress the wavelet sidelobes, contribute to better imaging of deep targets and large-scale facies variations as well as providing more quantitative pre- and post-stack seismic inversion results which match well log measurements more accurately.

Ideally, the seismic interpreter would like to see a seismic wavelet which resembles a spike, an impulsive response which clearly shows the true subsurface reflectivity. Adding in more high frequencies sharpens the wavelet central peak while introducing more low frequencies reduces the amplitude of the sidelobes, making the wavelet look more like a spike (Figure 2). Broadening the frequency spectrum at both the high and low ends thereby gives a wavelet closer to the genuine seismic signature of formation interfaces. For instance, Figure 3 displays a comparison focused around the top of the Dornoch Formation, which includes several thin and highly reflective coal layers, in the Outer Moray Firth area.

Figure 1Broadband vs. conventional comparison areas.

Figure 2Broadband data are less subject to tuning effects and allow interpretation of pinch-outs (Zone 1 in Figure 3) and thin beds (Zone 2). Furthermore, the absence of sidelobe interferences gives the genuine seismic signature of the Dornoch coal layer (Zone 3). Conventional data fails to resolve any of these details.

Shallow geology

Due to the steep slope of the near offsets when using an optimally curved variable-depth streamer profile, the benefits of broad bandwidth are achieved even at very shallow depths, giving clearer images of recent deposits and formations lying directly below the sea floor. Figure 4 shows a time slice comparison at 216 ms TWT (approximately 100 ms below the water bottom). The high-frequency content is key in defining

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Tertiary geology

Most of the Tertiary structural closures have been drilled in the North Sea basins. However, part of the remaining potential lies within subtle stratigraphic traps and pinch-outs. This is where broadband seismic has the potential to play a major role. The higher-frequency content pushes the limits of amplitude tuning effects further. Broadband data help in resolving thin beds and pinch-outs that have never been seen before. The low frequencies also play an important role by reducing sidelobe interferences, improving the 'resolvability' of these thin beds and helping in the interpretation of subtle facies transitions.

Focusing on the prospective Tertiary turbidite systems of the North Sea, Figure 5 displays images of a thick, low acoustic impedance shale sequence in the Paleocene Lista Formation. The seismic correlates very well with log data and the top and base of these soft shales are clearly identified.
impression of a shaded relief 3D image. In fact this effect is due to the presence of strong low frequencies as they bring in the true envelope signature of this formation, revealing a major impedance contrast. Away from the well calibration point, in the central part of the section, both the conventional and the broadband seismic data show a prominent relief structure corresponding to a channel compactional feature. The presence of such a feature usually tells the geologist that the channel fill deposits have a different lithology, i.e., are composed of less compactable sediments, including desirable reservoir channel sands. Figure 5 shows that the top of these sands can hardly be identified on the legacy data while it appears very clearly on the broadband image as a distinct black event. We can also see that channel levee sands, over bank deposits and sand body pinch-outs are easier to identify. Even Top Chalk appears as a much more continuous horizon. Interpretation workstation autopicking tests have demonstrated that it is five times faster to map this horizon on broadband variable-depth towed-streamer data as little or no correction and re-picking is required. This example emphasizes again the important role that broadband variable-depth towed-streamer data can play in efficiently and accurately mapping facies distributions and ultimately describing new stratigraphic play concepts in the UKCS area.

The colour scale uses the following convention: white for a decrease of impedance and black for an increase of impedance. At first glance, the broadband seismic data give the

Figure 4 Time slice comparison at 216ms showing shallow channels in the UKCS Q22 area.

Figure 5 Seismic section comparison focusing on the turbidite complexes of the Paleocene Lista formation in the UKCS Q20 area.
Figure 6 focuses on the Tay Formation which is a very prospective reservoir in the southern area of Quadrants 21 and 22. Top Tay is marked by a prominent black reflector on seismic data (i.e., increase of impedance). The comparison shows that, while the broadband data give a clear image of the Top Tay reflector (Figure 6A), the conventional data show amplitude losses in the middle of the seismic section where the Tay fan is thinner (Figure 6B). Applying a basic band-pass filter to the broadband data (10-40Hz – 50-70Hz) matching the frequency content of the legacy data (Figure 6C), one can notice that the dim zone becomes visible again on the downgraded data. This rudimentary analysis indicates the value of the additional bandwidth provided by broadband data, outside of the frequency range of the conventional data. In addition, we can see that by band limiting the broadband data we obtain an image that matches very well the character of the legacy dataset. In this geological context this is a good indication of the ‘backwards compatibility’ of new
broadband surveys with legacy conventional surveys and that they can always be downgraded for special requirements such as 4D matching or the merge of different vintage seismic datasets. This has been discussed in more detail by Charrier et al. (2012).

Upper Cretaceous Chalk geology
It is only further to the southeast, in Norway, Denmark, and UK Quadrants 29 and 30, that the Chalk has been prospective so far. In the area of Quadrant 22 the Late Cretaceous Chalk is about 1km thick and less porous. The uppermost interval consists of the Ekofisk and Maureen formations where, in places, wells drilled in this region of the North Sea have encountered some clay beds of very low acoustic impedance. It is thought that these formed as a result of large scale chalk dissolution processes leaving behind the clay content only. These dissolution features would represent some sort of soft ‘clay pools’ encased in the hard chalk beds. These are clearly identifiable on broadband data (Figure 7), producing bright seismic amplitude bursts within the upper part of the Chalk. The well displayed in Figure 7 ties with the edge of one of these amplitude bursts and a quick calibration with the composite log proves that this feature corresponds to a very low impedance marly/clayey interval at the base of the Maureen Formation. In comparison these features are hardly noticeable on conventional seismic because of interference of sidelobes with the bandlimited wavelet and the lack of low frequencies to differentiate the facies.

An RMS amplitude map was then extracted using the top of the Maureen Formation and the base of the Ekofisk Formation to further investigate these features. The comparison results are displayed in Figure 8 and they undoubt-
edly prove the superiority of the broadband variable-depth towed-streamer data. The sharp broadband wavelet resolves the edges of the ‘clay pools’ while the low-frequency content allows for clear discrimination of the softer ‘clay pools’ infill and the harder encasing chalk. Some of these chalk dissolution features are several hundred metres in diameter and the velocity contrast has an obvious impact, producing visible ‘pull-downs’ on the underlying reflectors (Figure 7). Furthermore, the low frequencies give information about the larger-scale, lateral facies variations: darker shades of grey in the left-hand part of the broadband RMS amplitude map indicate that the chalk is marlier while the lighter grey colours in the right-hand part correspond to a more carbonate-rich type of chalk. The level of detail and clarity found in the broadband variable-depth towed-streamer images emphasizes the potential for this technology to become a very important tool to map variations in chalk reservoir properties.

Sub-BCU geology

Sub-BCU (Base Cretaceous Unconformity) imaging can often be a challenge in the North Sea basins, especially for deep high-pressure/high-temperature (HP/HT) targets in the Central Graben or in the Viking Graben. The addition of low frequencies to the spectrum allows easy discrimination of the main stratigraphic sequences found below the BCU. These low frequencies give an envelope to the seismic signal that shapes the larger-scale impedance variations corresponding to major lithology changes. This way, broadband data help in correlating seismic interpretation across major Jurassic fault blocks as well as better defining sub-BCU fault planes (Figure 9). At depth, the rich low-frequency content looks at first glance to be overwhelming, making the broadband data seem somewhat simpler and lower-resolution, with fewer reflectors to be interpreted. In reality, the low-frequency content is additional information compared to the conventional seismic, which is now very band-limited with large sidelobes which may give the false impression of higher resolution. As demonstrated earlier, a similar character can be achieved with the broadband data by applying a filter to limit its bandwidth to that of the conventional data.

The benefits for sub-BCU interpretation are also demonstrated in Figure 10 which displays a comparison of BCU amplitude maps for broadband variable-depth towed-streamer data and conventional data. This comparison illustrates the fact that broadband data give a much better definition of fault polygons and their associated amplitude.
discontinuities. In the upper left corner, the broadband amplitude map gives additional details of sub-cropping horizons which are more difficult to identify on conventional data. It is also worth noting that using the same technique to pick the BCU reflector on both the broadband and conventional datasets (i.e. manual horizon picking every 10 inlines, no crossline interpretation, and 3D auto-tracking using a 10 ms correlation window), the auto-tracking was noticeably faster on the broadband dataset and interpretation of the final 3D BCU horizon was less erratic (i.e., fewer mis-picks and spikes).

Conclusions
Broadband seismic techniques, such as the broadband variable-depth towed-streamer solution, offer a new opportunity for unlocking the remaining hydrocarbon potential of the mature UKCS. By providing low frequencies all the way down to 2.5 Hz and an overall bandwidth of up to six octaves, it enables the interpreter to:

- Accurately interpret stratigraphy, thin beds and subtle structures – a benefit of the sharp broadband wavelet with high-frequency content
- Produce a clearer interpretation of deep targets (sub-BCU, sub-chalk) and large-scale and subtle facies variations – a benefit of the strong low-frequency content
- Extract the ‘true’ seismic signature of the geological formations by removing the wavelet sidelobes – benefits of expanding the bandwidth to include both the low and high frequencies

Thanks to these benefits, broadband images make interpretation easier and more intuitive, saving seismic interpreters precious time, a key benefit in the race for finding the remaining hydrocarbon accumulations in the UK Continental Shelf area.

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References