IDAR HORSTAD AND JO FIRTH, CGG, EXAMINE RECENT DEVELOPMENTS OVER THE HORDA PLATFORM.

HIGHLIGHTING HORDA

Recent discoveries on the Norwegian Continental Shelf, such as Johan Sverdrup in the North Sea, and Johan Castberg, Gotha and Alta in the Barents Sea, have boosted exploration activity, both in previously explored and new frontier areas. The attractive exploration tax regime has encouraged more companies to enter the region, including the super-majors who are active in the Barents Sea, especially in the previously disputed areas bordering Russia.

The high energy prices prevailing until last year also led to a rise in activity in the Norwegian petroleum industry, with upgrading of older fields in addition to exploration for potential discoveries on new plays. However, the level of costs also rose substantially – a development shared with other petroleum provinces, reflecting the fact that oil and gas are being produced in ever more demanding areas. The recent sharp fall in the oil price, combined with a number of cost overruns, has contributed to reducing the financial robustness of a number of potential field developments and caused the postponement of the development of Johan Castberg. Nevertheless, investment and activity on the Norwegian Continental Shelf (NCS) are expected to remain at historically high levels, although some players are showing interest in divesting assets to optimise their project portfolio according to the new reality.

Weaker oil prices could drive necessary readjustments, which will strengthen the industry over the long term. There is still strong interest in development and activity remains high as four new fields came on stream in 2014 and 22 new discoveries were made. New wells produced more than expected last year and oil production increased for the first time since 2000, reaching 87.8 million Sm^3, 3% higher than last year, according to the Norwegian Petroleum Directorate.

Multi-client surveys provide a cost-effective means of acquiring high-quality data, as costs can be shared and larger surveys acquired for a better overall view of the prospect than is generally the case with proprietary surveys. Even in relatively mature basins such as the North Sea, where acreage is shared by many operators, multi-client surveys can be a cost-efficient tool for use as an aid to development. Access to large surveys in mature and virgin areas allows oil companies to reduce their exploration risk at an earlier stage and also help to reduce the time required from license award to drilling wells in new licenses. Postage-stamp-size surveys often leave holes in the data coverage, are inefficient due to the disproportionate time spent on turns, and have different acquisition parameters and azimuths, making regional exploration more challenging. Large continuous and consistent surveys are cost-efficient to acquire and therefore contribute to the oil companies' cost-cutting objectives and help to reduce total exploration spending by drilling wells with better de-risking.

In addition to simple seismic data packages, new programmes, such as the multi-client one CGG is currently acquiring over the Horda Platform (Figure 1), can deliver an integrated geoscience package including geological context, potential fields, satellite imagery, a high-quality well package, a prospectivity review, seismic reservoir characterisation and biostratigraphy, sedimentology and geochemical data, all in addition to reservoir-quality seismic data. These value-added products can help to identify and support drill locations, and so improve recovery and reduce costs. Provision of all these products by a single integrated geoscience company, with expertise in all the geological and geophysical disciplines, can not only shorten decision times, but the knowledge of how each item fits into the broader workflow ensures that each item is of higher value. This means that a better-quality product is delivered, even to those clients who only wish to purchase a single item or service. The goal is to reduce the time spent by clients to condition and integrate the data and allow more time to be spent on the generation of new play models and identification of new prospects, or to improve production from existing reservoirs.

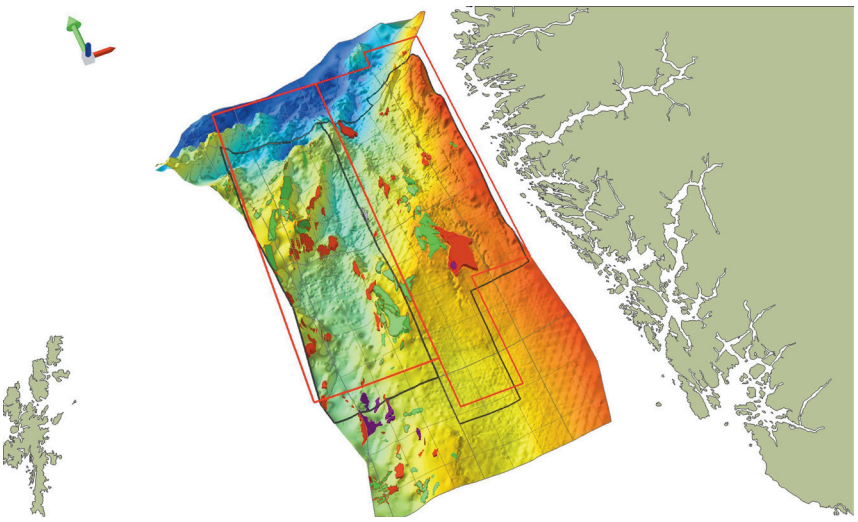

Figure 1. *Top Jurassic and outline of the Horda and Tampen surveys.*

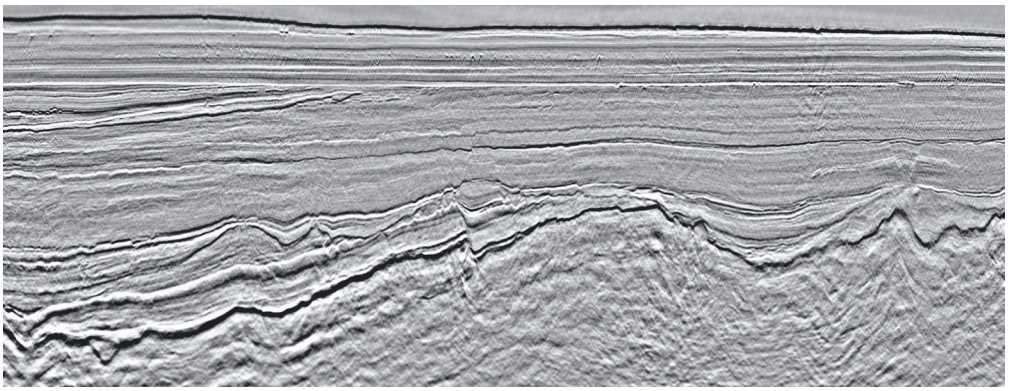

Figure 2. *Example of BroadSeis fast-track data showing the fine detail achievable in this area from full-bandwidth data (image courtesy of CGG Data Library).*

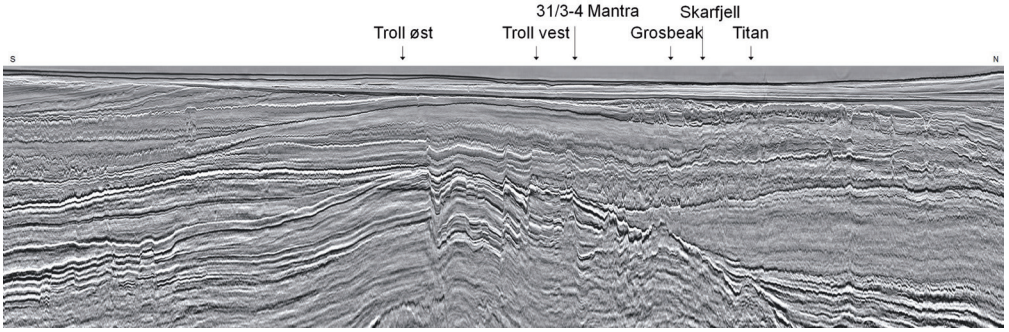

Figure 3. *Regional line through the major fields in the area extracted from the fast-track BroadSeis-BroadSource data (courtesy of CGG Data Library).*

The Horda programme is being acquired in two stages: the initial Horda survey launched in 2014 is still ongoing and will cover 18 000 km^2, while the adjacent Tampen survey, which began in April this year, will cover an additional 17 000 km^2. The two surveys will be merged in the future to form a contiguous data volume, providing the oil industry with a unique and continuous BroadSeis™ and BroadSource™ dataset over more than 35 000 km^2 of one of the most prolific basins in the world. The two surveys will cover the huge Troll gas and oilfield and giant oilfields such as Statfjord, Gullfaks, Snorre and Oseberg that have been in production for decades, in addition to several smaller oil and gas fields such as Gjøa, Fram, Vega and the recent Skarfjell and Grosbeak discoveries. These recent discoveries are demonstrating the future exploration potential in this region and CGG expects new data to provide the ground for new play concepts. The main challenges, in addition to the mapping and delineation of the Upper Jurassic sandstone and erosional remnants of Jurassic sandstones, are the complex petroleum migration system and late westward tilting of the entire region, resulting in remigration of oil and gas and the formation of new traps and

leakage from others. Remigration of gas is a very rapid process, whilst oil remigration requires millions of years to equilibrate and suggests that large volumes of oil might be present in stratigraphic or dynamic traps in this region. Whilst the previous seismic coverage in the area consists of a series of small surveys, ranging in vintage from the 1980s to 2010 with different acquisition parameters, a uniform high-end dataset such as that provided by the Horda and Tampen surveys is required to understand the complex geology in this area. The southern and eastern parts of the area are less explored and considerable interest is expected here as several companies have shown renewed interest in exploring for oil and gas outside the main oil play fairways after the recent new discoveries in the North Sea.

Both Horda and Tampen are BroadSeis variable-depth streamer surveys and are being acquired using the synchronised, multi-level broadband source, BroadSource, which provides the same low frequencies as a deep-towed conventional source, but fills the source ghost notch, to extend the spectrum in the high frequencies. This full-bandwidth solution includes specially developed deghosting algorithms to deliver ghost-free images with over 6 octaves of bandwidth, from 2.5 Hz to the Nyquist recording interval (Figures 2 and 3). One of the different deghosting algorithms that has been developed for performing ghost wavefield elimination (GWE) is being applied to the data pre-stack and pre-imaging (Poole 2013) to create an ideal broadband wavelet, i.e. one with a sharp central peak and minimal sidelobes.

BroadSeis capitalises on the exceptional low-noise characteristics of Sercel Sentinel® solid foam-filled streamers (Dowle 2006), which have been proven to be 10 - 15 dB quieter than gel streamers below 10 Hz in vibration tank tests. The proprietary curved streamer shape enables the majority of the streamer to be towed deep, up to 50 m. This deep tow avoids much of the sea-state noise and extends the weather window for greater operational efficiency and faster turnaround times, as well as enabling the recording of ultra-low frequencies. While BroadSeis addresses the low frequencies and the receiver ghost notch, BroadSource further extends the frequency range to the sampling interval Nyquist, by eliminating the source ghost notch, within the limits of the Earth's absorption. The notch is filled by combining acquisition using a multi-level source (Siliqi 2013), with specially developed processing algorithms to deliver full bandwidth seismic.

The ultra-low frequencies achieved using the BroadSeis solution provide better penetration through complex overburdens, improved signal-to-noise ratios for deeper targets and more quantitative seismic inversion. The enhanced layer differentiation, with improved texture and character, makes interpretation more straightforward.

The removal of the source ghost notch using BroadSource provides sharp ghost-free wavelets with frequencies up to the sample interval Nyquist in the shallow section. This delivers incredible resolution and detailed 3D images of the near-surface (Figure 4), enabling accurate velocity picking of the first seabed layers. It becomes possible to identify sedimentary infill in old glaciation channels and clearly delineate unconformities and geohazards.

Close collaboration with clients helped to identify which regions and stratigraphic intervals would be better imaged by improved resolution, as play models in this area range from the basement to the Pleistocene. The variability of the streamer depth and shape of the cable can be tuned for different water depths and targets so that the notch diversity and output spectra are optimised for the survey. By combining information from clients with the geological expertise of geoconsultants it was possible to design the optimum acquisition parameters for the Horda and Tampen surveys. In addition careful planning and co-ordination with the Maritime Research and Fisheries representatives on land avoided conflict and promoted a good working relationship during operations.

Last year's acquisition of part of the initial Horda survey was conducted by the Oceanic Phoenix and the Viking Vanquish, each towing twelve 8 km streamers, with 75 m separation. In order to acquire the data as quickly as possible, the two vessels were employed simultaneously on the survey, working semi-independently but making use of advanced navigation tools, that allow the planning and management of seismic interference (SI) (or noise contamination from

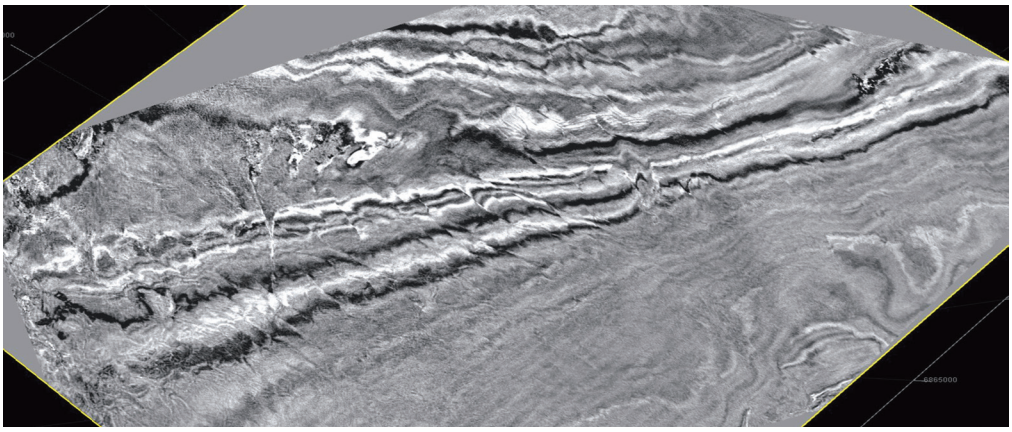

Figure 4. *Timeslice through Horda fast-track data (image courtesy of CGG Data Library).*

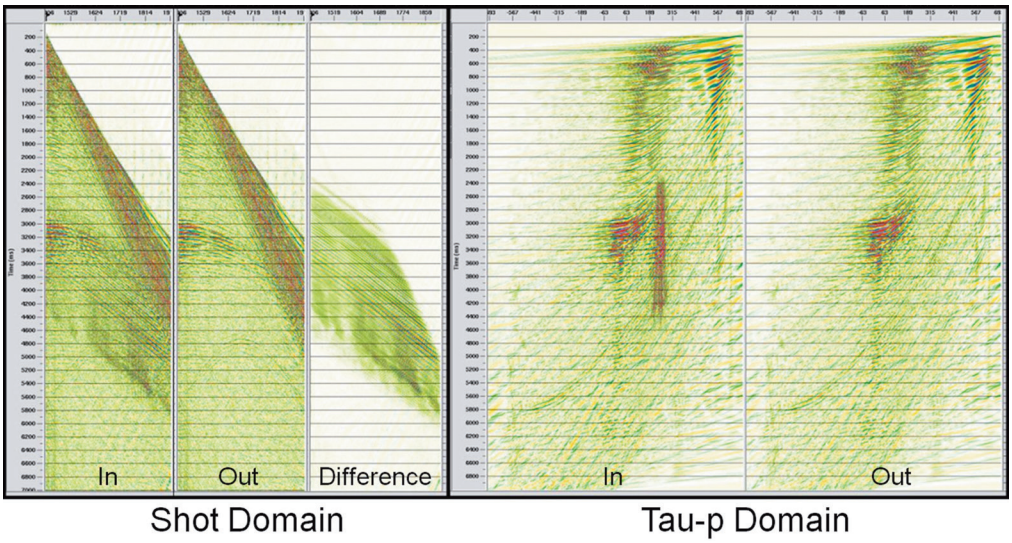

Figure 5. *Seismic Interference attenuation.*

the nearby vessel shots) to be only that which can be attenuated in processing. The success of this strategy last year has led to it being used again for this season's acquisition in order to acquire as much data as possible before the fishing season halts the surveys.

In the shot domain, SI tends to be coherent, dispersive and fairly linear. When sorted away from shot order it tends to be incoherent, random and intermittent, as long as it does not occur at the same time on each shot. The easiest way to ensure that SI is not synchronous is to vary the vessel speed when the two vessels are passing each other so as to avoid shot-to-shot coherence of noise. Where possible, SI is attenuated by careful dip filtering in the shot domain, but, when necessary, data can be sorted away from shot order so that the noise is randomised, and can be attenuated with multi-dimensional impulsive denoise tools. In extreme cases, the noise can be modelled in the tau-p domain and subtracted from the input data. This combination of planned acquisition and processing enables the vessels to work with up to 20 km separation and the data to be acquired in half the time without degrading quality (Figure 5). As both vessels use a conventional spread, there is no loss of near offsets (and therefore shallow coverage) that would come from using an extra-wide streamer spread to reduce acquisition time.

Both the fast-track and full imaging of the survey is being undertaken in Norway. Fast-track data of the first 8500 km^2 to be acquired was delivered in September 2014, only 10 weeks after completion of the acquisition. Both the final data for this area and the fast-track data for the full 18 000 km^2 Horda survey will be available in October/November 2015. Gravity data over the area is being used to define the basement depth, and this information is being incorporated into the velocity model building for imaging the data. The full production data is going through a comprehensive reservoir-oriented processing QC workflow to ensure the final delivered data will be reservoir-ready i.e. requires very minimal pre-conditioning prior to elastic inversion and reservoir characterisation studies. In this workflow, the data is migrated at various key stages to look at the evolution of well-ties, wavelet stability and AVO compliance, etc. Information from several pre-selected wells is being integrated and maps of relevant QC products, following horizons, will show spatial variations and conformity with known geological information.

The Horda and Tampen surveys have been designed with longevity in mind. The data are being acquired on a relatively dense grid (18.75 m crossline bins) and at an azimuth carefully selected to be correct for using the survey as a baseline 4D in future. They cover several discoveries, and although there are other 3D surveys in the area, none of these are broadband or are as extensive. Horda (and later, Tampen) will deliver an unprecedented array of integrated geoscience data in an easily accessible form, that can be directly used by clients for reservoir modelling, play evaluation, well location, etc. Even clients who wish to purchase only the seismic data will benefit from the integration of well and gravity data, as well as extensive QC using AVO tools, to deliver a dataset that is truly reservoir-ready for them to perform their own analyses. It is believed that this survey represents the future of multi-client seismic surveys in Norway – extensive, detailed, integrated and cost-effective.

Acknowledgement

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