Imaging drilling hazards in the Forties oilfield using nodal ocean-bottom seismic
K. Koster¹, D. Monk¹, A. Rokkan², S. Ronen², R. Bouraly², E. Bathellier²
¹Apache
²CGGVeritas

Summary
Reliable seismic images of gas accumulations in the shallow subsurface underneath the production platforms in the Forties oilfield are mitigating drilling risks and reducing drilling costs. Ocean Bottom Nodes were selected to record the seismic data for the ability to operate safely and efficiently in obstructed and busy oilfields. The resulting seismic images allow extra care to be taken during drilling of wells where gas is likely to be encountered. The resulting operations are therefore optimized in terms of both safety and costs.

Introduction
The Forties Field was acquired by Apache in 2003 and is the largest known single oil accumulation in the United Kingdom, with approximately 5 billion barrels originally in place and 2.6 already produced. Apache has since conducted an intensive seismic monitoring program to re-evaluate the field for further exploitation. However, all 3D seismic imaging programs occurred after the platforms were constructed and did not properly image and characterize the shallow gas accumulations. Even with a dual-source undershoot, Apache was unable to identify the shallow hazards directly beneath and around the platforms (Fig. 1).

In 2009, Apache decided to try a novel application of ocean-bottom seismometers to image the area directly underneath and around the platforms. Acquisition specifications for these devices can be accommodated using either ocean-bottom cable or ocean-bottom node (OBN) technology. The first method requires deployment of heavy cables from industrial reels at the back of a boat and, in practice, cannot be performed underneath platforms and among seabed obstructions such as pipelines and power lines. OBN technology, on the other end, can be deployed on an obstructed seabed. The remotely operated vehicles (ROVs) used to deploy the nodes have accurate acoustic and inertial positioning, visual communication, and controlled handling that enable deployment close to and even beneath platforms, as well as on a seabed obstructed by pipeline and power infrastructure. The compact nodal design is such that multiple nodes can be strategically placed to avoid the infrastructure, providing the optimal coupling to the seabed with the least noise, thereby recording a better signal and ultimately delivering better image resolution.

With the images produced from the acquisition and processing of nodal data, it was possible to identify the drilling hazards and either avoid them or prepare for them using gas-line diverters (Ronen et al., 2012).

Survey Design and Acquisition
The 15-day acquisition program called for a hexagonal receiver geometry using 58m (190 ft) spacing between nodes with a total of 154 nodes deployed (Fig. 2a). As this was a high-resolution shallow target, a small airgun source usually used for vertical seismic profiling was chosen, and a 10m (33 ft) source interval was used to optimize the area of coverage. As with many programs, the actual receiver layout varied to accommodate seabed obstacles such as facilities, fallen debris (scaffolding)
Imaging drilling hazards using nodal ocean-bottom seismic

from storms, and noise sources such as 50Hz power lines that would have contaminated the signal quality. The ROV acoustic and inertial positioning provided the actual placement locations, generating a more accurate dataset for record reconciliation.

The initial design specified parallel source lines, which would have required a larger area near the platforms and would have created gaps in the shot carpet. In addition, parallel source lines require turning the vessel 180° at the start of each new line, which would have wasted valuable time. To avoid these issues, the survey parameters were adjusted to accommodate new spiral source geometry, with 10m spacing between spirals (Fig. 2b), which reduced the shooting time and optimized the area of coverage near the platforms. Although the shots deviated from the preplot ideal spiral and there was a slight delay in shooting when a supply boat serviced the rigs, the shot gaps were relatively unimportant and easily corrected during processing. Infill shooting was performed over holes recognized in the primary sequence shot coverage, and the obvious larger hole where the platform was situated was purposefully designed to be infilled during processing. Coverage maps generated in the field confirmed that the holes were within reasonable processing constraints and allowed the acquisition to be modified in the field, saving time and money that would have been required for a reshoot.

In-field processing QC included preliminary imaging of the drilling hazards. This is particularly useful to an operator and an observer because soon after the nodes are retrieved, it is immediately possible to determine whether a sufficient amount of data, of sufficient quality, has been gathered before proceeding to the next platform. The onboard processing QC also enabled identification and quantification of seismic interference noise from another seismic survey taking place in the area. The node’s QC features made it possible to determine that the records were not contaminated by the additional noise and that the seismic interference could be filtered during processing without damaging the quality of the data.

To eliminate signal distortion caused by having a geophone on the outside of the node, as in some architectures, the Trilobit node contains a hydrophone and three geophones in a Galperin arrangement, meaning all four sensors are located within the casing of the node itself. The integrated design reduces the noise induced by the scattering of shear waves and P-waves into an external sensor. It also has an analog-to-digital converter with an accurate clock, memory and batteries for up to 90-day deployment. To minimize clock drift deviation from linear, the clocks were synchronized via the ROV on the seabed using coil and optical communication. A specially designed baseplate provided improved seabed coupling and a low center of inertia, thereby reducing the likelihood of movement of drifting due to strong currents.

The nodes were deployed from the ROV using a robotic arm equipped with a suction cup. The node containment system included a skid that fit under the ROV with a drawer holding up to 6 nodes, a standalone basket that contained up to 18 nodes (in three drawers) and the means to move drawers between the ROV and the basket (Fig. 3).

After training, the ROV pilots learned to deploy and retrieve the nodes and to dock into the node basket. The survey duration was two to seven days for each platform, depending on weather. During the acquisition, an average efficiency of two nodes per hour during the first platform deployment, three nodes per hour on the second and, finally, four nodes per hour on the third was reached. No nodes were dropped or lost during the survey.

Data Processing

Like all node surveys, the design is for sparse receiver and dense shot carpet. Most of the data processing is performed in common receiver gathers. Unlike most other node surveys the shooting was based on time and not on location, so a perfectly regular grid does not result. The processing sequence included correction for the internal node “clock drift” during acquisition, shot deviations, vector rotation to tilt the Galperin-oriented
geophones to true horizontal (x and y) and vertical (z) components, and some denoising on the vertical geophone component. The seismic data were mostly very clean, but the nodes nearest to the platforms had some shear-induced noise bursts.

A 1D geophone-hydrophone calibration was applied before separation into upgoing (P + Z) and downgoing (P – Z) wavefields. The upgoing data had a simple gap deconvolution applied to remove any residual multiple. The downgoing wavefield used prediction and adaptive subtraction to attenuate high-order multiples while leaving the first-order multiple energy intact for mirror migration. The data were Kirchhoff depth migrated using two imaging methods: 1) the conventional imaging of upgoing primary reflections and 2) imaging of first-order multiples in a method called mirror imaging (because the sea surface is used as a mirror). In the latter method, the lengthened ray paths of the multiples create virtual receivers above the sea surface, and allow longer offsets to be imaged for a given depth. Mirror imaging offered better results, mainly because it widens the illumination from each node (Grion et al., 2007). Post-imaging residual move-out corrections, stack and spectral shipping produced the final volumes. For each platform, three cubes were produced. The image of the upgoing P-waves, the mirror image of the downgoing P-waves (which is an image of the first multiple), and the mirror image of the first multiple with higher-order multiples attenuated (Fig. 4).

Data Evaluation and Interpretation

The area illuminated by the nodes covered an area away from the platforms that overlapped with area covered by streamer data. Data evaluation and validation was based on comparison of the images from the nodes to the images provided by 2D and 3D streamer surveys that were available away from the platforms (Fig. 5). Significantly, the same bright spots were seen by all three methods, wherever they were illuminated. This gives confidence to the interpretation as drilling hazards of bright spots under the platforms which were illuminated only by the nodes (Koster et al., 2011).

Conclusions

With the images produced from the acquisition and processing of node data, it was possible to identify the drilling hazards and either avoid them and/or prepare for them using gas-line diverters at the depth(s) predicted in the new seismic data. In addition, the flexibility of node technology enabled efficient deployment and improved imaging beneath platforms where conventional streamer and ocean bottom cable acquisition would have been economically and functionally prohibitive. The ability to tie OBN data to existing 2D and 3D data gives a more comprehensive overview of the field and can validate or refute initial assumptions, thereby creating opportunities to more fully exploit an asset with tighter well placements and reduced drilling risk.

References

Imaging drilling hazards using nodal ocean-bottom seismic

Figure 4: Comparison of node data imaged with three different processing methods. Note that the seabed and shallow reflectors are not imaged by the upgoing waves. Mirror imaging is of the first multiple but higher order multiples are still present. Otherwise, the same bright spots that are interpreted as drilling hazards are imaged more or less consistently by all three processing methods.

Figure 5: Comparison of node data imaged with three different acquisition methods. Note the differences in illumination, frequency content, and noise. Only the nodes provide an image of the shallow drilling hazards under the platforms. Otherwise, the same bright spots are interpreted as drilling hazards are imaged more or less consistently by all three acquisition methods.