Imaging shallow gas drilling hazards under three Forties oil field platforms using ocean-bottom nodes

Shuki Ronen, Arne Rokkan, Rafael Bouraly, Geir Valsvik, Leif Larson, Erik Ostensvig, Jimmy Paillet, Anna Dynia, Agata Matlosz, Simon Brown, Simon Drummie, and Julian Holden, CGGVeritas
Klaas Koster and David Monk, Apache
Mike Swanson, EPI

Reliable seismic images of gas accumulations in the shallow subsurface beneath production platforms are mitigating drilling risks in the Forties oil field. Ocean-bottom nodes (OBN) were selected to record the seismic data due to their ability to operate safely and efficiently in busy and obstructed oil fields. The resulting seismic images allow extra care to be taken during drilling where gas is likely to be encountered. The resulting operations can therefore be optimized in terms of both safety and costs.

Drilling hazards in the Forties Field

The Forties Field, 110 miles east of Aberdeen, Scotland is the largest single oil accumulation in the United Kingdom, with approximately 5 billion barrels remaining in place and 2.6 already produced. Apache acquired the field in 2003 and has conducted an intensive seismic monitoring program to reevaluate the field for further exploitation. It discovered an additional 800 million barrels of oil in place, a significant increase over the previously estimated 4.2 billion barrels remaining in place in 2003. A combination of 4D reservoir monitoring and commissioning new seismic surveys that included imaging areas beneath existing platforms helped Apache in the placement of new wells and in safe drilling and completion programs that increase production and recovery.

Shallow gas has been a major drilling hazard in Forties Field. A fire caused by shallow gas severely damaged the Delta platform in 1985. The gas is easily identified as bright spots on seismic data, and there is an abundance of such data in Forties Field (Figure 1) but all of it was acquired with towed streamers after the platforms were put in place. Hence, there was no usable seismic image of the shallow subsurface under the platforms!

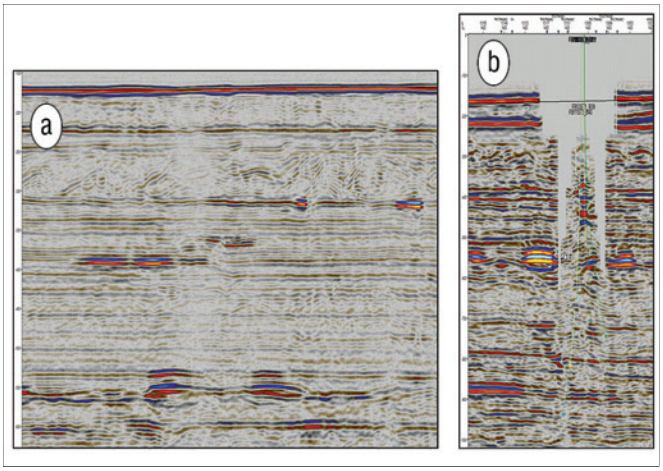

Figure 1. *(a) 2D high-resolution site survey. (b) 3D undershoot data taken from a 4D monitoring streamer survey using dual-vessel undershoot with a separate source vessel. Drilling hazards are identified in both data sets as bright spots. However, streamer data cannot image the potential drilling hazards under the platforms. The 2D data are 100 m away from the platform and the absence of data directly underneath the platform is clearly visible in the 3D undershoot (b).*

Figure 2. *Nodes serviced between retrieval and deployment. The nodes were containerized, deck handling included, and mobilized on a vessel of opportunity. There were two ROVs already on board; one was adapted to handle nodes. Apache chose to use Trilobit nodes for their ability to be containerized and mobilized on the ROV vessel already working in the field.*

After acquiring the field, Apache initially opted to drill more than 100 sidetracks from existing wellbores, thereby mitigating the shallow-gas risk altogether. This method substantially increased production, and in 2008–2009 Forties Field became the second-highest producing field on the United Kingdom Continental Shelf. However, the ability to continue with successful infill drilling required new wells and a thorough understanding of the subsurface to locate the shallow gas accumulations. Gas diverters mitigate blowout risk, but seismic images enable better planning.

Traditionally, the area around an offshore rig is a dead zone in a seismic data set if the data were not acquired before the platform was constructed. This is because towed-streamers must maintain a safe distance from the platform so as not to tangle, collide, or interfere with production. Production and drilling platforms prevent streamers from being used safely and effectively. However, ocean-bottom nodes can be deployed safely near and even under surface obstructions. Remotely operated vehicles (ROV) also can deploy nodes close to seabed facilities such as pipelines. For these reasons, Apache chose to use ocean-bottom nodes to obtain shallow images directly under existing platforms.

Data acquisition

CGGVeritas' Trilobit OBN solution (Figure 2) was chosen to perform the complex survey underneath three platforms: Bravo, Delta, and Charlie. An ROV vessel already working in the field was adapted for deployment and retrieval. The *Skandi Olympia*, owned and crewed by subsea specialist Dof, was available for use, and the chosen nodes were designed to be containerized and deployed on such a "vessel of opportunity." In a few days the *Skandi Olympia* was outfitted with nodes and a node-deck handling system, and one of the ROVs on the vessel was outfitted with the subsea handling system. A containerized source was also mobilized together with the nodes. Observers, navigators, and onboard processors came from CGGVeritas; the source crew, air guns, and compressors came from READ Well Services; the Fugro ROVs, pilots, mechanics, and surveyors were already on the boat. Apache sent three representatives: two U.K. health and safety executive supervisors and one geophysicist.

The volcanic eruption in Iceland in April 2010 interfered with the mobilization. Some of the crew were delayed due to canceled flights, but they made it to Aberdeen by ground transportation with only a slight delay. Several nodes, however, were stranded in Norway, and the *Skandi Olympia* departed from Aberdeen prior to their arrival. Fortunately, the nodes are heli-portable. They arrived at platform Charlie, and from there were delivered via crane to the *Skandi Olympia* (which does not have a helideck).

Utilizing the *Skandi Olympia* crew and vessel provided additional safety advantages. The crew had intimate knowledge of Forties Field and knew how to navigate the area safely while doing far more complicated work on the facilities than would be required to deploy and retrieve the nodes.

Careful coordination and management of the acquisition was led by an Apache consultant who, as a geophysicist, was on top of the mission and effectively assumed the role of party chief for the duration of the survey. As the overall project manager, Apache managed all of the intricate details of bringing together four highly reputable firms to collaborate on this complex acquisition. The successful completion of the program required that all parties understand the relevance of their functions and the interwoven nature of their expertise to the imaging objectives of Apache.

We designed the survey with hexagonal receiver geometry and spiral-source geometry. A total of 154 nodes were deployed with 58-m spacing between them. Because this was a high-resolution shallow target, a small air-gun source usually used for vertical seismic profiling (VSP) was chosen (Figure 3), and a spiral-source geometry of 10-m spacing inline and between spirals (Figure 4) was used to optimize the area of coverage. The spiral-source geometry allowed the team to optimize the area of coverage near the platforms and reduced the shooting time.

As expected (and perhaps somewhat more than expected), the actual shot-and-receiver geometry (Figure 5) deviated from the plan. This was for operational reasons and to accommodate seabed obstacles such as facilities, fallen debris such as scaffolding that fell from the platform during storms, and noise sources such as 50-Hz power lines that would have contaminated the signal quality. The ROV acoustic and inertial positioning provided accurate node-placement locations, and GPS on the source's float provided the actual source positions. Infill shooting was performed over small holes recognized in the primary sequence shot coverage but obviously the larger holes where the platforms were situated could not be infilled, and the inevitable geometry irregularities would have to be corrected in processing. Coverage maps generated onboard before node retrieval confirmed that the holes were within reasonable processing constraints and proved to be valuable tools in a decision to stop shooting and retrieve nodes.

Figure 3. *The crew utilized a small air gun as the energy source to illuminate the shallow target hazards. The source was containerized, compressors included, and mobilized on the vessel of opportunity.*

In-field data-processing quality control (QC) after node retrieval included first-break picking to QC the geometry and time drift on the clocks, and preliminary imaging of the drilling hazards using mirror imaging. This is particularly useful because soon after the nodes are retrieved, it is possible to discern if sufficient quality and quantity of data have been gathered before proceeding to the next platform. The onboard processing QC also enabled identification and quantification of seismic interference (SI) noise from another seismic survey in the area. The QC made it possible to determine that the records were not too contaminated by the additional noise and that the SI could be filtered during processing without damaging data quality. To ensure the SI noise could be tolerated, a memory stick carrying node data was lifted

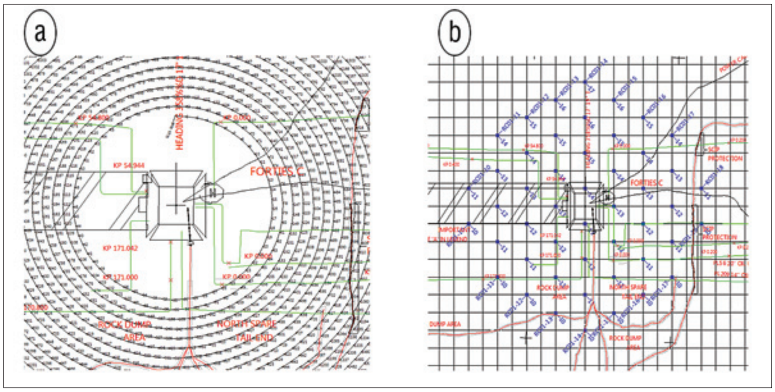

Figure 4. *(a) Preplot of the spiral-source geometry (10-m interval and 10 m between spirals). (b) Preplot hexagonal receiver spacing under the platform (58-m spacing between nodes).*

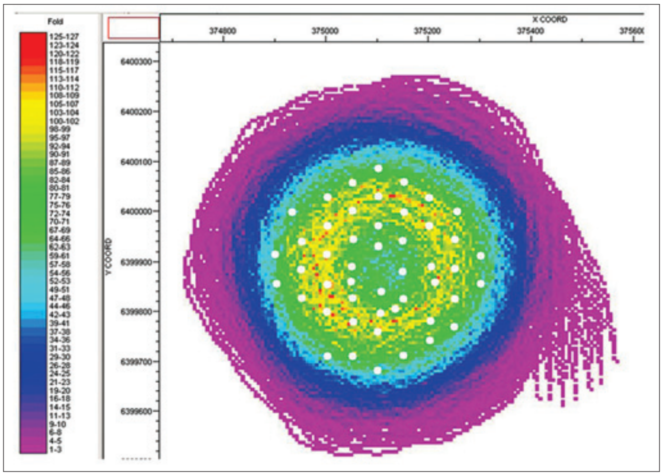

Figure 5. *Actual placement of source and receiver points. White dots indicate the location of the Trilobit nodes. Colors indicate the fold for 52 deployed nodes.*

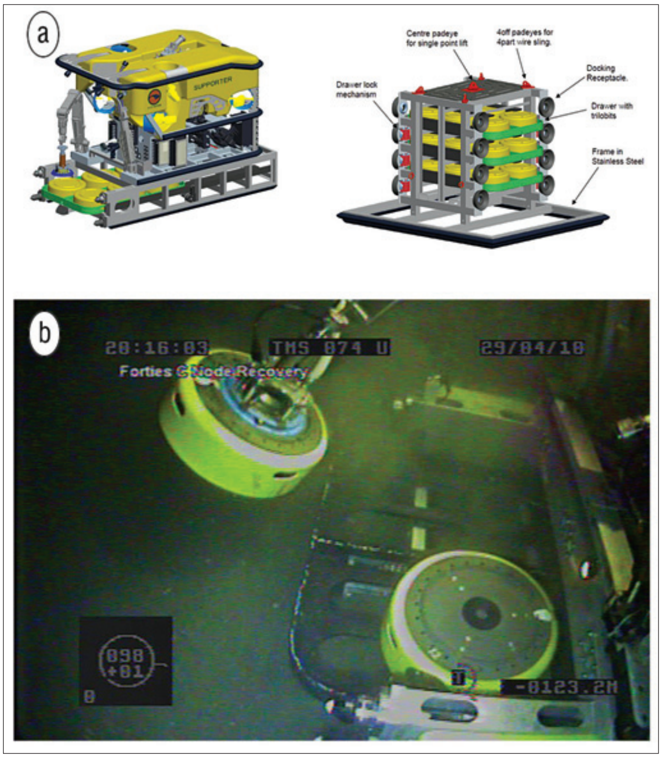

Figure 6. *(a) ROV that could be used to deploy the nodes on the seabed with suction-cup extraction from a special tray holding up to six nodes. (b) Node basket containing three drawers of six nodes that is lowered to the seabed for efficient deployment and retrieval. The special skids under the ROV move drawers between the ROV and the basket.*

via crane from the *Skandi Olympia* onto a platform, and then flown by helicopter to a processing center onshore. This example of offshore processing and onshore support proved invaluable in the decision to progress to the next platform.

In each node, a hydrophone and three geophones in a Gal'perin arrangement were located within the node casing. Each node contained an analog-to-digital converter with clock, memory, and batteries to last 90 days. The clocks were synchronized via the ROV on the seabed using electromagnetic coil and optical light communication. This minimized clock-drift deviation from linear because the nodes were in a constant temperature and physically stable between clock synchronizations. A specially designed baseplate provided improved seabed coupling and a low center of inertia, thereby reducing shear-induced noise and providing excellent vector fidelity.

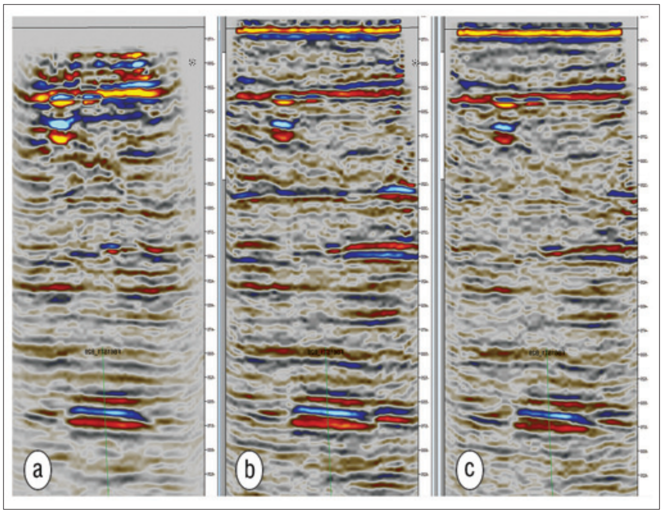

Figure 7. *Three sets of processed data were provided for each platform. (a) Upgoing P-wave. (b) Mirror image using the first-order multiple. (c) Mirror imaging with demultiple. Note that, as expected, the upgoing image fails to image the seabed and shallow drilling hazards. Also note the higher-order multiples that are attenuated (c) using a predict-and-subtract method. The drilling hazards under the platforms are clearly identified by the bright spots indicating shallow gas accumulations.*

The node deployment method, using a suction cup, is an industry-standard ROV-handling method (Figure 6). After video training, the ROV pilots, who had never handled nodes prior to this survey, learned to dock into the node basket and to deploy and retrieve the nodes. The survey duration was 2–7 days for each platform, depending on weather conditions. During the acquisition, the newly trained ROV pilots became more efficient, averaging only two nodes per hour during the first platform deployment, increasing to three nodes per hour on the second, and four nodes per hour on the third platform. No nodes were dropped or lost during the survey.

For accurate node positioning, we relied on the ROV's hydroacoustic-aided inertial navigation (HAIN), which was based on gyro-assisted ultrashort baseline (USBL). Node heading was derived visually from the ROV gyro. The node heading and positions, as well as the source positions, were checked and corrected during processing using the seismic data.

As expected, April weather in the North Sea and simultaneous operations with supply boats caused some delays, however the survey was completed safely and on schedule—within 15 days.

All 154 nodes were retrieved upon completion of the program. Only one node failed to record data all the time for a satisfactory data recovery rate (99.7%). Like most other node surveys, the design specified sparse receiver configuration with dense source geometry. Most of the data processing was performed in common-receiver gathers. Unlike most other node surveys, the

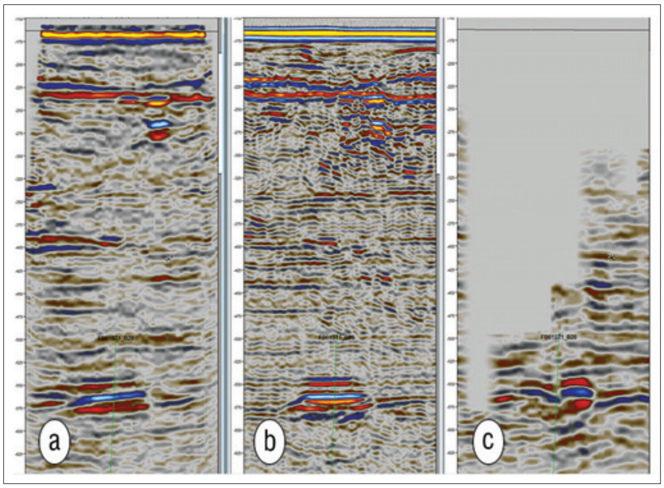

Figure 8. *To verify the node data (a), the team cross-referenced and compared the interpreted results utilizing a common subsurface line 100 m away from the platform. The data from the OBN acquisition were compared with legacy 2D seismic data (b) and the 3D undershoot data (c). The node data clearly identify the same hazards where streamer data were available. Most importantly, these data also can identify hazards where streamer data are unavailable.*

source lines were curved on spirals, and we gave precedence to shooting on time rather than on location. As planned, the geometry irregularities were taken into account during processing and imaging.

Data processing

The processing sequence included correction for the internal clock drift, shot geometry and signature deviations, vector rotation to tilt the Gal'perin-oriented geophones to true horizontal (x, y) and vertical (z) components, and some denoise on the vertical geophone component. Only the nodes near the platforms had shear-induced "VZ-noise." Geophone-hydrophone calibration was applied before separation into upgoing (P+Z) and downgoing (P-Z) wavefields. The upgoing data had a simple gapped deconvolution applied to remove any residual multiples. The downgoing wavefield used a predictive and adaptive subtraction technique to attenuate higher-order multiples while leaving the first-order multiple energy intact for mirror migration.

The data were Kirchhoff depth-migrated. The irregular subsurface coverage was accounted for during the imaging. The data were imaged using two methods: (1) conventional imaging of upgoing primary reflections, and (2) imaging the first-order multiples in a method called "mirror imaging." In mirror imaging, the sea surface is used as the mirror, where the lengthened raypaths 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 the illumination from each node is wider than with conventional imaging. Post-imaging residual moveout correction, stack, and spectral shaping produced the final volumes. The data-processing team produced three cubes of data for each platform: the image of upgoing P-waves, the mirror image of downgoing P-waves (which is an image of the first multiple), and the mirror image of the first multiple with higher-order multiples attenuated (Figure 7). The bright spots shown were interpreted as drilling hazards. The processing was completed on time for Apache's drilling program.

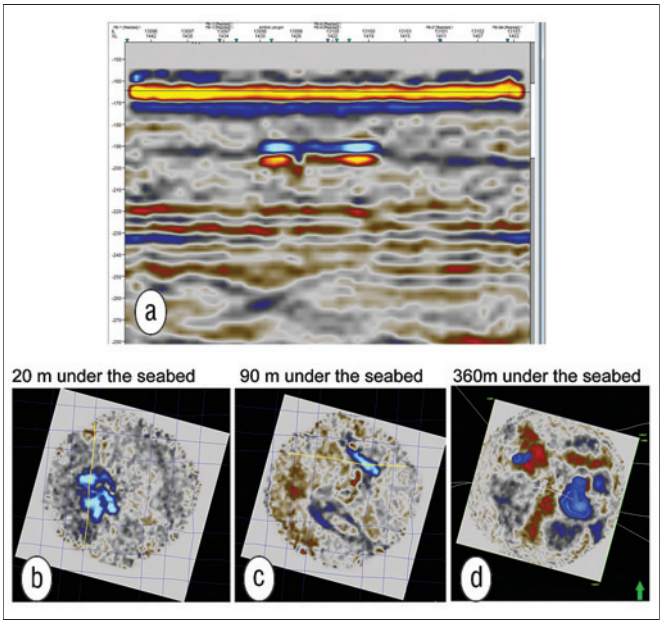

Figure 9. *Downgoing mirror-imaged node data provide 3D image of hazards below platform as shallow as 20 m below seabed. (a) Cross section. (b) Depth slice at 20 m under the seabed. (c) Depth slice at 90 m under the seabed. (d) Depth slice at 360 m under the seabed.*

The zone illuminated by the nodes included coverage of an area away from the platforms which overlapped an area previously covered by streamer data. Data evaluation and validation were based on comparison of the images from the nodes to the images provided by 2D and 3D streamer surveys (Figure 8). Significantly, the same bright spots were seen by all three methods, wherever they were co-imaged. The interpretation of drilling hazards depicted by bright spots underneath the platforms was visible only on the node data set, because the other data sets have no data where the platforms are located.

Summary

The successful use of OBN technology to identify drilling hazards (Figure 9), particularly gas accumulations, improves the ability to safely drill new wells in producing fields by providing a more complete understanding of the subsurface. 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 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. **TLE**

Corresponding author: shuki.ronen@gmail.com