

Mitigating drilling hazards in the North Sea using ocean-bottom seismic

To facilitate infill drilling at Forties field, 3D seismic data was needed to image any shallow gas accumulations, but towed streamers couldn't acquire data beneath or near existing platforms. A nodal acquisition technology using ROV-deployed sensors filled in the blanks.

■ **KLAAS KOSTER and DAVE MONK, Apache; ARNE ROKKAN, RAFAEL BOURALY, SIMON BROWN, ALLISON BRANAN and SHUKI RONEN, CGGVeritas**

It is imperative for operators to have detailed maps of pipelines and other offshore subsurface hazards, such as gas accumulations, in order to plan new well placements in an existing field. The capacity not only to evaluate the locations but also to quantify drilling hazards will greatly improve an operator's ability to exploit a field safely and cost-effectively. This necessity was illustrated at Forties field in the North Sea, where a fire

caused by a gas accumulation severely damaged the Forties Delta production platform in 1985.

To avoid a similar incident, Apache, which purchased the field from BP in 2003, designed an intensive seismic program to reevaluate the field for further exploitation. Located 110 miles east of Aberdeen, Forties field was first discovered in 1970 and began initial production in 1975. Thus, four decades worth of seismic data existed. 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 ob-

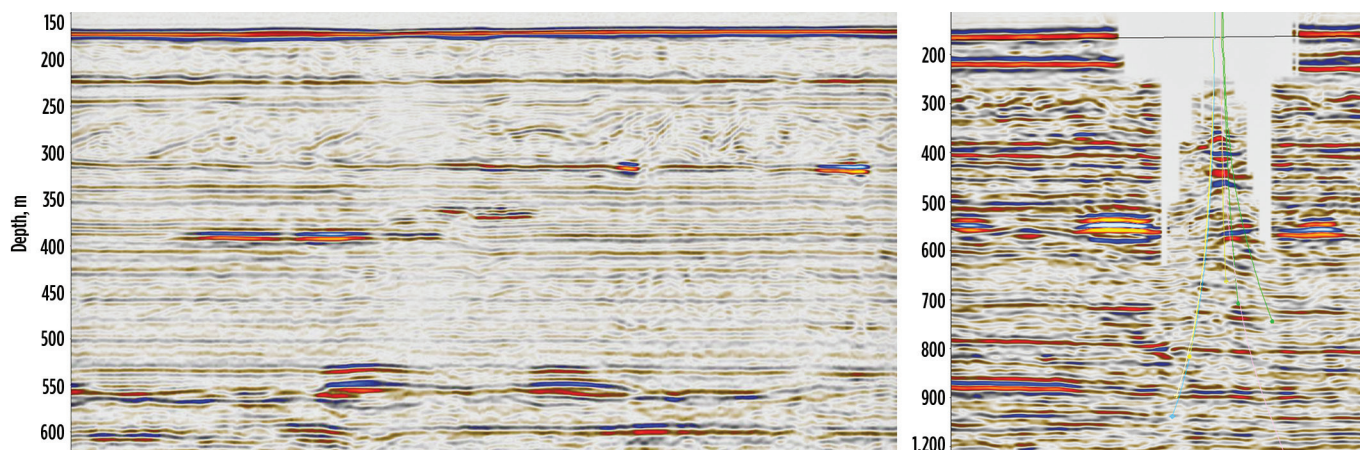
structions such as pipelines and power lines. OBN technology, on the other hand, can be deployed on an obstructed seabed. The remotely operated vehicles (ROVs) used to deploy the nodes have accurate acoustic and inertial positioning, visual communication and controlled handling that enable deployment 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.

DEPLOYMENT

Apache chose CGGVeritas' Trilobit autonomous nodes to perform the complex survey underneath three platforms: Bravo, Delta and Charlie. The nodes' containerized design allows deployment from a vessel of opportunity, which means the system can be easily transported and

Fig. 1. A high-resolution 2D site survey (left) and a dual-source 3D undershoot program. The 2D program identifies much fewer potential drilling hazards (imaged as bright spots) than the 3D survey. The absence of data directly under the platform is clearly visible in the 3D undershoot.



quickly mobilized on a boat already in use in the field, providing safety advantages and cost savings. Other nodal systems may require dedicated vessels that can take several weeks to mobilize and use additional fuel, personnel and overhead to operate. Utilizing a vessel of opportunity essentially requires training of the local vessel crew to ensure proper management and handling of the nodes and energy source.

For this survey, Apache was already contracting a vessel, the *Skandi Olympia*, through DOF Subsea for Forties field. The vessel was easily converted and outfitted in Aberdeen to support the nodes, handling system and personnel provided by CGGVeritas; the airguns provided by READ Well Services; and the ROV equipment and crew provided by Fugro. The volcanic eruption in Iceland in May 2010 delayed delivery of some of the equipment, including several nodes and crew who were stranded due to cancelled flights. Unfortunately, the *Skandi Olympia* had to maintain its schedule, and departed from Aberdeen prior to their arrival. However, the containerized design of the Trilobit nodes made it possible to transport the remaining equipment and crew via helicopter to the field, and the survey was able to begin as scheduled. Using the *Skandi Olympia* crew and vessel provided additional safety advantages because the crew had intimate knowledge of the field and knew how to navigate the area safely while doing far more complicated work on the rigs than would be required to deploy and retrieve the nodes.

Coordination and management of the acquisition was led by an Apache consultant who effectively assumed the role of

party chief for the duration of the survey. His role included locating the vessel of opportunity and coordinating the energy source, the node recording equipment and the ROV delivery and utilization throughout the acquisition. The successful completion of the program required that all parties understood the relevance of their functions and the interwoven nature of their expertise to the imaging objectives.

SURVEY DESIGN AND ACQUISITION

The 15-day acquisition program called for a hexagonal receiver geometry using 58-m (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 10-m (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) from storms, and noise sources such as 50-Hz 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.

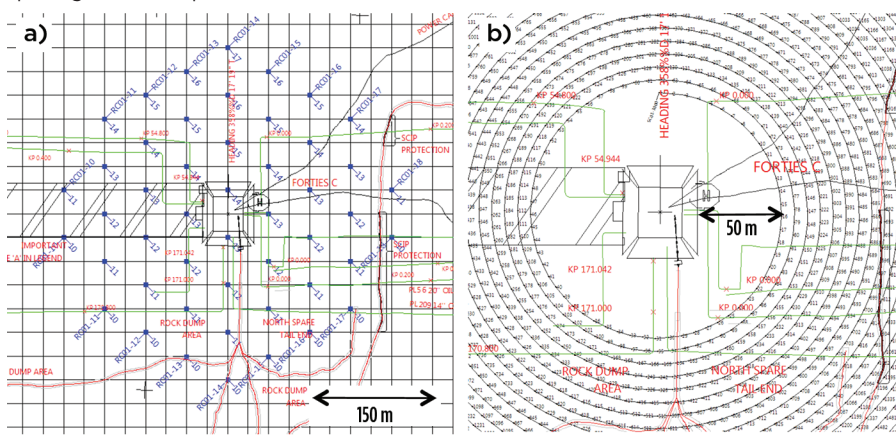
The initial design specified parallel source lines, which would have required a larger area near the platforms and would have created gaps in the shot carpet. In addition, parallel source lines require turning the vessel 180° at the start of each new line, which would have wasted valuable time. To avoid these issues, the survey parameters were adjusted to accom-

modate a new spiral source geometry, with 10-m 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 nodes' 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 75-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 or drifting due to strong currents.

Fig. 2. a) Preplot hexagonal receiver spacing under the platform, with 58-m spacing between nodes. b) Preplot of the spiral source geometry, with a 10-m interval and 10-m spacing between spirals.



Nodes are deployed from the ROV using a robotic arm equipped with suction cups. The node containment system includes a skid that fits under the ROV with a drawer holding up to six nodes, a standalone basket that contains up to 18 nodes (in three drawers) and the means to move drawers between the ROV and the basket, Fig. 3. After training provided by CGGVeritas, the ROV pilots learned quickly 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, the newly trained ROV pilots became increasingly efficient, averaging 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. No nodes were dropped during the survey.

RESULTS

All 154 nodes were retrieved upon completion of the program, with a 99.7% data recovery rate. As in all nodal 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 nodal surveys, the source line was designed as a spiral and precedence was given to shooting on time rather than on location. The geometric irregularities were taken into account during processing and imaging.

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 higher-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

Fig. 3. a) The ROV can deploy the nodes on the seabed using suction cup extraction from a drawer that holds up to six nodes. b) A skid basket containing three drawers of six nodes each is lowered to the seabed for simplified deployment and retrieval.

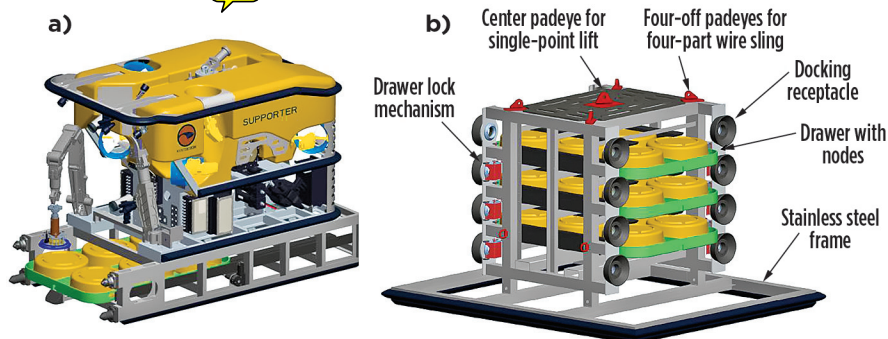
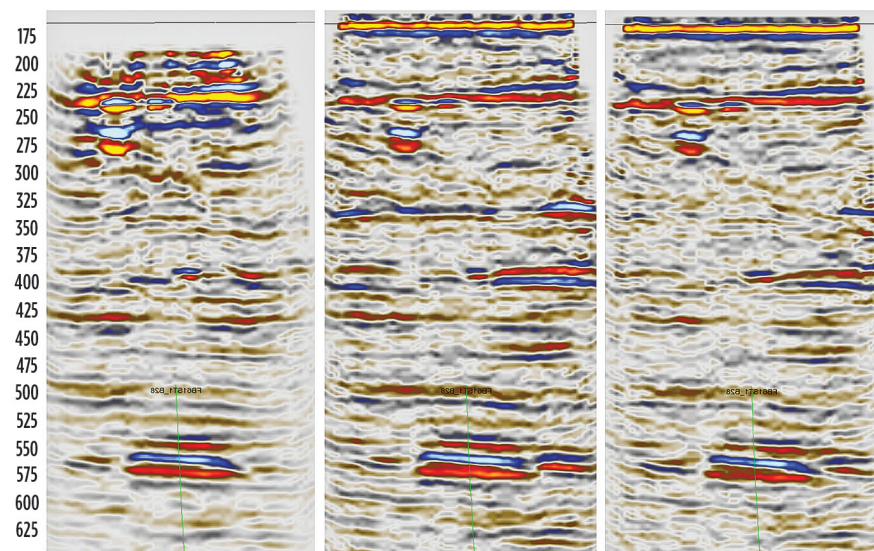


Fig. 4. Three sets of processed data were provided for each platform: from left, the upgoing P-wave, the mirror image and mirror imaging with demultiple. The drilling hazards under the platforms are clearly identified by the bright spots indicating shallow gas accumulations.



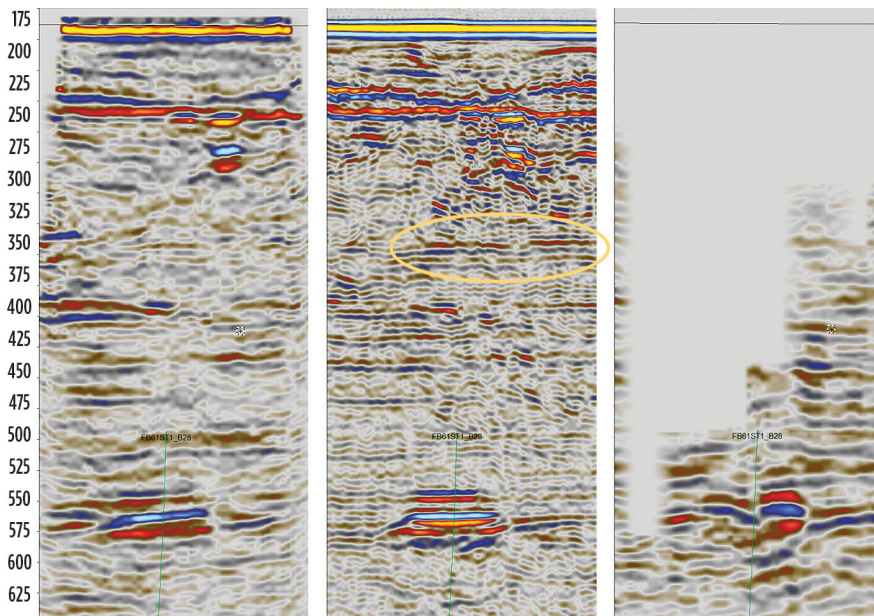
multiples in a method called mirror imaging (because the sea surface is used as a mirror). In the latter method, the lengthened ray paths of the multiples create virtual receivers above the sea surface, and allow longer offsets to be imaged for a given depth. Mirror imaging offered better results, mainly because it widens the illumination from each node. Post-imaging residual move-out corrections, stack and spectral shaping produced the final volumes. The data processing team produced three cubes of data for each platform: 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. The bright spots were interpreted as drilling hazards.

The zone illuminated by the nodes included coverage of an area away from the platforms that overlapped an area previously 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, Fig. 5. Significantly, the same bright spots were seen by all three methods, wherever they were illuminated. The interpretation of drilling hazards depicted by bright spots underneath the platforms was only visible on the nodal dataset, since the other datasets have no data where the platforms are located.

CONCLUSIONS

The International Association of Oil and Gas Producers (OGP) published a document in April 2011 proposing best

Fig. 5. To verify the nodal data (left), the team cross-referenced and compared the interpreted results of a patch 100 m away from the platform with legacy 2D seismic data (center) and the 3D undershoot data. The nodal data clearly identifies the same hazards and more, while the mirror image processing successfully removes the multiple seen in the 2D dataset (within the yellow oval).



practices for the conduct of offshore drilling-hazards site surveys. The guidelines include a strong recommendation that producers utilize “exploration 3D seismic data to enhance, or to replace, acquisition of 2D site survey data” as part of the survey framework.

When planning a new offshore well, operators are encouraged to analyze a number of datasets including existing exploration 2D and 3D seismic, offset well data, geotechnical data and any other information that will help formulate a more accurate model. Drilling-hazards site surveys are designed to exhaustively review manmade features, natural conditions of the seabed and subsurface geological properties to determine if the proposed location of the new wellbore is suitable, and to help predict and mitigate any foreseeable risks that may preclude the drilling of the well. While many known reservoirs have sufficient legacy seismic data available to provide a general overview of the area, some fields were developed before high-resolution 3D data became available. Exploration, development and production-monitoring seismic surveys are primarily designed to image the target reservoirs, and generally are not optimized to provide high-resolution imaging of drilling hazards. Therefore, 3D seismic infill programs are often necessary for a more in-depth view of the exact location

of interest. Traditional towed-streamer surveys are ideal for such program requirements, provided there is sufficient room to operate a 3D vessel with multiple lines of long cable without obstruction. Towed equipment is limited to areas without surface obstructions such as production platforms. Undershooting such obstructions using separate source and streamer vessels provides imaging of targets under the platforms with compromised resolution and quality, particularly in the shallow section below the seafloor.

As recommended by the OGP report, towed-equipment surveys, including streamers and ocean-bottom cable acquisitions, should be conducted in water depths that range from 25 m to 750 m (80–2,460 ft). The report also suggests using autonomous underwater vehicles (AUVs) to deploy sensors such as ocean-bottom nodes at water depths of 500 m (1,640 ft) or greater. An alternative to high-resolution surveys from AUVs is OBNs deployed by remotely operated vehicles (ROV).

The successful use of OBN technology to identify drilling hazards, 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 nodal data at Forties field,

it was possible to identify the drilling hazards and either avoid them or prepare for them using gas-line diverters at the depths predicted in the new seismic data. In addition, the flexibility of nodal technology enabled efficient deployment and improved imaging underneath platforms, where conventional streamer would have been technical unfeasible and ocean-bottom cable would have been economically prohibitive. The ability to tie OBN data to existing 2D and 3D data will provide a more comprehensive overview of the field to validate or refute initial assumptions, thereby creating opportunities to more fully exploit the asset with tighter well placements and reduced drilling risk. **WO**

KLAAS KOSTER recently became Apache's Senior Geophysical Advisor for the onshore Gulf region, having previously served as Development Manager for the North Sea. He has been with Apache since 2008 and has 20 years of industry experience, including work for Shell and Amoco. Dr. Koster is President of the Society of Exploration Geophysicists (SEG) and holds a PhD in geophysics from Delft University of Technology.

DAVE MONK is the Director of Geophysics at Apache, responsible for worldwide seismic acquisition and processing. He holds a PhD in physics and has authored more than 100 technical papers and a number of patents. He was the first Vice President of SEG in 2006.

ARNE ROKKAN is CGGVeritas' Vice President for Seabed Strategy and Technology.

RAFAEL BOURALY is Field Support Navigation Manager for CGGVeritas, in which role he has supervised marine and seabed operations since 2006. He joined CGGVeritas in 2003, working in the onshore navigation support group in France. Mr. Bouraly previously worked in the navigation department of WesternGeco.

SIMON BROWN is a team leader for CGGVeritas Processing, Imaging and Reservoir Services. Mr. Brown has been in the oil and gas industry since 1991, including work both in remote processing centers and on seismic vessels. He has several years of experience processing ocean-bottom data from both nodes and cabled systems.

ALLISON BRANAN is Marketing Communications Manager for CGGVeritas' Land division, with more than 10 years of experience in the oil and gas industry. Prior to joining CGGVeritas, she was responsible for product marketing, market analysis and corporate communications at Inova Geophysical and Decision Dynamics. Ms. Branan holds a BBA degree in marketing from the University of Houston.

SHUKI RONEN is Vice President for Ocean-Bottom Technology at CGGVeritas and a consulting professor at Stanford University. He has over 20 years of industry experience, having worked for Seabird, Chevron, Schlumberger and Saxy and served as a visiting professor at the Colorado School of Mines. He holds a PhD from Stanford University.