

Full-azimuth imaging using circular geometry acquisition

NICK MOLDOVEANU, JERRY KAPOOR, and MARK EGAN, WesternGeco, Houston, USA

Wide-azimuth (WAZ) towed-streamer acquisition has improved the quality and reliability of subsalt imaging in the Gulf of Mexico, where WAZ surveys have typically been acquired using 3–4 seismic vessels, each shooting in straight parallel lines. However, acquisition of WAZ data using a single vessel and a circular geometry offers several potential advantages, both for operational efficiency and geophysical analysis of subsurface rock properties. Modeling exercises indicate that circular acquisition geometry can deliver a better range of azimuths and offsets than parallel WAZ geometry. A feasibility test in the Gulf of Mexico shows that it is possible to sail along circles while maintaining constant streamer separation and achieving very accurate receiver positioning. Single-sensor recording enables effective attenuation of the additional coherent noise introduced by shooting in a curve. Prestack depth-migrated data from the circular geometry test compare favorably with a parallel geometry WAZ data set acquired previously.

WAZ imaging in the Gulf of Mexico

Accurate imaging of sediments beneath hard seafloors, salt, basalt, and carbonate layers has presented a long-standing challenge to developers of seismic technology. In deep water, towed-streamer geometries are currently the only viable solutions for acquisition of large 3D data sets. Conventional narrow-azimuth 3D surveys, usually acquired using a single vessel, have proved their value in a wide variety of geologic circumstances. However, complex geology and highly refractive layers cause ray bending that can leave portions of the subsurface untouched by seismic waves or poorly illuminated.

Figure 1 compares the images of subsalt sediments derived from a conventional narrow-azimuth acquisition and WAZ. Poor illumination is typically associated with low signal-to-noise ratio of the subsalt events. In such circumstances, conventional 3D data may not be good enough for exploration and are even less likely to be adequate for creating accurate models for reservoir development. WAZ towed-streamer acquisition has been shown to deliver better illumination, higher signal-to-noise ratio, and improved seismic resolution in several complex geologic environments, such as beneath large salt bodies with complex geometric dimensions. A growing list of Lower Tertiary discoveries in ultradeep water in the Gulf of Mexico has further stimulated industry interest in

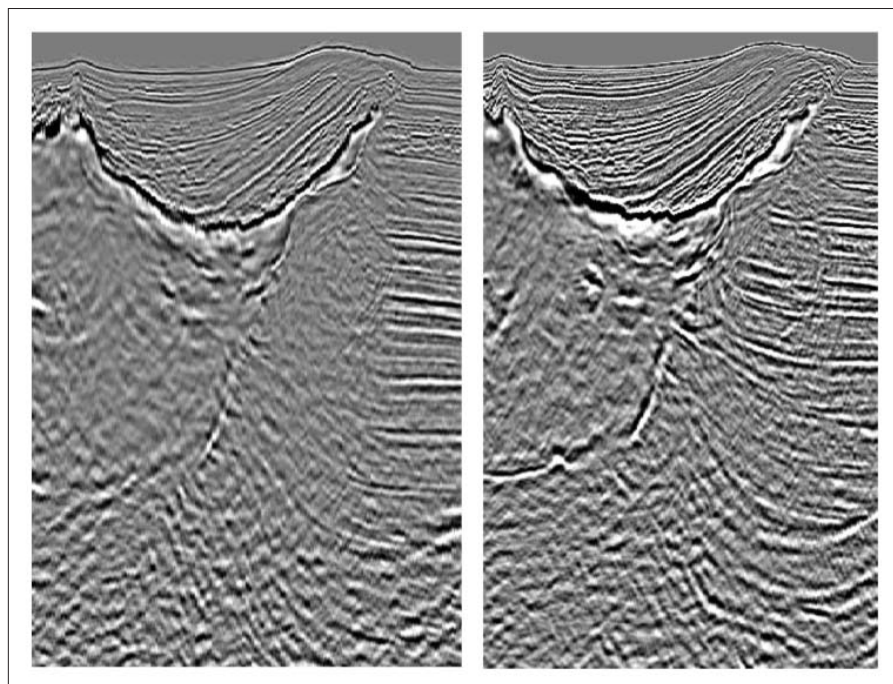


Figure 1. Comparison of subsalt imaging from a narrow-azimuth conventional marine acquisition (left) and wide-azimuth towed-streamer acquisition (right).

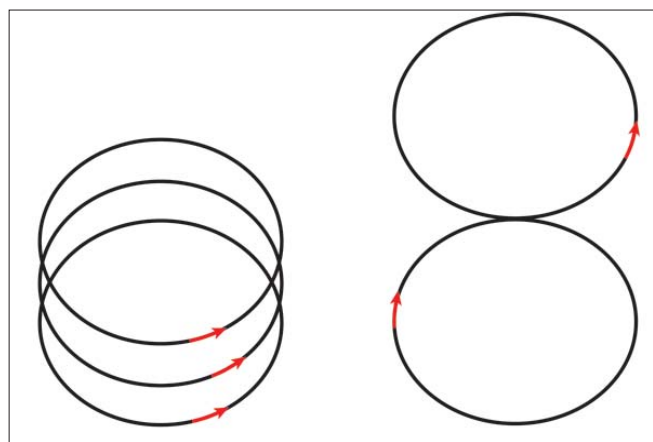


Figure 2. Sail paths for circular geometry: circle-by-circle (left) or multiple circles (right).

testing new subsalt imaging technologies, such as WAZ acquisition, in the area. The U.S. Minerals Management Service estimates that Lower Tertiary sediments may contain up to 15 billion barrels of oil equivalent within a potential play area as large as 3000 deepwater blocks in the central and western Gulf planning areas. Wells in this area typically cost about US\$100 million to drill and a single development project is likely to cost several billion dollars. In 2006, of 119 Gulf of Mexico exploration wells drilled in water deeper than 1000 ft, only 11 hit pay. It is, therefore, not surprising that companies are increasingly willing to invest in innovative new imaging solutions that may reduce the frequency of dry holes.

Several wide-azimuth surveys have been acquired in the Gulf of Mexico, typically using 3–4 vessels shooting in straight parallel lines. These types of surveys, combined with accurate velocity models and migration algorithms, can provide a step-change improvement in subsalt illumination, signal-to-noise ratio, and attenuation of some multiples, compared to conventional narrow-azimuth surveys. Wider crossline offsets lead to better results, and the best results are from data acquired over a complete 360° range of azimuths (rich-azimuth or RAZ surveys).

In one RAZ survey, useful data were recorded during turns between sequential straight lines, thereby increasing produc-

tivity by eliminating the down time during line changes. Sail lines acquired during line changes are typically semicircles, and so can be considered as a partial implementation of circular acquisition geometry. This successful acquisition of data during line changes convinced WesternGeco to investigate a fully circular geometry for WAZ towed-streamer acquisition.

The potential benefits of circular geometry for marine acquisition have been known for a long time. The geometry was proposed in the 1980s by French, who suggested that sailing in concentric circles around salt domes would improve structural imaging, especially for faults. Test surveys were acquired in the Gulf of Mexico and in the North Sea using concentric circle acquisition (Durrani et al., 1987). However, the technology at that time did not allow proper implementation of the method, so it was abandoned.

Circular acquisition geometry

The wide-azimuth coverage and the high fold associated with circular geometry allow splitting the data in different azimuth ranges for anisotropic velocity-model building and fracture analysis. The method requires only one vessel, equipped with multiple streamers and 1–2 sources. The vessel sails along single or multiple circles (Figure 2) to cover the survey area with overlapping circular sail paths. This continuous mode of acquisition virtually eliminates line changes.

WesternGeco has modeled the coverage, offset, and azimuth distribution for circular geometry and has performed a feasibility test in the Gulf of Mexico. A survey area of 42×42

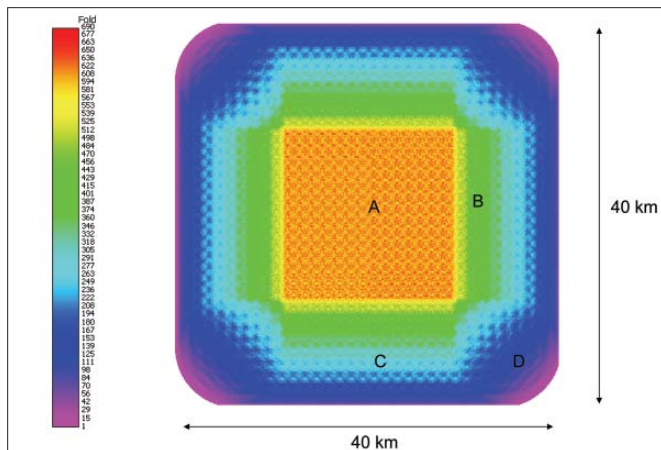


Figure 3. Fold of coverage for circular acquisition geometry.

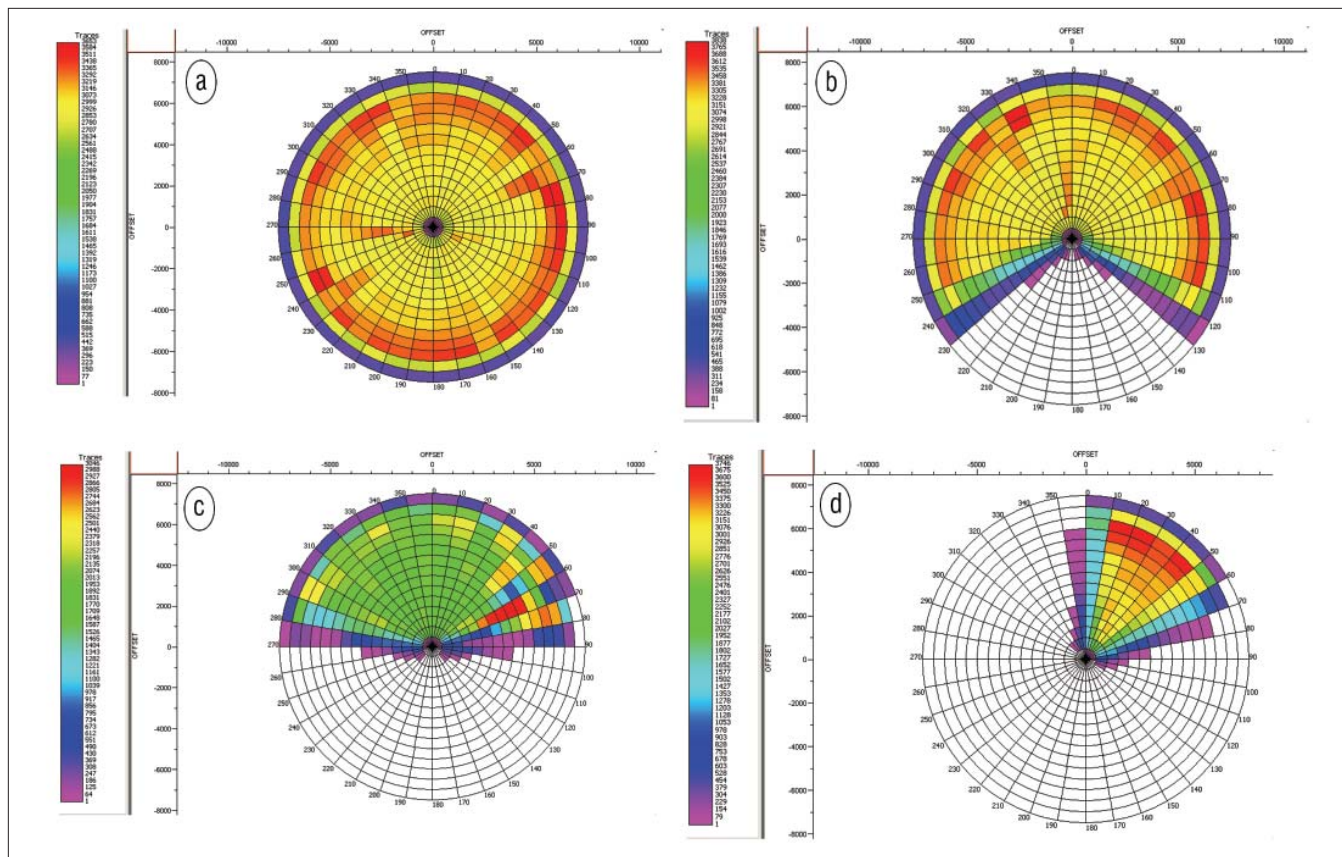


Figure 4. Azimuth offset distribution for circular acquisition geometry in four parts of the survey.

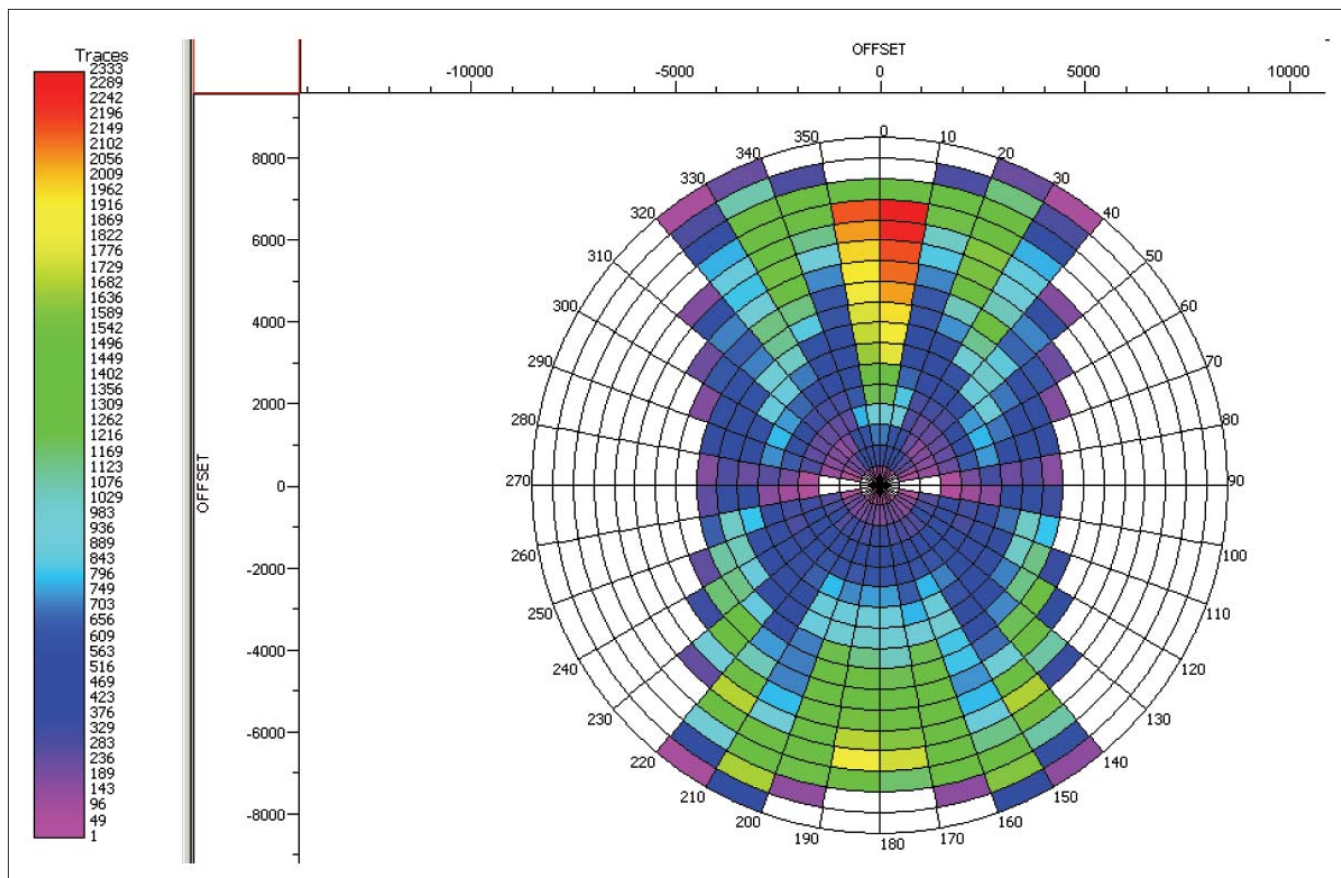


Figure 5. Azimuth offset distribution for parallel WAZ acquisition geometry.

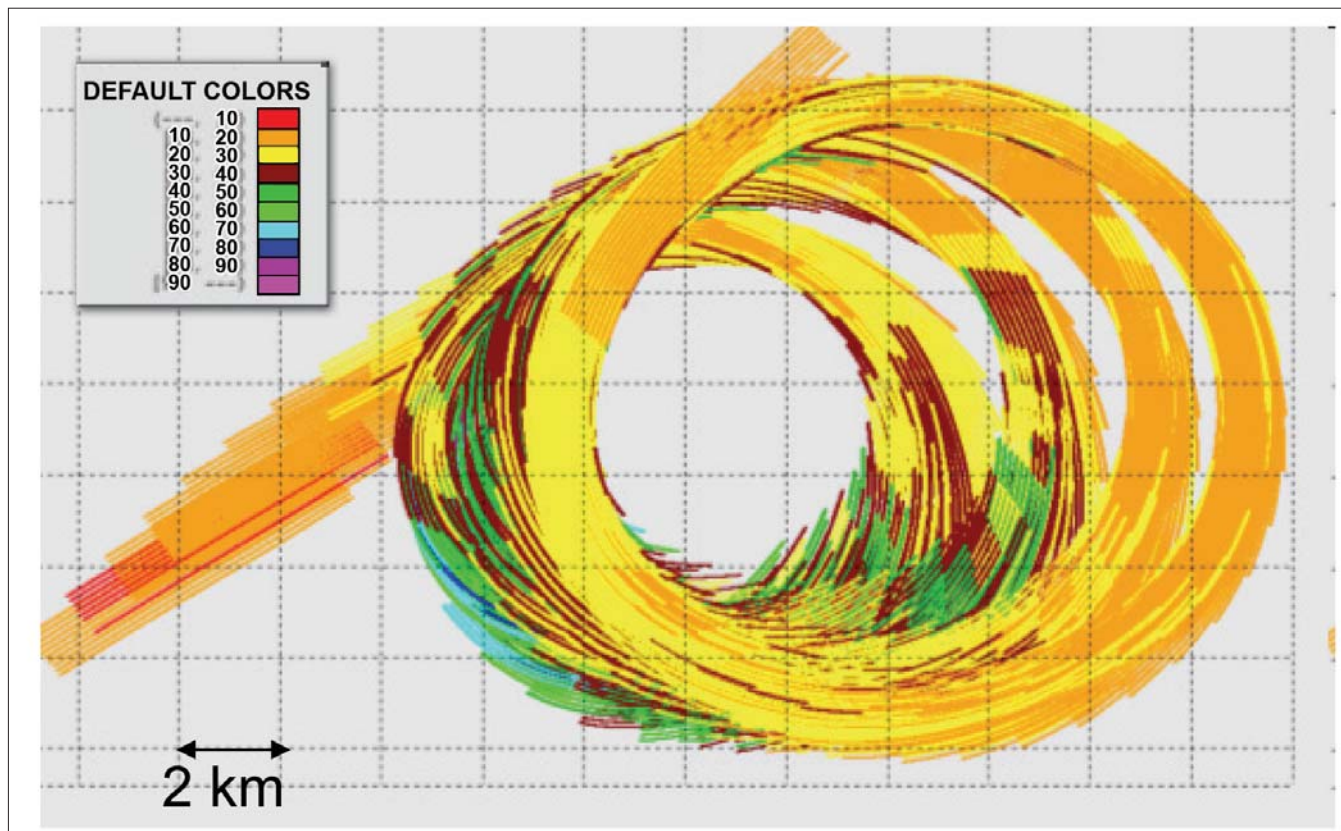


Figure 6. The rms ambient noise estimated from circular geometry test data.

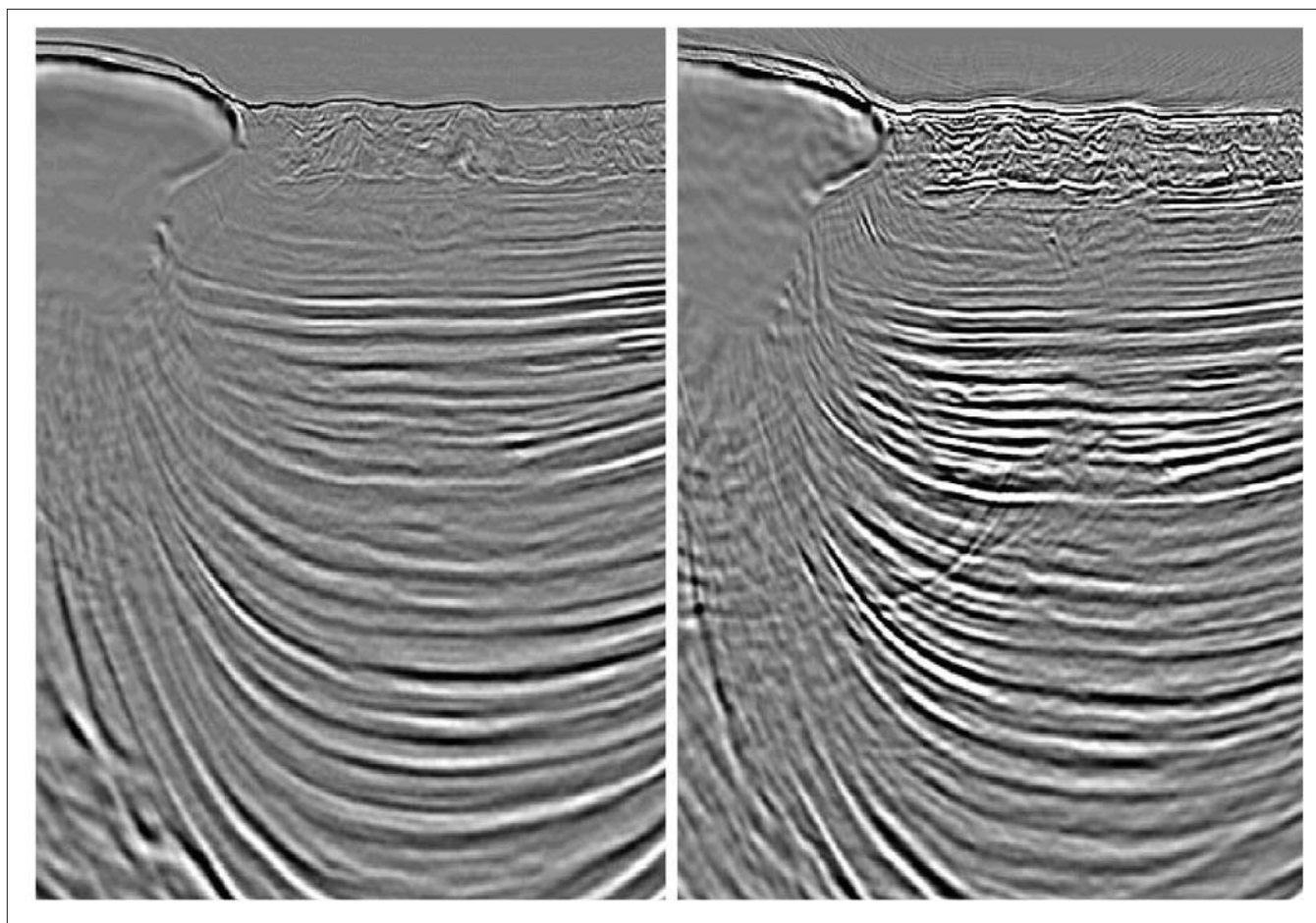


Figure 7. 3D prestack depth migration of full aperture, full-fold parallel WAZ survey (left), and circular geometry feasibility test data (right).

km was modeled with the following parameters: 10 streamers; streamer length = 7000 m; streamer separation = 120 m; one source, shot interval = 37.5 m; receiver interval = 50 m; circle radius = 6000 m; circle roll in x direction = 1200 m; and circle roll in y direction = 1200 m.

The modeling used a typical WAZ streamer configuration except for the receiver interval, which would normally be 12.5 m. A 50-m receiver interval was used to reduce the amount of simulated navigation data. A total of 610 720 shots were modeled and mapped into bins of 25×25 m. Fold (Figure 3) is at a maximum over the target area in the middle of the survey where the average is 1560. Fold decreases towards the fringes and is 290 at the edges. By comparison, the nominal fold of a parallel WAZ geometry survey acquired with two streamer vessels and two source vessels, a 600-m sail-line interval, and the shot spacing and streamer configuration described above would be 186 for a single pass, and 372 for two passes. The higher fold achieved with circular geometry is due to the high-density shot distribution which, depending on the design, could be 1.34-2.6 times larger. As shots are distributed along several overlapping circles, for real acquisition the shot distribution could be considered pseudorandom; this could be beneficial for multiple attenuation and imaging.

Figure 4 shows azimuth offset distribution in four different areas across the circular geometry survey presented as rose diagrams, where the offset is mapped along the radius and the

azimuths are represented in 10° angle sectors from 0 to 360° ; the color represents the number of traces. The rose diagrams were calculated for small areas (1200×1200 m). For comparison, Figure 5 shows the rose diagram for a parallel WAZ geometry survey acquired with a four-vessel configuration. This analysis shows that the circular geometry provides full-azimuth (FAZ) distribution over the target area and WAZ distribution over the rest of the survey. Near offsets are better recorded with circular geometry than with parallel WAZ geometry. The maximum offset from the modeled circular geometry is 800 m smaller than that of the modeled parallel geometry.

Circular geometry feasibility test

A feasibility test for circular geometry was performed in the Gulf of Mexico in April 2007 over an area previously covered by a parallel WAZ survey. The test used one vessel with a single source and 10-streamer configuration, as used for the modeling exercise. Four circles were acquired (with radii of 5.4 km, 6 km, 6.5 km, and 7 km). The roll from circle-to-circle was 1200 m. The 5.4-km radius corresponds to the turn radius typically used with the streamer configuration deployed. The test results proved that it is feasible to sail along circles while maintaining constant streamer separation and achieving very accurate receiver positioning. Ambient noise was estimated as an rms value in a 500-ms window at the end

of the shot record (Figure 6). The noise reached a maximum of 60 μ bars for some traces of the 5.4-km and 6-km radius circles. For the 6.5-km and 7-km radius circles, the level of noise is comparable to, or only slightly higher than, the noise recorded on straight lines.

The circular geometry data were processed using the same sequence as applied to the parallel WAZ data (which included single-sensor coherent noise attenuation, shot-by-shot bubble removal, anomalous noise attenuation, and 3D prestack migration). Despite low fold and migration aperture, the circular geometry test data compare favorably to the full-aperture, full-fold parallel WAZ data (Figure 7).

Acquisition of a 900 km² FAZ survey using a single-vessel circular geometry was simulated. Assuming 100% vessel utilization, the survey was estimated to require 61 days, recording 321 706 shots. Acquisition of a comparable parallel WAZ geometry with four passes using a four-vessel configuration was estimated to require 62 days and record 160 000 shots.

The Q-Marine system was used for the circular acquisition feasibility tests and also for the older parallel WAZ survey. Towing streamers in a curve increases coherent noise with characteristics similar to bad-weather noise. Finely-spaced single sensors record such noise with sufficient spatial fidelity so that it can be eliminated using targeted filtering techniques while preserving the integrity of the seismic signal (Ozbeck, 2000). The system also compensates for variations between individual sensors and has an advanced digital source controller that provides a fully calibrated air-gun source signature for every shot. Q-Fin steering devices precisely control the depth and lateral position of the streamers, enabling constant streamer separation to be maintained. A fully braced acoustic positioning network provides accurate positioning of the in-sea equipment. Dynamic Spread Control (DSC) technology adds steerable sources and automatic vessel, source, and streamer steering to achieve the best possible match with preplot positions.

Conclusions

The feasibility test confirmed that circular geometry data could be successfully acquired and processed. The high fold and wide range of azimuths achieved is expected to further improve noise attenuation and multiple attenuation using a 3D SRME approach. The modeling and feasibility tests indicate that the technique has considerable potential for addressing some challenges of imaging beneath salt and in other complex geologic situations. Circular geometry is very efficient, enabling continuous acquisition, and requires only one vessel. Acquiring data while turning is a practice that WesternGeco expects to extend to conventional 3D single-sensor surveys.

Suggested reading. “Subsalt imaging: The RAZ-WAZ experience” by Kapoor et al. (*TLE*, 2007). “New directions for marine 3D surveys” by Durrani et al. (SEG 1987 *Expanded Abstracts*). “Multichannel adaptive interference canceling” by Ozbeck (SEG 2000 *Expanded Abstracts*). **TLE**

Corresponding author: nmoldoveanu@westerngeco.slb.com