

Techniques Improve Subsalt Imaging

By S. Jerry Kapoor

HOUSTON—Technological advances over the past decade have significantly improved the industry’s ability to obtain accurate seismic images in subsalt. However, even with all the advances in imaging technology, there remain many geographic areas where obtaining an image of the subsurface structure beneath salt is still very challenging.

One such area is the deepwater subsalt play in the Gulf of Mexico, where drilling and development costs can run into billions of dollars for a single project. The complex geological structures, the presence of allochthonous salt, and well costs of \$50 million-\$100 million or more are driving the need for a step-change improvement in subsalt imaging technology.

The emergence of the Lower Tertiary play in ultradeep water is one of the key drivers behind the industry’s push to improve subsalt imaging capability. A growing list of discoveries has been made to date in the Lower Tertiary, and 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 3,000 deepwater blocks in the Central and Western Gulf planning areas.

With total depths ranging to 32,000 feet, Lower Tertiary discovery wells have drilled through as much as 15,000 feet of salt. These salt formations were once part of the underlying Jurassic-age Louann salt. Sedimentation on top of the Louann over geologic time caused salt to flow laterally, settling as allochthonous sheets at or just beneath the seafloor. In the Lower Tertiary and other plays in the Gulf of Mexico, exploration targets are often located beneath these salt bodies. Velocity variations, signal deformation and other technical challenges have made conventional towed-streamer 3-D seismic acquisition difficult, especially in those areas where salt bodies are large and have complex geometric dimensions.

While there have been numerous developments in processing technology in recent years in an effort to improve subsalt imaging, ultimately the limitations in the quality of the data itself have generally proven the biggest impediment. New acquisition techniques such as wide-azimuth (WAZ) and rich-azimuth (RAZ) designs, together with more accurate velocity models and migration algorithms, are being developed to meet

the demand to provide accurate images in Gulf of Mexico subsalt exploration areas. Although still relatively new acquisition techniques, the industry has already gained significant experience in acquiring and processing RAZ and WAZ surveys in the Gulf.

Three Survey Geometries

There are essentially three towed-streamer survey geometries designed for full-azimuth illumination at long source/receiver offsets (Figures 1A-1D). A multi-azimuth (MAZ) survey uses one multi-streamer recording vessel and one source (a single vessel if the streamer vessel is equipped with an onboard source) to acquire 3-D data over the survey area in as many as six different directions.

A WAZ design uses multiple sources with a multistreamer recording vessel to shoot each source line multiple times in a single direction with increasing lateral offset. Each acquisition pass along a source line is called a “tile.” Some surveys use two sources (two source boats with no onboard source on the streamer vessel) while others use three sources (two source boats plus the recording vessel’s onboard source). Different designs are available for WAZ surveys, with varying quality and cost ben-

FIGURE 1A
Narrow Azimuth

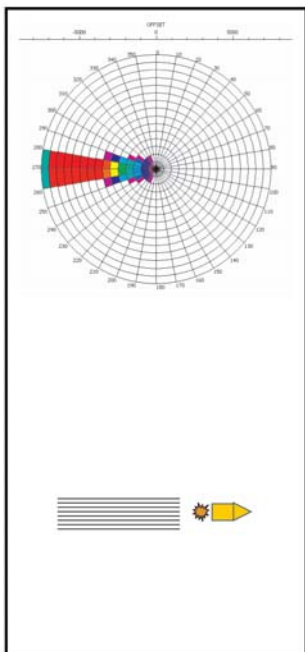


FIGURE 1B
Multiazimuth

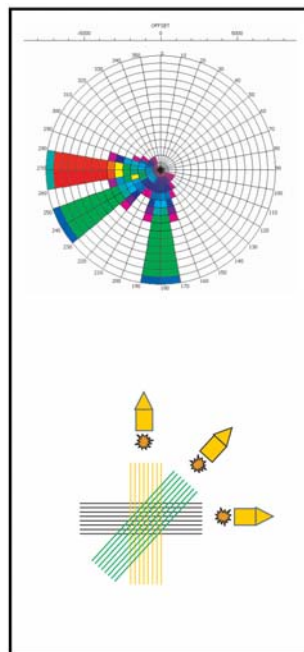


FIGURE 1C
Wide Azimuth

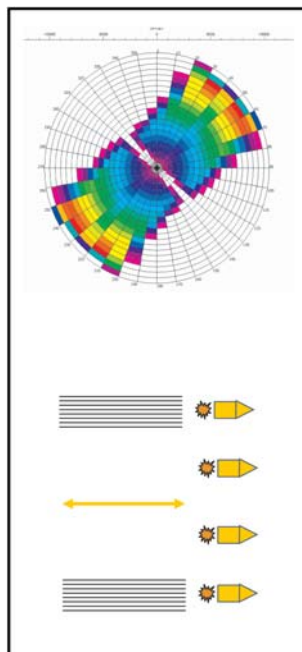
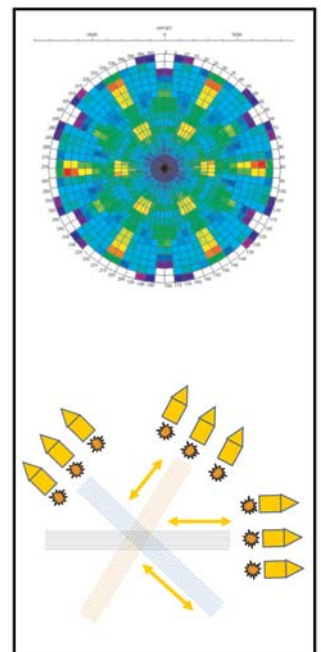


FIGURE 1D
Rich Azimuth



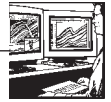
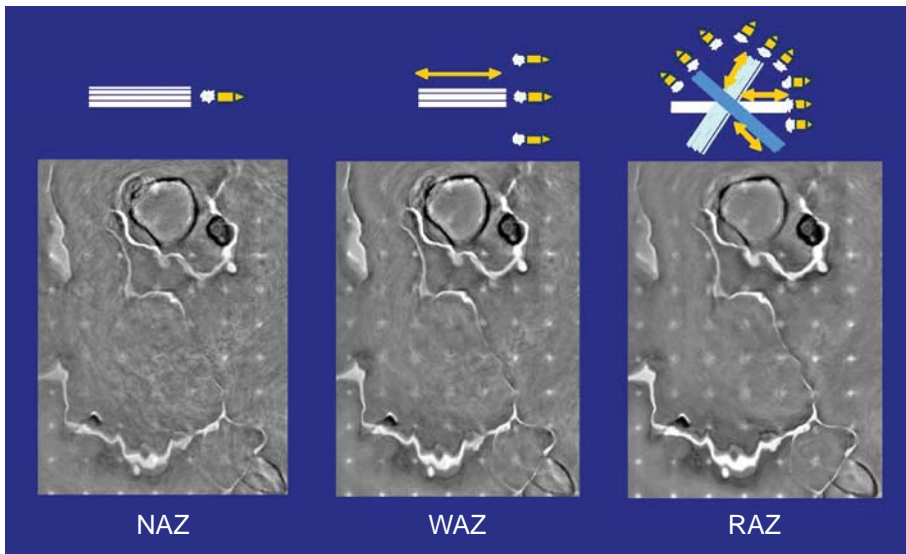


FIGURE 2

Wave Migration Illumination Modeling



efits that can be modeled for individual objectives. A number of these surveys have either been acquired in the Gulf or are now being acquired, including multiclient projects.

A RAZ survey is essentially WAZ surveys acquired in multiple directions. The first RAZ towed streamer survey was acquired last year by BHP Billiton Petroleum and its partners at the deepwater Shenzi Field in the Green Canyon area. The survey used two source boats and a master vessel with a third onboard source towing 7,000-meter streamers to make multiple passes in three sailing directions for full azimuth illumination beyond 6,000 meters of source/receiver offset (See “Rich Azimuth: Moving A Step Beyond,” *The Reporter*, November 2006).

Modeling studies have shown that these new acquisition approaches provide an opportunity for improved subsalt illumination, enhanced signal-to-noise ratio, and better attenuation of multiples compared to conventional narrow-azimuth surveys. Figure 2 shows modeled data migrations using simulated narrow-, wide- and rich-azimuth acquisition geometries. Note the improvement in resolution, especially of the embedded grid of spheres from MAZ to WAZ to RAZ.

WAZ, RAZ Surveys

During the past year, we have been processing four wide- or rich-azimuth surveys recorded in the Gulf of Mexico, two proprietary and two multiclient, each with a different acquisition design (Figure 3). Survey 1 was acquired with two flip-flop source vessels front and aft, and six

passes of the streamer vessel (three on each side 1,200, 2,400 and 3,600 meters from the source vessels). Eight 9,000-meter streamers were deployed in a spread 1,200 meters wide, yielding a 4,200-meter cross line offset on both sides.

Survey 2 was acquired using three single-source vessels, including a source on the streamer vessel in three azimuths interleaving in two reciprocal directions with two source vessels 1,200 meters across on either side of the recording vessel, along with recording data during turns for additional aperture. Ten 7,000-meter streamers were deployed in a spread 1,200 meters wide, yielding a 2,400-meter cross line offset in three azimuths.

Survey 3 was acquired with three single-source vessels spaced 1,200 and 2,400 meters apart, including a source on the streamer vessel in two reciprocal directions. Ten 7000-meter streamers were

used in a spread 1,200 meters wide, yielding a 3200-meter cross line offset on both sides.

Survey 4 was acquired with four single-source vessels spaced 1,200, 2400 and 3,600 meters apart, including sources on two streamer vessels interleaving in two reciprocal directions. Ten 7000-meter streamers were used in a spread 1,200 meters wide, yielding a 4,200-meter cross line offset on both sides. This four vessel design using two recording vessels can acquire data almost twice as fast as the three vessel design, and also provides better quality data as a result of the larger cross line offset. Consequently, the four vessel towed-streamer design is now setting the standard in the marine seismic industry.

All four of these WAZ/RAZ surveys were acquired using an advanced, fully-calibrated point-receiver marine seismic acquisition system with single-sensor recording, enabling optimum noise attenuation/reduction and a broader frequency at both the lower and higher ends of the seismic spectrum.

Processing the data acquired with wide- and rich-azimuth surveys brings its own challenges and opportunities for improved seismic imaging. Initial processing results with minimal processing, no multiple attenuation, and shot-domain wave equation migration using an existing velocity model show that all four survey designs lead to improved subsalt imaging over conventional narrow-azimuth surveys with full processing including multiple attenuation. For comparative purposes, Figure 4A shows narrow-azimuth data with multiple attenuation, while Figure 4B shows wide-azimuth data without multiple attenuation.

Improved Data Quality

Data examples from the testing of var-

FIGURE 3

Gulf of Mexico Survey Designs

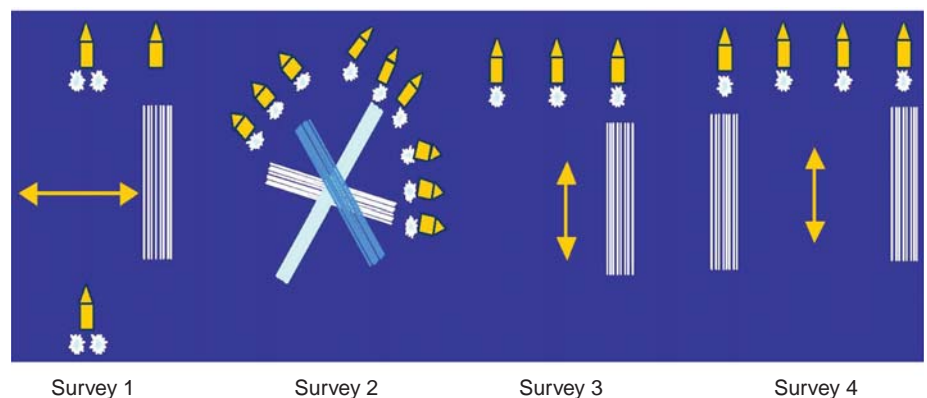




FIGURE 4A
NAZ Data with Multiple Attenuation

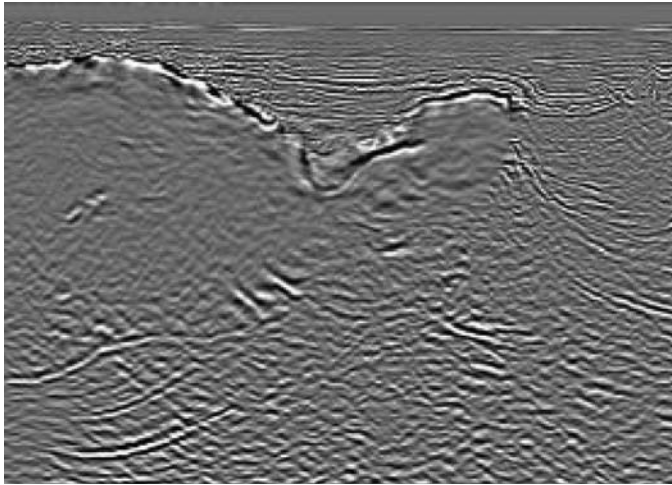
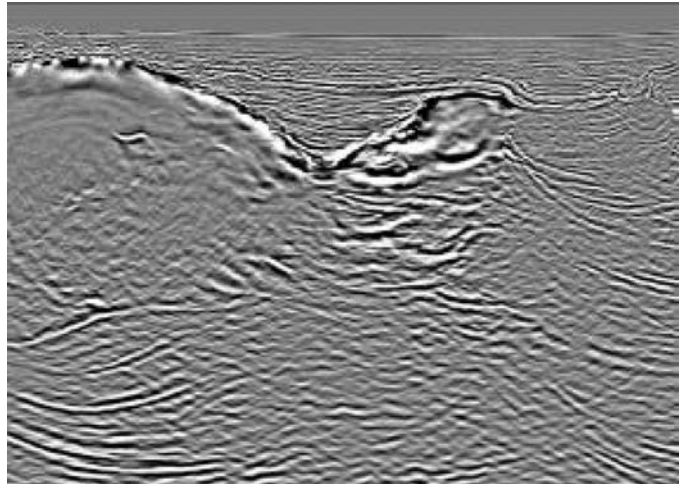


FIGURE 4B
WAZ Data without Multiple Attenuation



ious WAZ and RAZ design configurations using subsets of the acquired data sets show that wider cross line offsets lead to better signal-to-noise ratios, multiple attenuation, and subsalt illumination.

Acquiring data from both directions yields the best results because true source/receiver reciprocity is not recorded as a result of feathering, obstructions and complex subsalt wave fields.

Processing tests on Survey 1 data show better imaging using front sources versus aft sources and front sources versus front and aft combined. Again, this could be caused by variable feather and less control of near and mid offsets on aft sources.

Single-source deployment allows for larger gun arrays, providing more energy penetration in subsalt regions and more accuracy in source location repeatability with multiple passes of the source vessels, which is important when performing shot-domain wave field extrapolation migration.

Another distinction is that data acquired with different azimuths exhibit differences in move-out, and therefore require multiazimuth tomography, which leads to building more accurate velocity models.

Although WAZ acquisitions geometries naturally attenuate multiples better than conventional narrow-azimuth surveys, new multiple attenuation techniques are needed

to attenuate residual multiple energy. For optimum performance of surface-related multiple elimination (SRME) methods, sources are needed at all receiver locations. Although interpolation techniques can be employed to fill in the necessary data, this becomes quite challenging for WAZ acquisition designs because of the sparseness of sources relative to the receivers.

Another method that may be more suitable for such surveys is wave equation migration demultiple, where the required data can be generated by predicting the multiples using a velocity model and the inverse of wave equation migration and then adaptively subtracting the multiples, as with SRME methodology.

Shot-domain wave equation migration accurately represents subsalt multipaths and is quite cost effective for such surveys because data from repeatable source locations can be combined into one “super shot,” thereby reducing the number of shot migrations by factors of three to 12, depending on the acquisition geometry. The source repeatability of the four surveys referenced in Figure 3 was excellent, with more than 90 percent of the shots within 20 meters of each other.

Wide- and rich-azimuth surveys provide a step change improvement in subsalt imaging. These survey designs improve signal-to-noise ratios and illumination in complex subsalt geology. In addition, mul-

tiazimuth tomography improves velocity models, and by virtue of their designs, WAZ and RAZ surveys naturally attenuate multiples better than conventional narrow-azimuth surveys.

These new surveying geometries that use multiple source boats to vary the azimuth of conventional streamer acquisition have emerged as the preferred solution to better illuminating sediment below salt. However, despite the improvements seen to date in seismic imaging in subsalt plays, WAZ and RAZ acquisition techniques are not “silver bullets” and further improvements are still needed. □

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