Seismic Imaging Technology

PART II: LESSONS FROM WIDE AZIMUTH SUBSALT IMAGING IN DEEPWATER GULF OF MEXICO

Seismic imaging is considered key to reducing risk and cost in exploratory as well as development drilling. Seismic acquisition geometry impacts the seismic image, so in this article we show how advances in imaging deepwater subsalt plays in the deep water Gulf of Mexico is a result of the way the industry has embraced the wide azimuth streamer survey technique.

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In GEO ExPro No 2/2008 we demonstrated with field examples that seismic illumination and the imaging of complex structures clearly depend on acquisition geometry. High-fold, multi-azimuth and full-azimuth seismic, albeit much more expensive than traditional 3D streamer surveys, has been proved to yield the high quality detailed seismic imaging that is required to improve our understanding of complex fields.

Towards wider azimuths

The US Minerals Management Service (MMS) estimates that up to 56 Bboe can be found in the deep water Gulf of Mexico (GoM). Many companies are hunting these hydrocarbons, which are often found beneath salt bodies that were once part of Jurassic Louann salt. Sedimentation on top of the salt has caused it to flow laterally, before settling as allochtonous sheets below the seafloor. In many deepwater GoM plays, exploration targets are located beneath these bodies of salt, which can be large and have complex geometry.

One problem, however, is that the success rate of deep-water GoM subsalt exploratory drilling is less than 10%. Since deep-water wells can cost more than USD 100 million this level of risk is unacceptable. High-quality seismic may thus reduce exploration risk and allow identification of previously hidden prospects.

The real challenge surfaces when a discovery is made. With a few well penetrations only, the discovery possesses many unknowns. The structural geometry, including faults and compartmentalization, which is necessary to determine new well placement, is often very uncertain. Better seismic is again the key to finding the details needed to make more informed decisions.

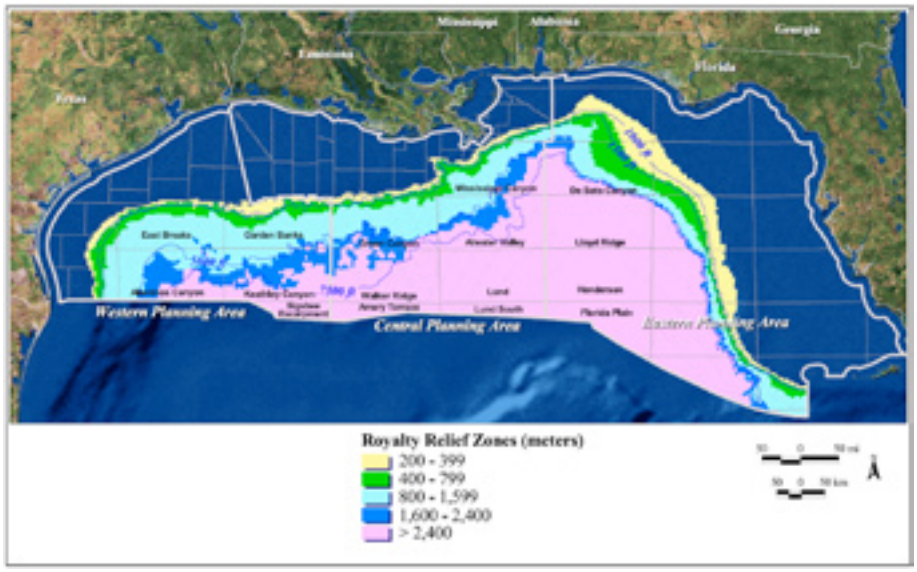
In the GoM the recent trend has been to invest in wide azimuth (WAZ) seismic both for exploration, appraisal and field development in subsalt settings, to minimize risk and to optimize field economics. WAZ surveys are hugely expensive, however, as they involve several vessels. Although the new generation vessels, like those introduced by PGS this year, have a capacity to tow 21 streamers, the WAZ concept might still need one or two extra shooting vessels. It remains to be seen if the next generation acquisition techniques will include a single vessel capable of operating several sources and streamers, both covering a wide spread of several kilometers.

WAZ and RAZ towed streamer survey benefits

Even though new pre-stack depth migration techniques applied to traditional 3D seismic data have enhanced our interpretation power in areas hidden below salt canopies in GoM, much of the traditional seismic may be of poor quality due to various kinds of noise, which makes detailed reservoir characterization an onerous undertaking at best.

The industry has found that using WAZ and RAZ surveying techniques in the Gulf brings improved subsalt illumination, better signal-to-noise ratio, and importantly, improved multiple attenuation, particularly with regard to multiple diffractions.

Although new multiple suppression techniques are needed to attenuate residual multiple energy, it is an incontrovertible fact that the stacking process of data from WAZ acquisition geometries suppresses not only



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The Gulf of Mexico deep water plays are characterized by considerable imaging problems due to thick, extensive salt sheets.

water bottom and top salt multiples but also multiple diffractions, more efficiently than from conventional NAZ surveys. The stacking of traces acquired with many azimuths is an effective form of multiple suppression in itself. Multiples frustratingly often coincide with and contaminate primary reflections at the reservoir level. Remnant multiple energy makes reservoir characterization a considerable challenge, but WAZ streamer surveys present the opportunity to improve on multiple attenuation.

The first WAZ towed streamer surveys

In 2000, a conventional 3D streamer survey focusing on improved acquisition parameters over the Mad Dog discovery did not deliver the needed improvements over a previous traditional 3D streamer survey shot in a different direction. This result lead several companies to investigate the possible benefits of widening azimuthal coverage.

The first GoM WAZ survey was conducted by BP with the contractor CGGVeritas over the Mad Dog field in 2004-05, using one recording vessel and two source vessels. The WAZ data delivered a breakthrough in imaging, and initiated a broad WAZ acquisition program to enhance the imaging of subsalt discoveries.

In 2006, Shell shot a WAZ survey with WesternGeco, aiming at improved imaging of a deep target below a complex salt structure near the deepwater GoM Friesian discovery. The acquisition program comprised two dual-source vessels and one eight-streamer vessel. Shell concluded that while not all areas below the salt were illuminated, the WAZ survey improved the image of the subsalt sedimentary structure. Furthermore, the dominant multiples were removed without specific processing.

By combining MAZ and WAZ concepts, rich azimuth (RAZ) coverage can be obtained. The first RAZ streamer survey was acquired by BHP in 2006 over the Shenzi discovery in the Green Canyon area. The survey

Definition of NAZ, MAZ, WAZ, RAZ, AAZ and FAZ surveys

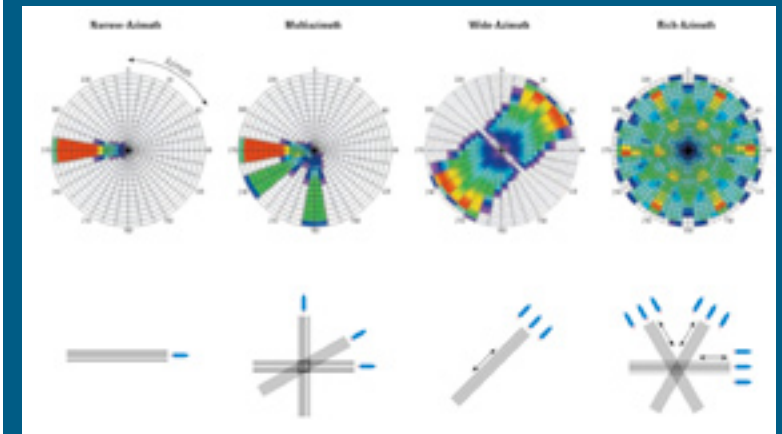
In a typical 3D marine seismic survey the vessel traverses the surface in a predetermined direction above the subsurface target. Since most of the recorded seismic signals travel nearly parallel to the sail line, at small azimuth, the survey is called a narrow azimuth or NAZ survey. Azimuth is the angle at the source location between the sail line and the direction to a given receiver. The target essentially is illuminated from one direction in NAZ surveys.

In a multi-azimuth (MAZ) survey the seismic vessel acquires 3D seismic data over the survey area in multiple directions, up to six. The azimuth distributions are clustered along azimuths associated with the sail lines.

Wide azimuth (WAZ) surveys are designed to widen the azimuth distribution over the target in one preferred single direction. Different designs are available, but they require at least two source vessels in addition to the streamer vessel. Each source line is shot multiple times with increasing lateral offset. To improve acquisition efficiency, some WAZ surveys are acquired with multiple streamer vessels.

A rich azimuth (RAZ) survey is essentially MAZ surveys acquired in multiple directions. The first RAZ survey was acquired in 2006 by BHP Billiton over the deepwater Shenzi field.

An all azimuth (AAZ) or full azimuth survey (FAZ) is a survey where "all" azimuths are acquired. FAZ surveys are best realized using OBS technology.



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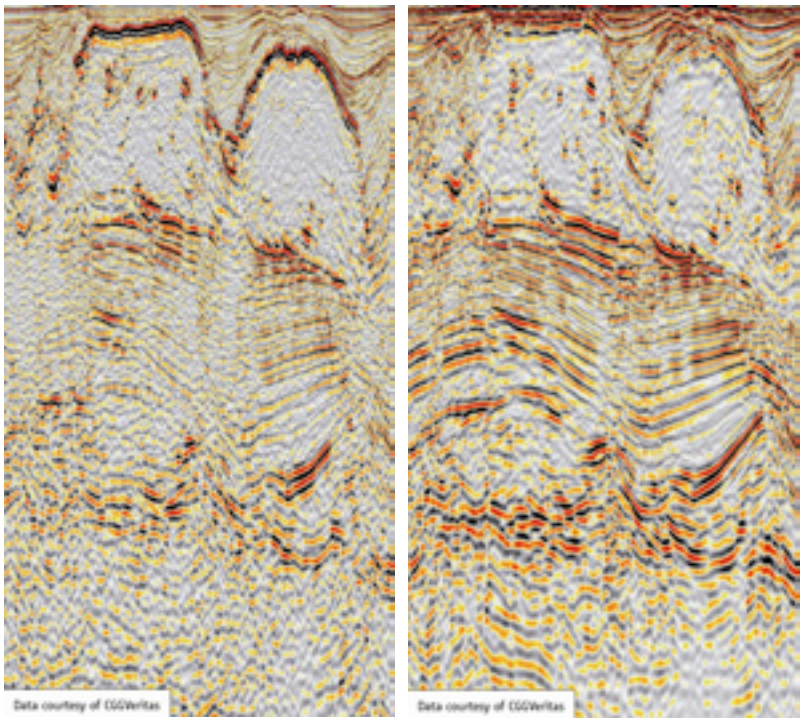
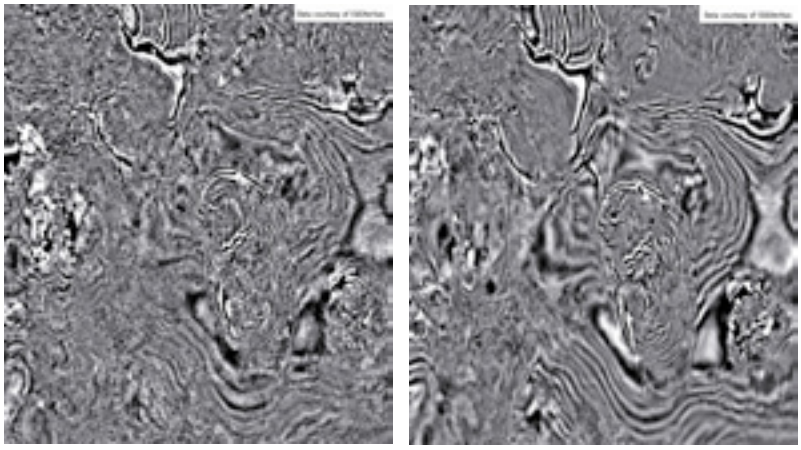
Traditional and new acquisition geometries (bottom) and azimuth-offset distribution plots (top). Colors range from purple and dark blue for a low number of traces (low fold) to green, yellow and red for a high number of traces (high fold).



Comparison between images acquired with narrow-azimuth (left) and wide-azimuth (right) methods. The WAZ streamer data was shot with one streamer vessel and four source vessels, each firing a single source, in a configuration designed to give split spread shot records. The wide-azimuth image illustrates both the illumination and imaging uplifts by showing clearer reflections. Multiples are significantly suppressed by the WAZ stack.



Comparison between images acquired with narrow-azimuth (left) and wide-azimuth (right) methods.

was acquired with one streamer vessel equipped with a source and two source vessels shooting along three sailing directions. Each shot location was repeated at least three times. The Shenzi RAZ survey took 88 days to acquire and delivered six times the data of a conventional survey. The RAZ survey significantly improved reflections deep below the salt compared to a previous narrow azimuth (NAZ) survey.

WAZ towed streamer surveys wildfire – many vessel configurations

Most of the major seismic contractors are today shooting massive multiclient WAZ surveys in the GoM due to the rapid acceptance of WAZ methodology and its benefits by the major E&P companies. Various geometries are being tried as there is no agreed optimum WAZ vessel configuration. The survey design is challenging since the geophysicist is asked to propose a geometry that gives full illumination, full noise suppression, and easy processing – all at a low cost.

CGGVeritas is currently running two projects covering around 1,050 blocks in the Walker Ridge and Garden Banks/Keathley Canyon areas. WesternGeco has shot more than 900 blocks spanning from Garden Banks and Keathley Canyon to the north-west of Green Canyon. In partnership with TGS, WesternGeco is acquiring data over 650 blocks in Mississippi Canyon. PGS covers 570 blocks in Crystal 1 and 2 and has a new project planned for 2009 in Crystal 3. By the end of 2008, it is estimated that 60,000 sq km (the equivalent of 10 North Sea quadrants) of multiclient WAZ data will be on the market. Several large and ambitious multiclient WAZ surveys are planned, and in the three next years much of the deep-water GoM could be covered by WAZ surveys.

Conclusions

The experience with WAZ and RAZ surveys in the GoM has demonstrated several benefits. Seismic shot from several azimuths results in better illuminated reservoirs. Attenuation of multiples and other types of coherent noise are improved, providing increased signal-to-noise ratio for subsurface reflectors. But in order to make the full benefit of this new technology, new advanced data processing tools are needed, such as multiple attenuation, migration, and iterative model building, including geological process understanding. Finally, it should be kept in mind that the WAZ and RAZ acquisition methods are not silver bullets. The industry is making clear progress, but we expect further step-change improvements in data acquisition in the years to come.

Acknowledgment: We thank CGGVeritas for providing seismic sections that compare NAZ and WAZ imaging.