Azimuth diversity in towed marine seismic: Multi-Azimuth (MAZ) and Wide-Azimuth (WAZ) acquisition

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Introduction

In an ideal world seismic data will provide complete illumination of the reservoir, be of sufficiently high resolution to meet exploration and development objectives, and be free from all noise and multiple events. In practice however, there are two main ways in which we can damage the seismic data: first we can record complex coherent noise, and secondly, we can create artifacts via inadequate acquisition, processing and imaging. In conventional towed marine seismic acquisition, target illumination is never uniform. Uniform illumination requires that each subsurface point is represented by a fold of data with uniform distribution of source-receiver offsets, and, importantly, a uniform distribution of source-receiver azimuths. Specialized towed marine acquisition geometries, in some cases requiring more than one vessel, have been developed in an effort to overcome the narrow azimuth limitation of conventional towed marine seismic and increase the azimuthal diversity of the recorded data.

Illumination and Multiple Contamination

The impact of shooting direction on the illumination of a complex target is illustrated in Figure 1. In this example from Brunei, dip-related ray bending gives rise to gross variations of illumination at the target when dip and strike shooting are compared. If discontinuities in target illumination or subsurface coverage exist, imaging artifacts can result.

Multiples are routinely recorded in seismic data and suppression of multiple events is a significant challenge in the processing of the data. However, complex multiple diffractions behave differently depending upon their source-receiver azimuth of recording, so that a diversity of source-receiver azimuths in the recorded seismic data is beneficial in attenuating the multiples when the data is stacked. This is illustrated conceptually in Figure 2.

Azimuthal diversity, therefore, benefits seismic data by providing more uniform illumination and improved multiple attenuation.

Conventional towed marine seismic acquisition has traditionally yielded data with a narrow range of source-receiver azimuths as a direct consequence of the fact that the source and receivers, both towed by the same vessel, are geometrically coupled. But in geological regimes where the overburden and or target are structurally complex, narrow azimuth data fails to illuminate the target adequately. This has moved the seismic industry to pursue acquisition methods that aim to deliver a wider range of source-receiver azimuths, de-coupling the source from the receivers in towed marine geometries, resulting in different techniques such as Multi-Azimuth (MAZ), Wide-Azimuth (WAZ), and Rich-Azimuth (RAZ). Nowadays we refer to conventional single vessel acquisition as Narrow-Azimuth (NAZ) recording. Multi-Azimuth refers to the technique of acquiring the same survey in two or more directions with a single vessel. Wide-Azimuth, also referred to as WATS (Wide-Azimuth Towed Streamer), requires the use of at least one additional source vessel in addition to the streamer vessel. Finally in RAZ, the same survey with WAZ is acquired in two or more directions.

Multi-Azimuth (MAZ)

Multi-Azimuth 3D seismic acquisition is a robust solution to target illumination problems that involves acquiring the same survey in more than one direction; the different
Azimuth diversity in towed marine seismic: Multi-Azimuth (MAZ) and Wide-Azimuth (WAZ) acquisition

shooting directions illuminate different parts of the target, and collectively the overall target illumination will be more uniform and complete. One early example is the Varg field, operated by Pertra, which lies on the Norwegian side of the North Sea. In 2001 production from the field was in decline, and confidence in understanding the reservoir, which sits beneath a chalk layer, was poor. In 2002 PGS re-acquired the survey in two additional azimuth directions, and together with the legacy survey, processed the data as a 3-survey MAZ. The improvement in the seismic data and the illumination of the target can be seen in Figure 3, which compares the legacy data with the processed MAZ data. The new data led to a much improved understanding of the compartmentalization in the reservoir, and subsequently a renewed well development plan. Production from the new infill wells, made possible by the MAZ data, is shown in Figure 4.

In the Mediterranean, offshore Nile Delta, imaging of channel sand bodies beneath a complex Messinian layer is challenging not only because of illumination problems, but also because of severe multiple contamination from shallow diffractions. In this case, the illumination problems stem in part from the focusing and defocusing of raypaths which result from the overlying Messinian layer. The Messinian is of varying thickness and is made up of fast velocity anhydrite and slow velocity channel fill. In 2005 BP acquired five additional azimuths to complement a legacy survey, for a 6-survey MAZ named Raven. Comparisons of Pre-Stack Time Migrated sections derived from one of the six azimuths with the data derived from the orthogonal azimuth clearly show differences in illumination throughout the data. Specialized processing routines are required when the component azimuth surveys are summed; a windowed weighted stack approach is utilized so that the best illuminated signal in the component azimuths is retained in the final multi-azimuth stack product. Figure 5 shows improved multiple attenuation and improved clarity and interpretability of sand channels which results in the MAZ data.

Wide-Azimuth (WAZ)

In the MAZ approach, a number of different azimuths are acquired where each of the component surveys is a NAZ survey. The pre-stack data is binned so that each component NAZ survey contains source-receiver azimuths within a tolerance of +/- 15 degrees departure from the direction of shooting. MAZ data therefore contains a fixed number of discrete source-receiver azimuths. In contrast, WAZ acquisition geometries result in data with a large range of source-receiver azimuths, sampled evenly. A further distinction is that the component surveys in a MAZ project are typically processed independently, and the final result is a summation of the components, whereas in the WAZ approach, the whole data set is processed as one volume. This requires specialized processing algorithms for applications such as True-Azimuth 3D SRME (Surface Related Multiple Elimination) and Pre-Stack Depth Migration.

Numerous marine acquisition geometries which yield a range of finely sampled azimuth data are possible. In the Gulf of Mexico, Wide-Azimuth techniques are replacing conventional NAZ surveys for sub-salt exploration. During 2007-2008 PGS acquired a 9500sqkm survey named ‘Crystal WATS’ using a configuration which involved a Ramform vessel tows 10 streamers, 8.1 km in length and 120m separation, and with two source vessels, one at each end of the spread. Successive passes of the recording vessel with the sources vessels in the same position are referred to as ‘tiles’; for the Crystal survey, 2 tiles were conducted. The effort to acquire large areas of Wide-Azimuth data efficiently can lead to remarkable production records: with an acquisition footprint of 9 sqkm, moving at 4.3 knots and covering 215 sqkm/day, the Crystal WATS acquisition system was ‘the largest moving object on Earth’.

Figures 6 shows the improvement which resulted from the Wide-Azimuth acquisition in the Crystal survey by comparison with the legacy NAZ data; the WAZ data shows superior imaging of the sub salt section. In addition to addressing the illumination issues in sub-salt exploration, the WAZ approach gives improved signal/noise by virtue of the strong multiple attenuation which results from the azimuthal diversity of the data.

Even more sophisticated marine techniques are possible. An ‘ultimate’ approach, referred to as Rich-Azimuth, combines MAZ and WAZ: instead of NAZ surveys being acquired in a number of different directions, the same is done but with WAZ surveys.
Azimuth diversity in towed marine seismic:
Multi-Azimuth (MAZ) and Wide-Azimuth (WAZ) acquisition

Conclusions

Multi-Azimuth and Wide-Azimuth marine acquisition geometries aim to provide a diversity of source-receiver azimuths in the recorded data. In the Multi-Azimuth case, the survey is acquired a number of times in different directions, whereas in WAZ, a range of source-receiver azimuths is recorded by decoupling the source and receiver vessels. The motivation is to better illuminate the target, which results from azimuth diversity in the data. Azimuth diversity also means complex multiples are better attenuated. MAZ data will be represented with a specific number of discrete source-receiver azimuths, whereas WAZ data will contain a broad range of smoothly varying source-receiver azimuths. In the MAZ approach, improvement in data quality comes primarily from improved illumination, with second order improvement from azimuthal stacking; this order is reversed in the WAZ approach. Specialized geometries such as MAZ and WAZ are becoming increasingly important in seismically challenging regimes. Efficiency in acquiring the large amounts of data involved in these techniques becomes an important cost consideration.

Acknowledgements

We wish to thank Pertra for permission to show the Varg data examples, BP Egypt and partners for permission to show the Raven Multi-Azimuth survey data examples, and PGS for permission to publish.

References

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Figure 1: The impact of shooting direction on the illumination of a complex target. Strike (left) and dip (right) shooting directions illuminate the target differently. Colour scale represents the number of ‘hits’; white is zero illumination.
Azimuth diversity in towed marine seismic:
Multi-Azimuth (MAZ) and Wide-Azimuth (WAZ) acquisition

Figure 2: Complex multiple diffractions behave differently depending upon their source-receiver azimuth of recording, and are attenuated in the azimuth stack process.

Figure 3: Comparison sections from the Varg surveys: on the left, the legacy narrow-azimuth survey; on the right, the 3-azimuth MAZ result. Significant improvement is seen at the target level and deeper in the section.
Azimuth diversity in towed marine seismic:
Multi-Azimuth (MAZ) and WideAzimuth (WAZ) acquisition

Figure 4: Return on investment: The development wells which resulted from the improved understanding of the reservoir as a consequence of the MAZ survey, shown in blue. In light brown, depleting production from earlier wells.
Azimuth diversity in towed marine seismic:
Multi-Azimuth (MAZ) and Wide-Azimuth (WAZ) acquisition

Figure 5: Raven survey, offshore Nile delta: comparisons of single-azimuth data (top row), with Multi-Azimuth (bottom row).
On the left, much improved multiple attenuation, in center, improved imaging of complex channel systems, and on the right, improved imaging in section form.

Figure 6: Significant improvement in sub-salt imaging from the Crystal WATS survey, Gulf of Mexico. On the left, legacy NAZ data example; on the right, the Wide-Azimuth data.