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Survey design for wide-azimuth towed-streamer acquisition

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Summary

Wide-azimuth towed-streamer acquisition emerged in the last two years as a step change in marine acquisition technology in the Gulf of Mexico. This came about because the risky exploration and development of deepwater subsalt reservoirs required seismic data to have better illumination, higher signal-to-noise ratio, and improved resolution. Early results from the initial programs confirm that the expected benefits can be obtained. However, although the survey design principles for land and OBC wide-azimuth programs are well understood, the fact that the towed-streamer implementation is still in its infancy means that survey design principles in that case are still evolving. The objective of this paper is to discuss some of those principles.

Introduction

A conventional narrow-azimuth towed-streamer survey is acquired by a single vessel possessing multiple streamers and one or more sources. A multiazimuth towed-streamer survey is simply the superposition of narrow-azimuth surveys that were acquired in different directions over the same area. So it too is characterized by a single-vessel operation. Wide-azimuth and rich-azimuth towed-streamer surveys, on the other hand, require a minimum of three vessels – utilizing one streamer vessel and two source vessels. More advanced designs utilizing two streamer vessels and two source vessels are now also being used. A description of how Gulf of Mexico wide-azimuth and rich-azimuth surveys have been acquired to date can be found in Moldoveanu and Egan (2006).

We can describe the fundamental feature that distinguishes wide-azimuth streamer surveys from traditional 3D marine designs by borrowing nomenclature from sister surveys in the onshore and OBC worlds. Wide-azimuth towed-streamer surveys can provide symmetric split spreads in the inline and/or crossline directions. That is, depending upon the specifics of the survey design, reciprocal azimuths can be acquired in the inline direction, or the crossline direction, or both. A convenient way to portray this is in terms of vector-offset distributions, as shown in Figure 1.

In addition to the macrogeometry issue that defines the nature of wide-azimuth streamer programs, there are also microgeometry issues such as the manner in which source arrays are deployed. Some of the wide-azimuth surveys acquired so far in the Gulf of Mexico employed dual-source arrays while others used single-source arrays. In the next section we will analyze the associated implications of this.

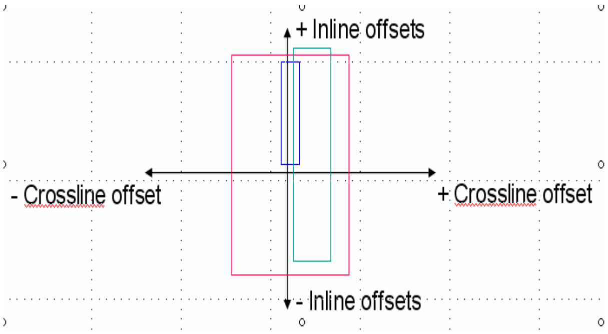

Figure 1: Vector-offset distribution for different types of towed-streamer surveys: narrow-azimuth (blue), wide-azimuth with inline reciprocal azimuths (green) and wide-azimuth with inline and crossline reciprocal azimuths (red)

Dual-source arrays vs. single-source arrays in wide-azimuth towed-streamer surveys

Sample wide-azimuth towed-streamer configurations using dual-source arrays and single-source arrays are shown in Figures 2 and 3 respectively.

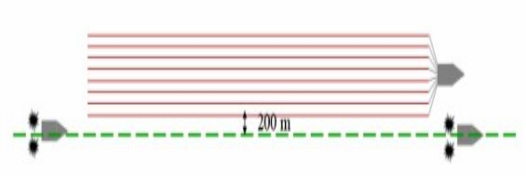

Figure 2: A wide-azimuth configuration using one streamer vessel and two source vessels; each source vessel has a dual-source array.

Figure 3: A wide-azimuth configuration using one streamer vessel and two source vessels; each vessel has a single-source array.

For a given record length, with sequential source shooting the total number of shotpoints that can be acquired over the survey area in a fixed amount of time is the same regardless of whether single-source or dual-source acquisition is used. So from the total prestack migration fold standpoint, the issue of which approach to use is moot. From the illumination point of view there are not significant azimuth differences between the data acquired with a single source vs. a dual source because the typical crossline separation is 50 to 60 m. However, the use of single-source designs can indeed bring geophysical benefits for other reasons. Chief among these is that single-source arrays can typically be larger, thereby providing a greater signal-to-noise ratio in the data.

We performed an experiment to prove the benefits of a larger source for subsalt imaging. Over a subsalt prospect in the Gulf of Mexico three seismic datasets were recorded using 5085-in³, 6780-in³ and 8475-in³ airgun arrays. The results are shown in Figure 4 and these illustrate the improved signal-to-noise for the subsalt events with the increased source array volume. Also, steering of single-source arrays is more accurate – thereby leading to improved repeatability of the source positions in subsequent passes of the vessels. (Repeating source positions is a feature inherent in all wide-azimuth streamer designs). Accurate repositioning of sources has many benefits including the efficient facilitation of common shot migration in the processing center.

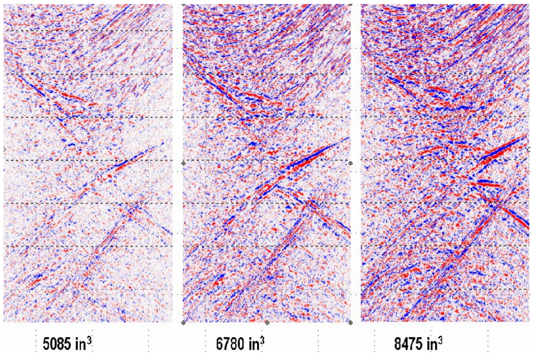

Figure 4: Comparison of data acquired with 5085-in³, 6780-in³ and 8475-in³ source arrays.

Of concern to some explorationists, is the issue of crossline sampling in single-source survey designs. Typically the separation between the arrays of a dual-source geometry is ½ that of the streamer separation. So for a 100-m streamer separation, the nominal crossline bin dimension is 25 m for a dual-source configuration and 50 m for a single-source configuration. As shown by the graph in Figure 5, imaging the 30-Hz component in a challenging but realistic subsalt scenario for the Gulf of Mexico requires a bin dimension of 28 m. This would therefore seem to imply that the single-source geometry leads to undersampling in the crossline direction; however, this is not the case. The concept of the traditional nominal bin size is a throwback to the CMP poststack imaging workflow for traditional narrow-azimuth surveys. The resolution of the final image after prestack depth migration of wide-azimuth data depends on data space sampling, image space sampling and migration operator sampling. By virtue of cable feathering and the multiple passes of the seismic vessels mentioned above, the reflection point spatial sampling in wide-azimuth surveys is very rich, and the migration fold is very high – allowing for selection of suitably small output migration bin dimensions, regardless of the dimensions dictated by traditional nominal bin calculations. For example, Figure 6 shows the distribution of reflection points for a subsalt target horizon from an actual wide-azimuth streamer survey in which single-source arrays were used on each vessel. These reflection points were computed from ray tracing using the real navigation data from the field. It is seen that the distribution of reflection points is nearly random. In this display, the survey area was covered twice – by forward and reverse traverses of the seismic fleet. In many wide-azimuth surveys, however, the number of traverses can be even more – yielding even greater migration fold.

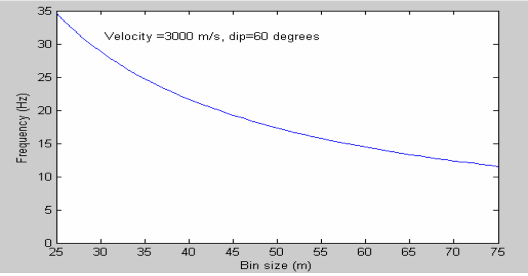

Figure 5: Maximum non-aliased frequency after migration as a function of bin size, dip, and velocity

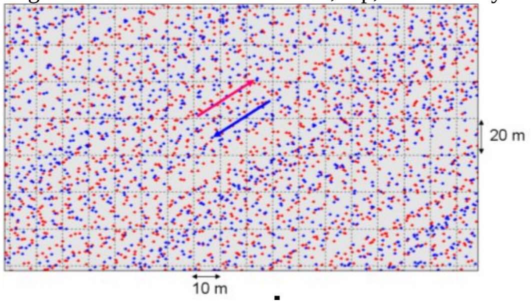

Figure 6: Reflection point distribution on a target horizon for a wide-azimuth survey using a single-source array; the survey area was shot twice in opposite directions (red and blue)

We performed an in-house experiment using an existent wide-azimuth dataset to simulate a single-source and a dual-source acquisition. The two datasets were selected to have equivalent prestack migration fold. The simulation result is not included in the abstract, but it showed that single source and dual source produced similar subsurface images.

Four-vessel wide-azimuth towed-streamer survey design for exploration purposes

The main acquisition parameters that determine the cost of a wide-azimuth towed-streamer survey are the maximum crossline offsets, the sail line interval and the acquisition of reciprocal azimuths. The maximum crossline offset divided by the streamer width determines the number of passes, or how many times the survey area is acquired. The survey size for an exploration wide-azimuth survey could be quite large and the survey design should balance between the optimum design parameters and the survey cost. The use of a four-vessel configuration consisting of two streamer vessels and two source vessels can improve the acquisition efficiency. This type of design was first proposed by Sukup (2002). The four-vessel configuration that we used for a 6250-km² exploration survey in the Gulf of Mexico is presented in Figure 7.

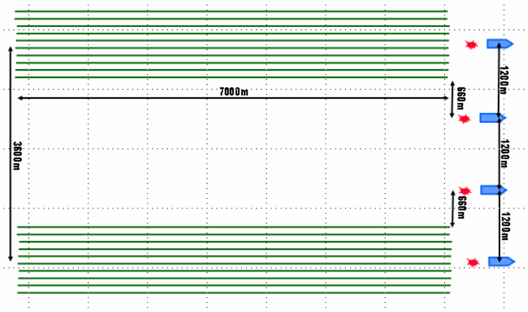

Figure 7: Wide-azimuth towed-streamer configuration with two streamer vessels and two source vessels.

On each vessel, we had a single 8475-in³ source array. This acquisition is split-spread type in the crossline direction and produces reciprocal crossline azimuths with a maximum of 4200 m crossline offset. To get inline reciprocal offset and azimuths we designed interleaved sail lines running in opposite directions. The source sampling corresponding to this four-vessel design is 150 m inline and 600 m crossline. The benefits of this four-vessel design for an exploration survey are: it produces a large crossline offset and large fold (186), and it requires only one pass at 600-m sail line interval.

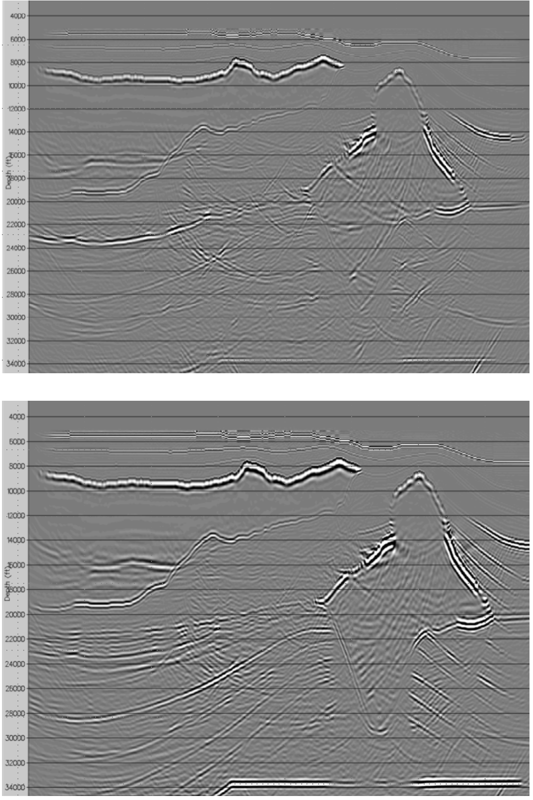

Figure 8: Conventional narrow-azimuth survey imaging (above) and four-vessel wide-azimuth imaging (below)

To demonstrate that this design produces a good imaging of the subsalt reservoir 3D finite difference shot records with primaries and multiples were generated. From the synthetic records a conventional narrow-azimuth acquisition and a four-vessel wide-azimuth acquisition were simulated and the shots were migrated with common-shot wave extrapolation migration. The results are presented in Figure 8 and these show significant improvement in signal-to-noise ratio and illumination of the subsalt events for four-vessel wide-azimuth acquisition.

When a wide-azimuth exploration survey is designed we must consider how the proposed acquisition can be "upgraded" to a development-type acquisition on smaller areas. One possible upgrade of the four-vessel configuration is to "infill" to a denser sail line interval, for instance 300 m, or to acquire another pass, using the same parameters, in an orthogonal direction. A comparison of the offset-azimuth distribution (rose diagram) for an exploration and a development-type four-vessel wide-azimuth acquisition is shown in Figure 9.

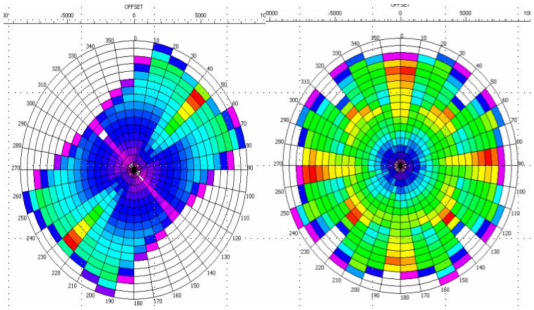

Figure 9: Offset-azimuth distribution for a four-vessel exploration survey with one pass (left) vs. a four-vessel development survey with two orthogonal passes (right).

Acquiring an additional pass in an orthogonal direction produced a very rich azimuth distribution and doubled the fold, attributes that could translate in improved reservoir illumination and improved signal-to-noise ratio of the subsalt events.

Reducing the migration aperture by acquiring data during vessel turns

Imaging of deep subsalt reservoirs requires a large migration aperture, which could be more than 12000 m in the Gulf of Mexico. Adding this to the image area increases the cost of the survey. Acquiring seismic data during the vessel turns can reduce the area required for the migration aperture. This is particularly important for rich-azimuth acquisition because data acquired during turns are naturally wide-azimuth. As part of the survey evaluation and design study conducted jointly by BHP and WesternGeco for Shenzi rich-azimuth survey in the Gulf of Mexico, three experiments were conducted to determine if acquiring and processing turn data was feasible from operational and geophysical points of view. These experiments confirmed that data can be accurately recorded and processed. Based on these positive results it was decided that for the Shenzi rich-azimuth towed streamer survey to acquire seismic data during vessel turns (Howard and Moldoveanu, 2006). The sail lines were designed without run-in and run-out (Figure 10). The Shenzi rich-azimuth survey was successfully acquired and the acquisition efficiency was significantly increased by reducing the line change from nearly three hours to less than five minutes. We performed migration of wide-azimuth Shenzi data with and without turn data included. Although not shown in this abstract, the results show clearly the benefits of turn data: better imaging of steep subsalt events and extended subsurface information towards the edge of the survey.

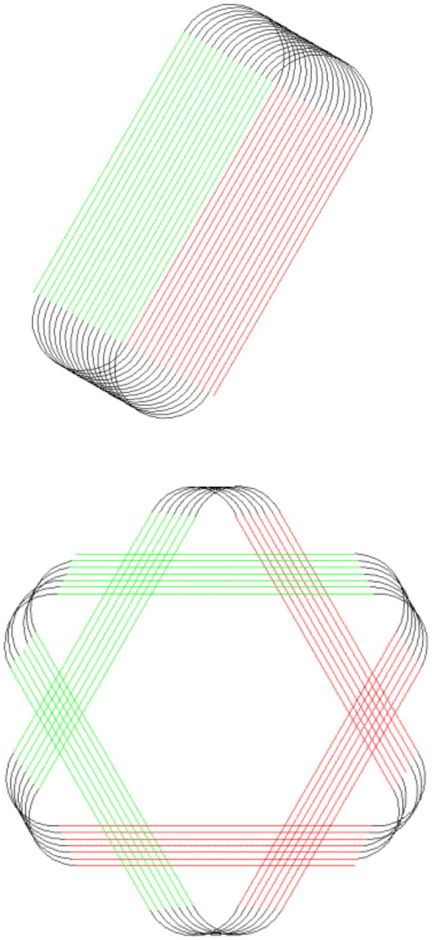

Figure 10: Examples of Shenzi rich-azimuth sail lines with shooting in turns; the run-in and run-out were eliminated; the examples are courtesy of BHP

Discussions and conclusions

The source crossline sampling is an important attribute of wide-azimuth survey design because it could affect the subsurface illumination and the performance of the method used for multiple attenuation. The crossline source sampling could be improved by decreasing the sail line interval or by adding more source arrays. Decreasing the source line interval increases the cost of the survey. Adding more source arrays could be a more attractive alternative if this could be implemented with dual-source arrays on each vessel, separated in the crossline direction with the desired source line interval. However, with the sequential source shooting technique, which is standard in the industry these days, the inline source sampling will be decreased. If two sources are fired simultaneously the total number of traces will be doubled and the signal-to-noise ratio will be increased. Although the simultaneous source shooting for marine acquisition was proposed in 1998 by Beasley and Chambers, so far it has not been used in production jobs.

Survey design aspects discussed in this paper are based on the experience we gained from the planning, acquisition and processing of several wide-azimuth surveys acquired in the Gulf of Mexico in 2006 and 2007. The preliminary results from these programs show the benefits of this new marine acquisition technology for subsalt reservoir exploration and development, proving that survey design was properly carried out.

Acknowledgements

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Reference

Beasley, C. J., and R. E. Chambers, 1998, A New Look at Simultaneous Sources: 60th Meeting, EAGE, Expanded Abstracts, Session: 02-38.

Moldoveanu , N. and Egan, M., 2006, From narrow-azimuth to wide- and rich-azimuth acquisition in the Gulf of Mexico, First Break, volume 24, December 2006

Sukup, D.V., 2002, Wide-azimuth marine acquisition by the helix method, The Leading Edge, 21, 791.

Howard, M. and Moldoveanu, N., 2006, Marine survey design for rich-azimuth seismic using surface streamers, SEG, Expanded Abstracts 26, 2915 (2006)