What is the next step after WAZ for exploration in the Gulf of Mexico?

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Summary

The concept of circular geometry for towed-streamer marine acquisition was introduced in the early 1980s by French (French, 1984). Due to the limitations in marine technology and processing methods at the time, circular geometry had a short time span. Recently, it was proved that is feasible to use this type of geometry to acquire full-azimuth (FAZ) data using a single vessel, if the vessel sails along a pattern of overlapping circles (Moldoveanu, 2008). This technique is called Coil Shooting* single-vessel full azimuth acquisition. In this paper we demonstrate the benefits of implementing coil shooting acquisition with multiple vessel configurations.

Introduction

Wide-azimuth (WAZ) towed-streamer acquisition is acquired with parallel-type geometry using multiple vessels. The most efficient configurations used to date in the Gulf of Mexico for WAZ acquisition have four vessels: two receiver vessels and two source vessels or one receiver vessel and three source vessels (Figure 1). Typical parameters for this type of configuration used for exploration purposes are:

- Number of streamers: 10
- Streamer separation: 100 m or 120 m
- Streamer length: 7000m or 8000 m
- Number of sources: 4
- Nominal source interval: 37.5 m (4 sources, sequential shooting)
- Sail line interval: 600 m

A WAZ survey for development purposes could be acquired with a reduced sail line interval, for example 300m. Another option could be to acquire two surveys in orthogonal directions, with a 600-m sail line interval. If an exploration WAZ survey was already acquired and we want to convert this to a development-type survey, this could be achieved in two ways: record a new WAZ survey on top of the existent one with exploration parameters, for instance 600-m sail line interval, and interleaving the sail lines. The other option is for two surveys to be shot in orthogonal direction with a 600-m sail line interval.

The results of WAZ surveys in the Gulf of Mexico acquired over existent 3D narrow-azimuth (NAZ) or multi-azimuth (MAZ) data, show significant improvements in the illumination of subsalt reservoirs and in signal-to-noise ratio. However, as we progress in the interpretation of these results, we started to see that in complex geologic situations, where the salt structures are very complex and the subsalt reservoirs have steep dips, the seismic image is questionable. Studies conducted so far to explain poor seismic image show that offset longer than 10 km, and WAZ data are required to image the steep-dip reservoirs. One drawback of multi-vessel WAZ parallel acquisition is the limited offset, in both inline and crossline direction. Increasing the offsets, in either direction, would make a WAZ acquisition very expensive.

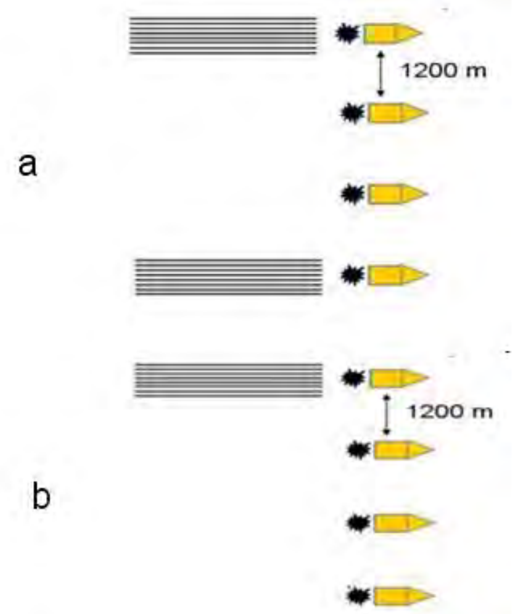

Figure 1: WAZ configurations with two recording vessels and two source vessels, or 2 x 4, (a) and one recording vessel and three source vessels or 1 x 4, (b)

Circular geometry offers the possibility to acquire efficiently long offset and FAZ data, by using multivessel coil shooting configurations, and this will be examined in the next sections.

Multivessel configuration for coil shooting

Coil shooting was introduced as a single vessel FAZ acquisition and the technique is very attractive due to superior geophysical attributes and efficiency. However, considering the need for WAZ long offset data, we decided to investigate if using multivessel coils shooting could be beneficial for solving imaging problems in areas with steep- dip subsalt reservoirs. The following configurations where analyzed:

- Two recording vessels, or 2 x 2

- Two recording vessels and two additional source vessels, or 2 x 4
- Single recording vessel with three additional source vessels, or 1 x 4

In the abstract we will focus on the 2 x 2 configuration which we refer to as dual coil shooting. This configuration is described in Figure 2. The two recording vessels are placed on two circles that are separated in X direction by a distance dx, and in a Y direction by a distance dy.

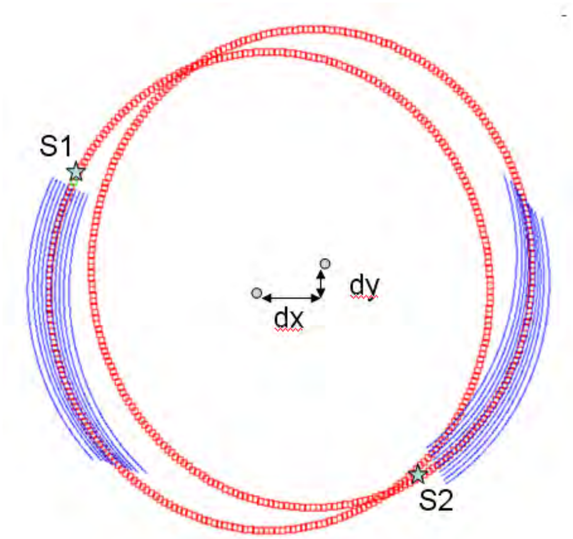

Figure 2: Dual coil shooting acquisition; two recording vessels sail along two circles that have the centers separated by dx and dy distances.

Each vessel generates a shot that is recorded in two spreads. The vessels could shoot sequentially (flip-flop) or simultaneously. The vessels move with the same speed following the pre-plot sail circles. The circles roll in X direction with distance 2*dx and in the Y direction with distance 2*dy. These distances are selected based on the following criteria: offset-azimuth distribution in the offset-azimuth sectors or in the vector-offset tiles, spread-width, and efficiency.

We simulated a dual coil shooting survey with the objective to acquire FAZ distribution over the target area.

The following acquisition parameters were used:

- Number of streamers per vessel: 10
- Streamer separation: 120 m
- Streamer length: 8000 m
- Group interval: 25 m
- Number of sources: 2 (one per vessel)
- Shot interval: 75 m flip-flop
- Circle radius: 6250 m

To reduce the volume of navigation data generated in simulation, we used a 25-m group interval and a 75-m shot interval.

The shot distribution for this survey is presented in Figure 3 and the coverage fold and offset-azimuth distribution are shown in Figure 4. Offset-azimuth distributions (rose diagram) for the whole survey and for a small area of approximately 1 km² were calculated and are displayed in Figure 5.

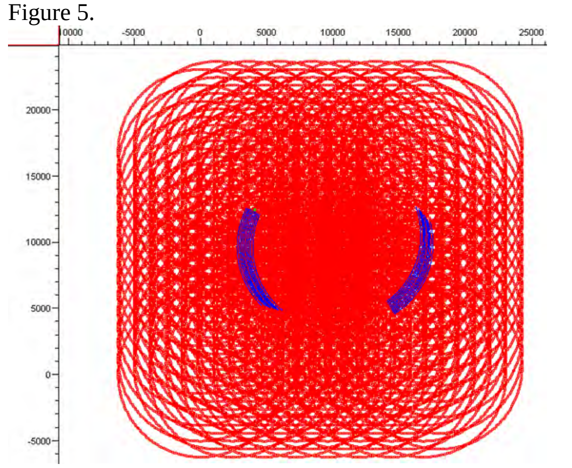

Figure 3: Shot distribution for an area of 24 km²; every shot is recorded in two receiver spreads (blue color)

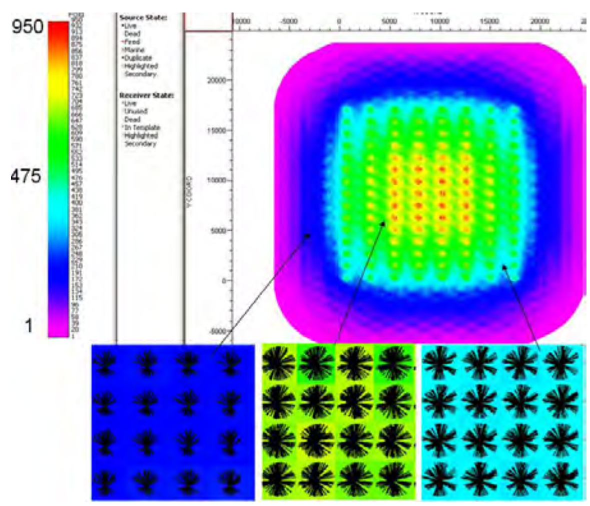

Figure 4: Coverage fold and bin offset-azimuth distribution (spider diagram); the bin size used to calculate the attributes was 25 m x 25 m

The following remarks can be made based on the design attributes:

- Dual coil generates high density data resulting in FAZ distribution and high fold over the target area; the fold decreases toward the survey fringes

- Maximum offset reaches 14 km
- The coverage fold is not uniform and requires fold regularization in processing

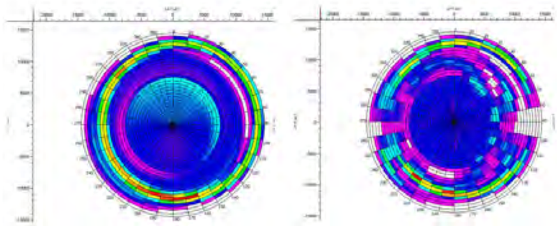

Figure 5: Rose diagram for the whole survey (left) and for an area of 1km² (right); maximum offset is 14 km

The acquisition time of dual coil shooting for a given survey is half of the acquisition time with single coil shooting. Dual coil acquisition has the important advantage of acquiring long offset and FAZ data with no extra cost.
In the next section we will discuss the benefit of dual coil shooting for illumination of steep subsalt reservoirs.

Illumination comparison of WAZ, areal and dual coil shooting acquisitions

A WAZ survey was acquired over a Gulf of Mexico subsalt reservoir that has steep structural dips. The processing results of the WAZ data revealed that the steep parts of the reservoir were not illuminated. A 3D ray-tracing study was conducted to determine target illumination using the WAZ navigation data and the velocity model derived in depth imaging (Figure 6). The simulated area was approximately 38 km x 38 km.

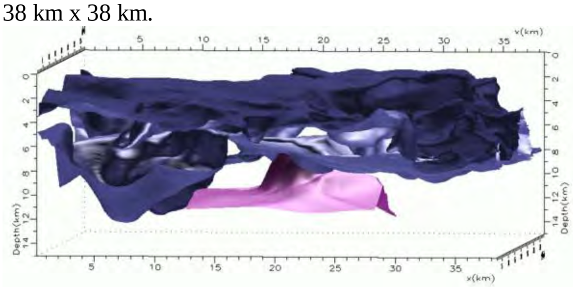

Figure 6: Velocity depth model used for the illumination study; only the salt body and the target horizon (pink color) are shown

Target illumination was evaluated using different attributes maps: hit count, simulated migration amplitude, offsets contributing to target illumination, and angle of incidence at the target. In the abstract we included only the hit count maps.
The WAZ acquisition used in the simulation was an exploration-type survey, as described in the introduction. The maximum offset for the configuration described above was 8122 m. The hit map (Figure 7) shows that most of the steep portions of the target reservoir were not illuminated, confirming the depth imaging results.

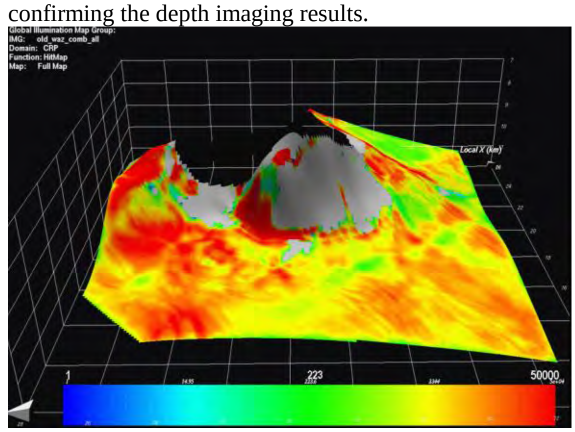

Figure 7: Hit count map for the WAZ exploration survey; the areas colored in gray were not illuminated

The next step in our study was to determine if the target could be illuminated with longer offsets or with a wider range of azimuths. To answer this question we simulated an areal-type geometry, which can have FAZ distribution and very long offsets. For this study we selected a receiver grid of 100 m x 100 m, and a source grid of 400 m x 400 m, both grids covered the whole survey area. All receivers were kept lived for every shot to generate very long offsets. However, we looked at illumination results for 7 km, 10.5 km and 14 km maximum offset range. We included in the abstract only the hit map for 10.5 km (Figure 8). The areal geometry results show that offsets from 10.5 km to 14 km are required to illuminate the steep dips.

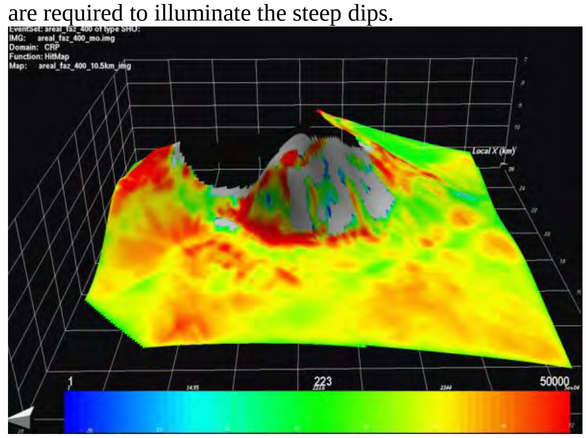

Figure 8: Hit count map for the areal geometry with 10.5 km maximum offset

The cost of areal or WAZ acquisitions with a maximum offset of 14km could be very expensive and this prompted us to investigate how multivessel circular geometry would perform. . We started with dual coil acquisition and this was simulated with the acquisition parameters presented in the previous section. The maximum offset for dual coil acquisition was 14 km. The hit count map is presented in Figure 9 and this proved that FAZ long offset data generated by dual coil acquisition illuminates the reservoir. The cost of dual coil acquisition is less than long-offset areal or WAZ geometries due to a very efficient acquisition, and a minimum line change.

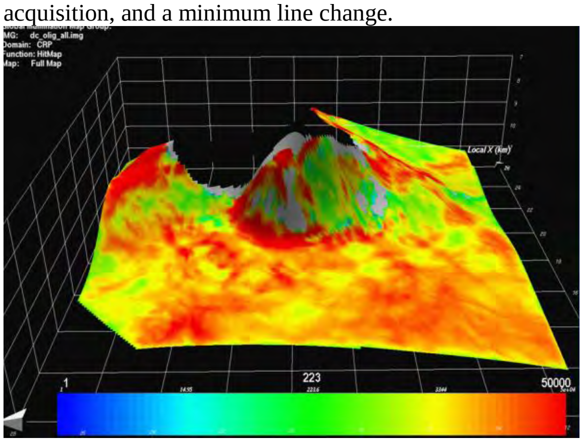

Figure 9: Hit count map for dual coil acquisition

Simulation of a dual coil acquisition with 3D finite difference and common shot migration

Work is in progress to simulate a dual coil acquisition using the new SEG SEAM model (Fehler, 2009). A vertical cross-section of the SEAM model is presented in Figure 10.

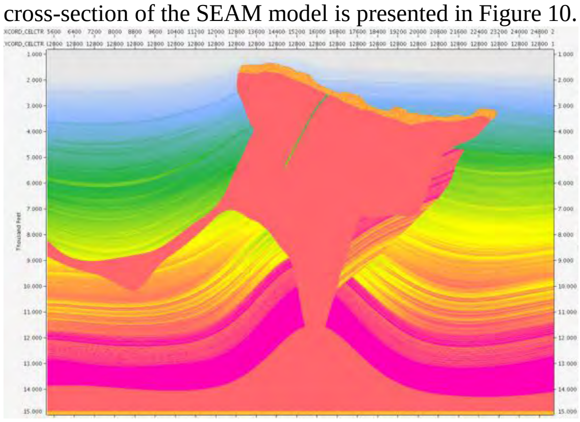

Figure 10: Vertical section through the SEG SEAM model

An example of dual coil shot gather data generated with 3D finite difference software is displayed in Figure 11. This shows a far offset and a near offset streamer data. The data was simulated with a non-absorbing surface in order to generate surface-related multiples. Preliminary processing includes only first arrival removal. After that, each shot is depth migrated with common shot wave-equation migration (WEM).

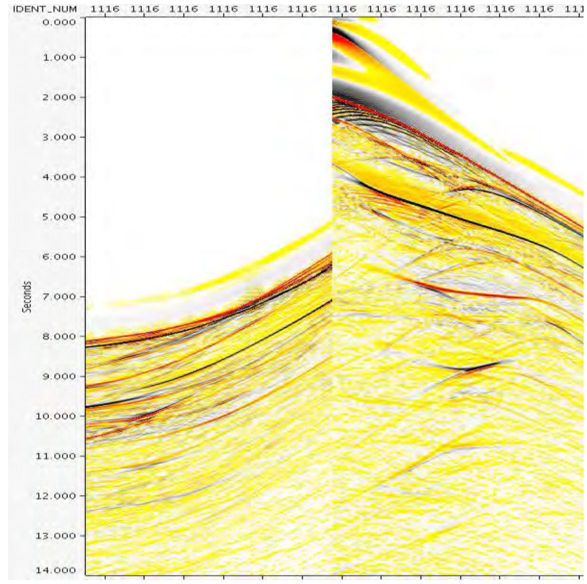

Figure 11: Simulated dual coil data: far offset data (left) and near offset data (right)

Discussions and conclusions

Single vessel coil shooting acquisition allows acquiring FAZ data with a maximum offset that depends on the streamer length. If the geological conditions require long offset and FAZ data, multi-vessel coil shooting is a very attractive method because the very long offsets can be acquired with no extra cost, while WAZ and areal acquisitions could incur significant cost increase

One important criterion in survey design of multi-vessel coil acquisition is to determine the acquisition parameters based on the azimuth and offset distribution in offset-azimuth sectors or offset vector tiles.

The multi-vessel configuration 1x 4 and 2 x 4 were not discussed in this abstract, but can be also used for coil shooting with similar benefits as dual coil shooting.

The illumination study presented in this paper demonstrated the value of the FAZ and large-offset dual coil acquisition for exploration of steep-dip subsalt reservoirs.

Acknowledgments

We acknowledge Tierra Geophysical for licensing of the 3D finite difference software used in this study.

We are grateful to WesternGeco for the permission to present this paper.

EDITED REFERENCES

Note: This reference list is a copy-edited version of the reference list submitted by the author. Reference lists for the 2009 SEG Technical Program Expanded Abstracts have been copy edited so that references provided with the online metadata for each paper will achieve a high degree of linking to cited sources that appear on the Web.

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