Coil shooting acquisition – an efficient method for subsalt exploration

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Abstract

Exploration and development of offshore deep water subsalt reservoirs could be very costly due to the drilling challenges. Seismic image of the reservoir is the key factor for generating the reservoir model that is used for drilling. In the last four years wide-azimuth (WAZ) towed-streamer acquisition has been established as a successful technology for exploration and development of the complex subsalt structures in the Gulf of Mexico. In this paper we present coil shooting acquisition, a novel method to acquire WAZ surveys using circular geometry.

Introduction

The main challenges for seismic exploration in deep water subsalt environment are related to lack of illumination, poor signal-to-noise ratio and insufficient resolution. Wide-azimuth surveys acquired so far proved that seismic data quality was improved due to enhanced illumination, better signal-to-noise and improved multiple attenuation. Wide-azimuth marine towed-streamer surveys are acquired with multiple vessels and are using a parallel geometry (Moldoveanu and Egan, 2007). An example of four-vessel configuration used in the Gulf of Mexico to acquire WAZ data for large exploration programs is presented in Figure 1. Each streamer vessel is equipped with 10 streamers, 7000 m length, and separated by 120 m. On each vessels there is a single source array shooting sequentially, with 37.5 m nominal shot interval.

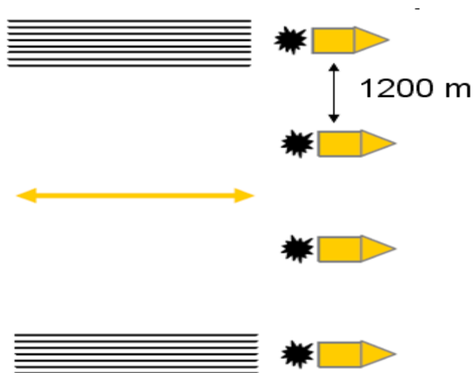

Figure 1: WAZ four-vessel configuration with two streamer vessels and two source vessels

The data is acquired in forward and reverse direction, interleaved, with a sail line interval of 1200 m, producing 600m shot line interval.

The sampling of the data acquired with WAZ parallel configuration shown in Figure 1 for exploration and development surveys is presented in table 1. With parallel geometry the data is sampled well in the inline direction but not very well in the crossline direction.

Parameter	WAZ exploration	WAZ development
X-receiver	12.5 m	12.5 m
Y-receiver	120 m	120 m
X-shot	150 m	150 m
Y-shot	600 m	300 m
Shot density per km²	53.33	106.66
Max. inline offset	7400 m	7400 m
Max. crossline offset	4200 m	4200 m
Aspect ratio	0.56	0.56

Table 1: Example of data sampling for WAZ parallel geometry

From operational point of view the multi-vessel parallel geometry typically incurs significant amount of non-productive time due to the line change. Also, the technical downtime could increase with a multi-vessel operation.

An acquisition geometry that could have better properties, in terms of data sampling and acquisition efficiency, is circular geometry proposed by French (French, 1984). Few surveys were acquired in the Gulf of Mexico and in the North Sea using circular geometry implemented as concentric circle acquisition around salt domes, in order to image better the radial faults. However, the marine technology and 3D imaging at that time did not allow properly implementing circular geometry and the method was abandoned.

The simulation studies and the field tests performed in the last two years proved that is feasible now to acquire efficiently full azimuth data with a single vessel sailing in a pattern of overlapping circles, as is shown in Figure 2. This acquisition technique is called coil shooting. In the next section we will describe the geophysical attributes of coil shooting acquisition based on simulation.

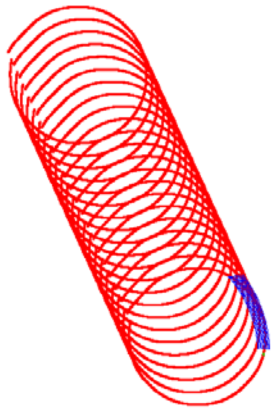

Figure 2: Coil shooting acquisition with a single vessel; the shot points are colloured in red, and the streamers, for one shot location, are colored in blue

Simulation of a coil shooting survey

The simulation of coil shooting survey is based on the navigation data collected during the first field experiment performed in the Gulf of Mexico. From the field test we selected one circle, presented in Figure 3, and simulated a survey that covers an area of 35 km by 37 km. The results of survey simulation based on real navigation data could give information about the effect of the marine currents on fold, offset and azimuth distribution.

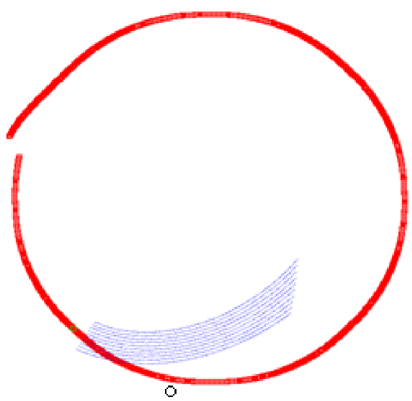

Figure 3: Circular sail line with shot positions in red and the receiver position for a shot point in blue; the effect of the currents on the spread can be noticed

The main design parameters for a coil shooting surveys are number of streamers, streamer length, streamer separation, circle radius, and circle roll in X and Y directions. Four our simulation the following parameters were used:

- Number of streamers: 10
- Streamer length: 7000 m
- Streamer separation: 120 m
- Number of sources: 1
- Shot interval: 37.5 m
- Receiver interval: 50 m
- Circle radius: 6000 m
- Circle roll in X and Y direction: 1200 m

The total number of shots modeled was 440,440 and the shot distribution is shown in Figure 4

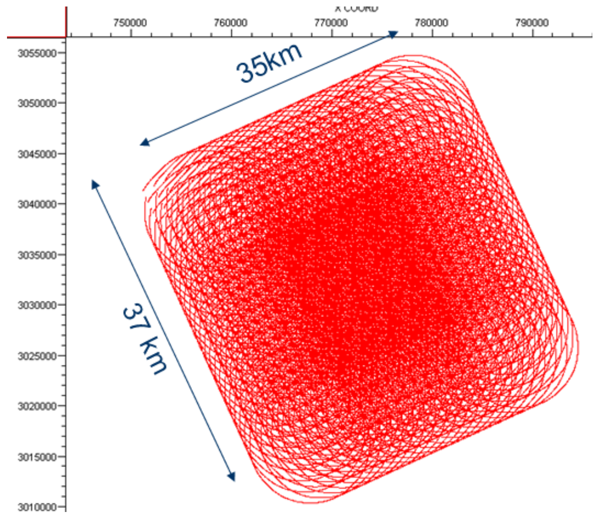

Figure 4: Shot distribution for a coil shooting survey

The number of shots for coil shooting data is typically larger than for wide-azimuth parallel geometry due to the gain in efficiency achieved by reducing the line change from several ours to few minutes. The average number of shots per km² for this design is 340. As shots are distributed along several overlapping circles, the shot distribution could be considered pseudorandom, a feature that could be beneficial for multiple attenuation and imaging.

The fold coverage, azimuth, and offset distributions were calculated after the data were binned with a 25-m x 25-m bin size. The fold coverage shows that maximum fold is placed in the middle of the survey or the target area, and the fold decreases towards survey fringes (Figure 5). Over the target area full-azimuth distribution is achieved. The nominal fold of a parallel WAZ geometry survey acquired with two streamer vessels and two source vessels, 600-m sail line interval, 37.5-m shot spacing, and the streamer configuration described above, is 186 for an exploration survey and , and 372 for a development survey. Higher fold is acquired with circular geometry due to the high-density shot distribution, which, depending on the design, could be between 1.34 to 2.6 times larger.

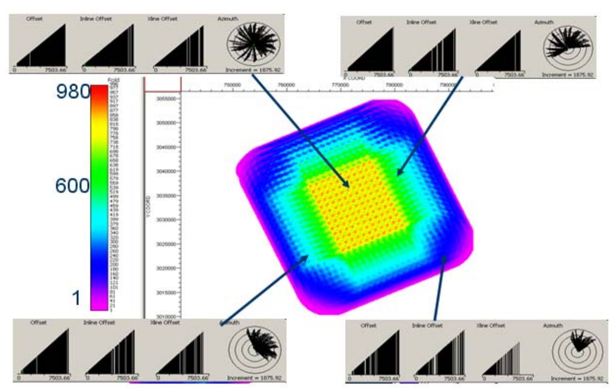

Figure 5: Coverage fold and azimuth and offset distribution (spider diagrams) for different parts of the survey

Comparing azimuth offset distribution for circular geometry and parallel WAZ geometry, we may notice:

- Aspect ratios of circular geometry and parallel WAZ geometry are 1 and 0.56, respectively.
- Full-azimuth distribution can be acquired over the target area and wide-azimuth distribution is acquired over the rest of the survey.
- Near offsets are better recorded with circular geometry than with parallel WAZ geometry.
- The maximum offset of circular geometry is smaller than the maximum offset of a parallel WAZ geometry; for a cable configuration of 10 streamers, 7000-m and 120-m streamer separation, the difference in the maximum offset is 800 m.

The wide-azimuth coverage and the high fold associated with the circular geometry allow splitting the data in different azimuth ranges for anisotropic velocity model building and fracture analysis.

In the next sections we will analyze the properties of coil shooting for subsalt reservoir illumination, multiple attenuation and signal-to-noise.

Subsalt reservoir illumination

Subsalt reservoir illumination was analyzed based on 3D ray tracing for the velocity model presented in Figure 6.

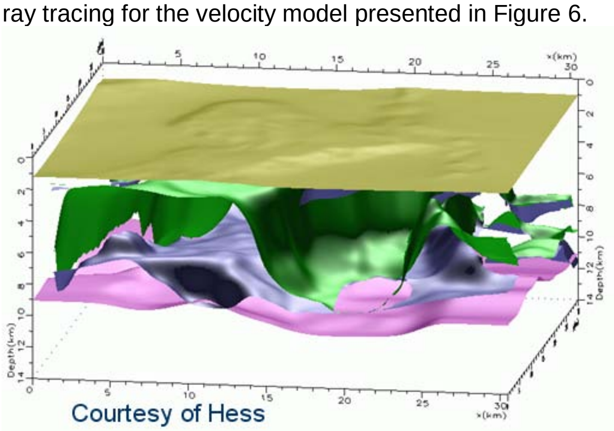

Figure 6: Velocity depth model for a Gulf of Mexico subsalt reservoir; the target horizon is coloured in pink

The ray tracing was performed for three acquisition geometries: narrow-azimuth (NAZ), wide-azimuth for development and coil shooting. The results of 3D ray tracing are presented in Figure 7 as hit maps. For this particular subsalt reservoir illumination is improving as the azimuth coverage becomes wider. Coil shooting produced the best illumination.

Multiple attenuation

Attenuation of multiples in the near offset ranges is typically more challenging due to lack of NMO discrimination. We analyzed how coil shooting geometry performs on a synthetic model that consists in a dipping plane reflector and a scatter point (Figure 8). A near offset section was extracted from the synthetic volume and this is shown in Figure 9. GSMP method, which is a 3D SRME method independent of the acquisition geometry (Moore and Dragoset, 2008), was used for multiple prediction. The final result of GSMP is shown in Figure 10. This synthetic test, as well as the results of feasibility tests, proved that coil shooting geometry is very adequate for 3D SRME type multiple attenuation due to better data sampling of sources and receivers, and better acquisition of the near offsets.

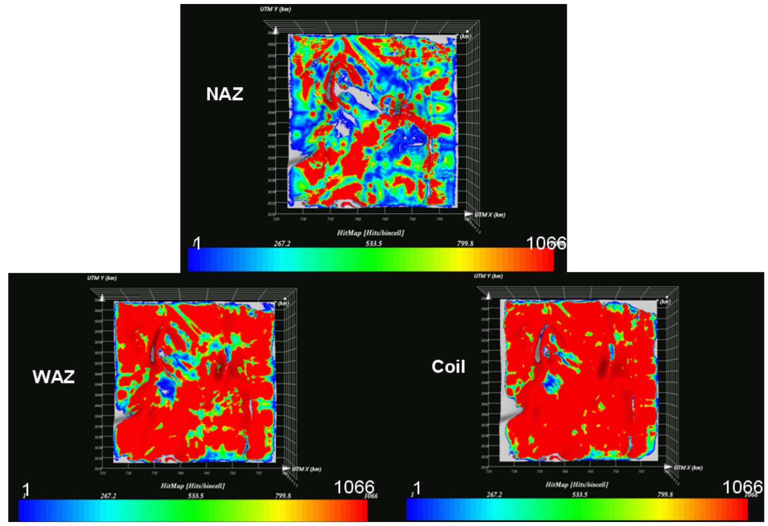

Figure 7: Subsalt target hit maps for NAZ, WAZ and coil shooting acquisitions

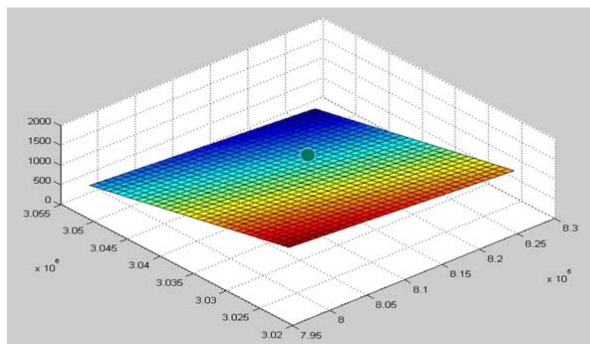

Figure 8: The model used to generate synthetic coil shooting data: a dipping plane with a scatter point.

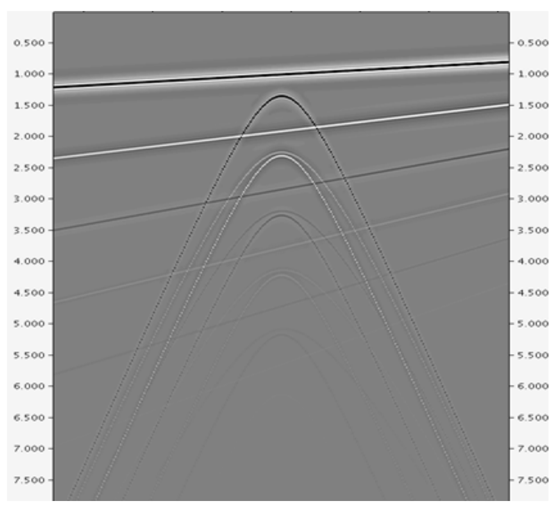

Figure 9: Synthetic near offset section (offset =554m) generated from coil shooting geometry; two primary events and five bounces of free surface multiples were generated

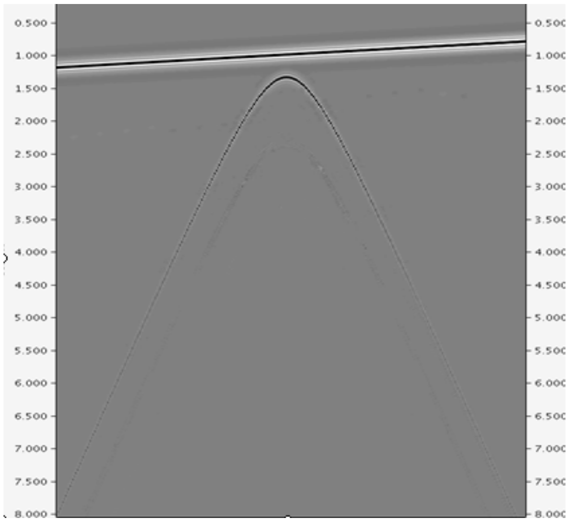

Figure 10: The result of surface multiple attenuation using GSMP method

Signal to noise ratio

A coil shooting feasibility test was performed in the Gulf of Mexico that consisted in the acquisition of 4 circles with different circle radii: 5.5, 6, 6.5 and 7 km. (Figure 11). The main objective of the test was to determine the level of turn noise as a function of circle radius. The data was collected over an area where a WAZ survey was already acquired.

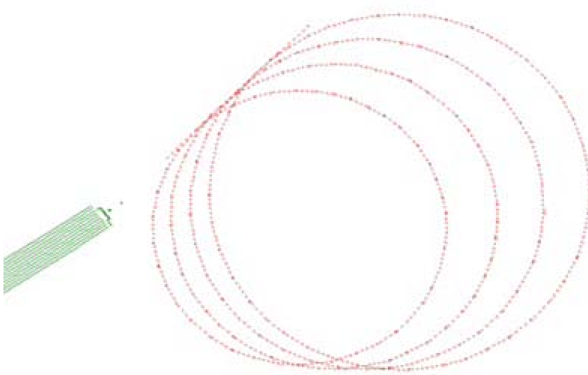

Figure 11: Coil shooting feasibility test: four circles with radii of 5.5, 6, 6.5, and 7km were shot

The coil shooting data was processed with the same processing sequence as WAZ data, and the same velocity model was used to generate a depth image using WEM common shot migration. The processing sequence did not include multiple attenuation. As the two datasets were processed with the same processing grid it was possible to extract the same part from an inline and compare the results. The comparison between WAZ parallel geometry and coil shooting are presented in Figure 12. Although the coil data was limited as aperture and fold, the result compares very favorably with the full fold, full aperture WAZ data. The coil shooting results demonstrates that coil acquisition could produce good signal-to-noise ratio data

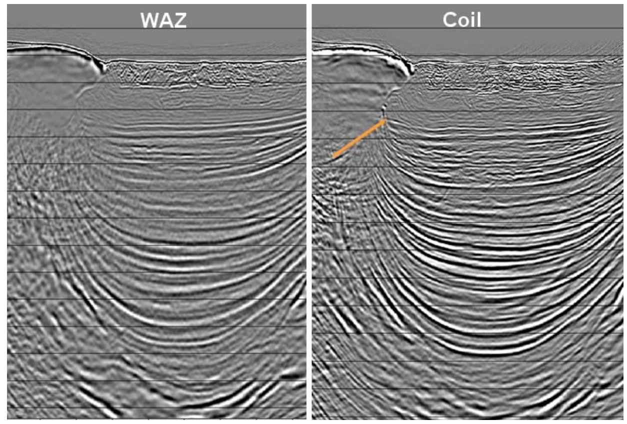

Figure 12: Comparison between WAZ parallel geometry acquisition and coil shooting acquisition; the depth images were generated with common shot WEM migration

Conclusions

The simulation studies, the feasibility tests and the commercial projects performed to date, demonstrated the following:

- Coil shooting acquisition is a single vessel method to acquire efficiently, full azimuth and high density data;
- Coil shooting could be used for subsalt reservoir due to improved illumination, efficient attenuation of multiples and improved signal-to-noise ratio associated with the very high fold.
- Coil shooting is more efficient than WAZ parallel geometry for development projects
- Minimum amount of infill is required for coil shooting
- Data can be split and processed in offset azimuth bins or offset vector tiles for anisotropic processing and fracture characterization

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