First nodal OBS acquisition from the Thunder Horse Field in the deep water of the Gulf of Mexico

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Summary

We describe an experimental four-component (4C) nodal ocean-bottom seismic (OBS) survey that was conducted in 2001 at Thunder Horse field in the deep water of the Gulf of Mexico. At a water depth of 6000 ft, this is to our knowledge the deepest-water OBS survey shot by industry to date. The goal of this survey was to investigate the technical feasibility of deep-water OBS surveys, which hold the promise of improved imaging due to the wide-azimuth nature of the data. We present the results from prestack depth migration of these OBS data and compare them to an image computed from towed-streamer data. The results lead us to conclude that deep water OBS is feasible and may be a powerful technology for future deep-water imaging projects.

Thunder Horse field

Thunder Horse field is located in the south-central part of the Mississippi Canyon protraction area of the Gulf of Mexico. BP owns 75% of working interest and ExxonMobil owns the remaining 25% interest in this field. The water depth in this area is approximately 6000 ft. The Thunder Horse discovery contains hydrocarbon resources in two structural closures commonly referred to as the Thunder Horse South (THS) and Thunder Horse North (THN). The THS was discovered in 1999 by the 778-1 well. The structure is a 4-way dip closure related to salt withdrawal and is segmented by a complex system of faults. THN was discovered in 2000 by the 776-1 well and is a dip closure against a salt wall. A salt canopy covers THN and part of THS. Oil is contained within three middle-lower Miocene units with high reservoir pressures and temperature.

A Description of the Problem

The Boarshead basin is located in the south-central part of the Mississippi Canyon protraction area of the Gulf of Mexico. Three large structures exist within this basin but all of them are obscured to a varying degree by allocthonous salt bodies. Thunder Horse South development in this basin is associated with one of those major structural features. The area of interest along with location of the major fields is shown in Figure 1.

Seismic imaging in the area is complicated due to the abundance of salt bodies, which obscure all major structures. A number of different vintages of towed-streamer seismic datasets with different acquisition geometries are available in this area, but none of these have been able to deliver the image quality required for proper geologic understanding of many areas. Attenuation at the deeper reservoir levels as well as multiples from the water bottom and the salt-sediment interfaces degrade the image in many places. Resolving structural complexity and stratigraphic details through adequate seismic imaging is key to the success of future development. The imaging problems associated with conventional data in this area prompted us to look into alternative acquisition techniques.

Figure 1: Location of Thunder Horse Development

Nodal OBS acquisition

There is evidence that considerable improvement in subsalt image quality may be achievable through wide-azimuth acquisition [1]. Towed-streamer surveys at Thunder Horse shot at different azimuths have been seen to illuminate different parts of the subsurface [2], indicating the potential benefits of wide-azimuth acquisition. Promising technologies for this task include vertical cable [3] and OBS. The latter includes both ocean-bottom cable as well as ocean-bottom node technologies. OBS (like vertical cable) acquisition lends itself to efficient wave-equation migration, our preferred method for subsalt imaging. This is true in particular for areal-patch shooting, i.e., in the case where there are many more shots than receivers. Areal-patch shooting is also expected to yield superior images compared to other geometries (as, for example, land-type wide-patch shooting with large spacing between shot lines) [1]. Both cable- and nodal-style OBS acquisition have been applied successfully in many different locations around the world. However, industry applications of OBS technology have so far been limited to water depths shallower than those at Thunder Horse, while deep-water applications have been limited largely to academic research.

The experiment that we discuss here was conceived as a study of the technical feasibility of OBS at Thunder Horse (and other prospects with similar water depth). The main question we wanted to answer was whether we could manage to get a usable image from OBS data obtained with currently available OBS technology, and thus if there would be potential for using OBS technology in deep water more extensively in the future.

Our survey was shot in 2001 using GeoPro OBS nodes. These nodes are battery powered autonomous units that are deployed from a boat. Each unit sinks to the sea bottom under the weight of an anchor, which is left on the sea bottom at the end of the experiment after the unit has been acoustically released. While on the sea bottom the instruments record continuously. We had a total of 80 nodes available. We decided to deploy them twice, first in a 2D-line configuration with 400 m spacing between adjacent nodes, and then in an 8-by-10 node 3D patch with 1km spacing in both directions (Figure 2).

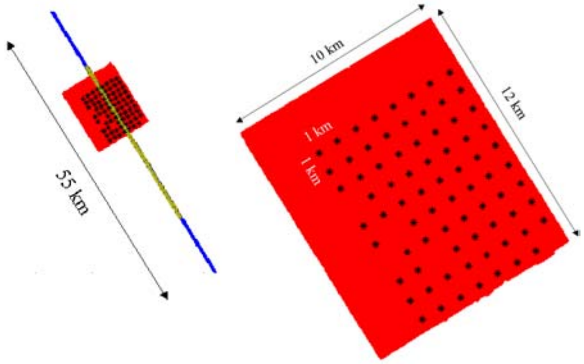

Figure 2: Acquisition geometries of the 2D and 3D surveys (left) and a close-up of the 3D survey (right). 2D shots are shown in blue, 2D receivers in yellow, 3D shots in red, and 3D receivers in black.

Previously, we had conducted an extensive ray-trace modeling exercise to optimize some of the acquisition parameters. For the 2D-line layout, a long shot line (1100 shots at 50m spacing) was shot over the receiver line. For the 3D-patch layout a 3D 240-by-200 shot patch (at 50m spacing in both directions) was acquired. Ideally, the shot patch should have been larger; however, we were limited by the battery life of the nodes. After shooting the 2D line, all nodes were recovered, but three nodes had failed to record any data. After the 3D survey two nodes were permanently lost. Three more did not record any data, while some of the other nodes stopped recording prematurely, i.e., before the shot patch was completed. In our opinion this failure rate is a bit higher for any commercial application. Substantial improvement in technology may be available now and GeoPro should be consulted in this matter.

Processing of OBS data

In the processing discussed here, we focused on P-wave imaging using the hydrophone (P) and vertical-geophone (Z) components of the 4C data. Preprocessing of these data involved some noise removal as well as correction of positioning and timing errors. Figure 3 shows typical common-receiver gathers for both P and Z components. Both gathers in Figure 3 had some noise removal applied. Comparison of the two components shows a certain amount of converted-wave energy on the Z component, which is not present on the P component. Also clearly visible on both components is the receiver ghost, which we attempted to attenuate using PZ summation.

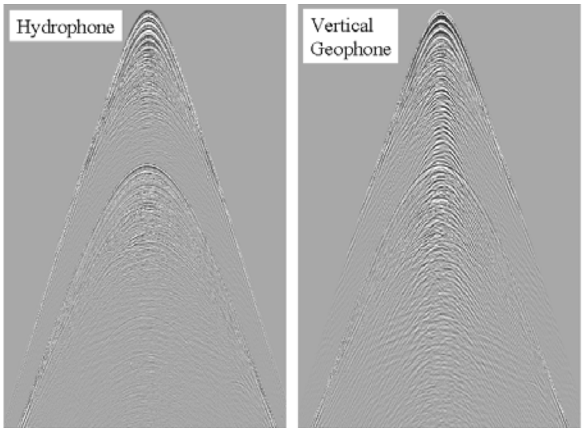

Figure 3: Common receiver gathers for hydrophone and vertical geophone components.

Further processing steps included attenuating the converted-wave energy on the Z component. This was attempted by subtracting from the Z component a converted-wave prediction computed from the two horizontal components. We then matched the amplitude spectra of the P component to the Z component. We migrated both components separately using a wave-equation shot-record migration algorithm and applied PZ summation to the migrated images. Doing PZ summation after migration allowed us to inspect the P and Z images separately, in addition to the PZ image, and thus provided us with more insight into the data quality on these two components. Generally the signal quality was higher on the P component and summing the Z component added some noise to the final image.

Discussion

Figure 4 shows the 2D PZ image and a cross-section through the 3D PZ image. Also shown for comparison is a cross-section of a 3D towed-streamer image that was obtained through wave-equation migration with the same velocity model as the OBS images.

Comparison of the images shows that we achieved reasonably good images from the OBS survey. The 2D OBS image appears to be better than the 3D OBS image. This is primarily due to the denser spacing (400 m vs. 1000 m) of the nodes in the 2D layout. Due to the small number and sparseness of the nodes (and the resulting low fold), as well as the limited extent of the shot patch, it would be unrealistic to expect an image of comparable quality to the towed-streamer image. Overall, given these constraints and the highly experimental nature of the survey, we view the quality of the final results as strongly encouraging for the future pursuit of deep-water OBS technology.

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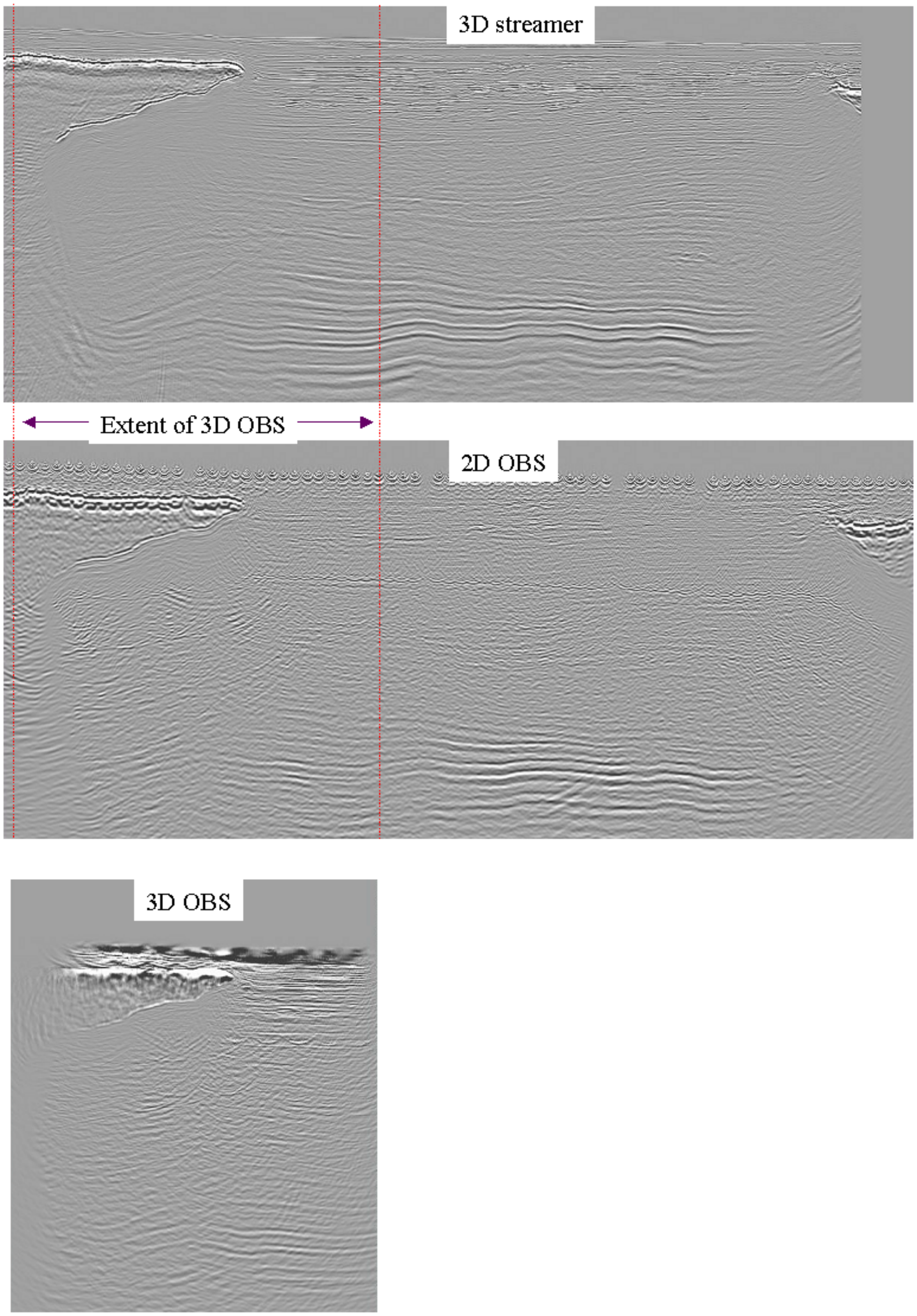

Figure 4: Comparison of 3D towed-streamer image (top), 2D OBS image (middle), and 3D OBS image (bottom), all extracted along the same line.