Application of ocean bottom cable as a new tool in offshore 3-D seismic data acquisition

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Abstract
The ocean bottom cable (OBC) seismic technology involves the deployment of some multi-sensor cables on the ocean floor to record both the velocity and pressure signals of seismic waves. The OBC method has advantage for obtaining coverage in congested producing fields clustered with platforms, pipelines and drilling rigs. In shallow waters, lakes, bays and rivers where towed source vessel operations are difficult or impossible, the OBC method comes in handy, offering a range of benefits including higher signal bandwidth, high spatial resolution, low noise, minimum down-time, design flexibility and improved near surface resolution. Dynamically positioned recording vessels are connected to several kilometers of cables deployed along predetermined lines on the ocean floor. Strapped to the cable at regular increments are multi-component (4C) receivers or dual sensors (2C) which detect seismic signals reflected from the subsurface formations. These signals are filtered, amplified, and digitised in remote electronic modules along the cables and telemetered via the cable to a recording vessel. OBC surveys were recently introduced into 3D seismic operations in offshore Niger Delta, Nigeria.

Introduction
This paper presents an overview of a standard ocean bottom cable (OBC) seismic technology, a marine seismic data acquisition system that has now been introduced into Nigeria by one of the major multinational companies. This technology is compared with the normal marine seismic data acquisition system using a towed streamer. This is to demonstrate the superiority of the OBC to the traditional streamer method and to show the virtually unlimited advantages of this new method. The OBC data acquisition and processing stages and the concept of multi-sensors, are also discussed.
expensive, is often used to avoid this possibility. Dynamically positioned recorders are also less likely to drift from this set-up position and drag cables offline from pre-planned locations. In contrast to the conventional towed streamer operations, the source boat tows only the airgun array, allowing it to manoeuvre very close to obstructions as well. The chase or utility boat facilitates movement of people and equipment from vessel to vessel and to and from the shore. It also performs picket duty and warns encroaching vessels of the cables below.

A typical OBC crew comprises four to six vessels, with minimum configurations being a source boat, a recording boat and at least one cable boat. Cables are normally squirted from the back deck of the cable boat by an operator-controlled hydraulic device while the vessel traverses the pre-planned line. Many crews have at least two cable boats and one chase/utility boat. A additional cable boats provide storage for more in-water equipment (cables, phones and electronic modules) and facilitate quicker deployment and retrieval, which boosts productivity. OBC crews typically operate in water depths up to 100m or greater. The low end of the range is determined more by vessel draught than equipment. Cables can actually be brought on land, but it is not unusual to lay cables across islands or sandbars.

Recording, navigation and positioning systems
"Jumpers" connect the OBCs to the stationary recording vessel at its "set up" location. Fig. 2 is a schematic sketch of the recording vessel and 4-receiver lines. Some crews have two recording boats, but the addition of a second recorder usually results in higher productivity. The next set of cables, i.e. the next patch or "swath" can be powered up, tested and located before ending of recording on the current set of cables. This reduces the time spent moving from one recorder set-up to the next. Good seismic data depends also on good quality control by the QC geophysicists in the recording room. The problem of correct positioning arises during OBC surveys, especially as regards the following factors. These are knowing the good repeatability and accuracy; steering the ship on the planned lines in the presence of tides, winds and water currents; and firing the guns (seismic sources) to give common midpoints at regular intervals in the ocean floor.

A remote-positioning system is adequately met by the use of navigation systems, which include radio and satellite/sonar sensor systems mounted on the vessels and the cables. There are two different methods for locating the source and receiver groups. These are the absolute positioning methods and the acoustically coupled position. The absolute positioning method employs a radio-navigation system receiver on or near the source array. This relaxes gyrocompass dependency thereby improving positioning accuracy. In the second method, acoustic measurements are used to couple source arrays to relative or (preferably) absolute surface positions. An accurate knowledge of ocean-bottom receiver groups is required to properly image the subsurface data required. Care is taken to ensure accurate placement of receiver groups at pre-planned positions (Edington, et al., 1993). However, due to the nature of deployment, vessel movements, currents and water depth, the groups do not generally end up on the ocean-bottom directly beneath the surface. Receiver group drop locations can be determined either by a "first break" or acoustic method.

Advantages of the multicomponent dual-sensor OBC technology
High signal bandwidth and high spatial resolution
Subsurface imaging with the OBC technique is specially suited for shallow water and obstructed offshore areas. The industry standard dual-sensor technology enables a separation of up-going (desired) and down-going (undesired) wave fields. Since the receivers are located on the water bottom, potentially all the water layer reverberations may be eliminated with the ancillary benefit of extracting the relative water bottom reflectivity. This has the practical

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Fig. 2. The schematics of a typical OBC recording vessel and a 4-receiver line configuration.
effect of increasing bandwidth. The original OBC data were with dual-sensor receivers, which included detectors that responded only to seismic pressure waves (hydrophones) and the vertical or crossline component of water-bottom motion (vertical or crossline geophone). But recently, the added value of converted waves PS-waves produced by the compressional waves at an interface is being exploited by the seismic industries.

An important advantage of recording S-waves is their insensitivity to the type of fluid in sediments. Shear waves see through gas chimneys that plague economically important areas such as the North Sea. The chimneys caused by free gas in the sediments, destroy P-wave continuity but hardly affect S-wave reflections. Shear waves also help explorationists discriminate among lithologies (sand and shales) and are important in fracture detection (Gaiser et al., 1996; Western Atlas, 1997, 1998). Because dual-sensor recording uses co-located hydrophones and geophones, when traces from co-located hydrophones and geophones are suitably combined, the receiver ghost tends to cancel and the reverberation problem is attenuated. Frequencies missing from the notch in the hydrophone spectrum are supplied by a peak in the geophone spectrum. It can be shown that the two spectra can be complimentary; where there are notches in one, there are peaks in the other. Summing the two signals, removes the spectral notches yielding a much more desirable spectrum. The dual-sensor method intrinsically offers higher signal bandwidth data than comparable streamer data and extends the signal bandwidth at the low end of the spectrum (Fig. 3).

Low noise and minimum down-time
An OBC receiver cable gives characteristics clustering of subsurface midpoints around the centre of 3D bins, while streamer surveying with unavoidable feathering scatters subsurface midpoints throughout the bin. Since OBC shots and receivers are positioned at all accessible pre-planned positions, expensive in-fill and under shooting are virtually eliminated, preserving the integrity of the 3D design. Towing noise, which is common with streamer surveys is absent in OBC work since the OBC cable is static and in water depths below the zone of wave action. OBC seismic operations are generally less weather dependent and in many cases operations can continue under weather conditions which prohibit towed streamer data acquisition. In OBC survey, offsets are virtually unlimited thus providing super-wide aperture recording for sub-salt areas. Usually layout flexibility can accommodate radial cable patterns for shooting steeply-dipping domed structures. This has been particularly very useful in the Gulf of Mexico, where sub-salt imaging has become a major issue in oil and gas exploration in that area.

Improved near surface solutions and full coverage in obstructed areas
A true surface-consistent OBC geometry provides the statistics required to solve static problems using either refraction or reflection methods. This can be of great use in areas characterized by buried channels or other near-surface anomalies. The OBC technology is currently the prime method for acquiring high quality coverage in areas densely populated with structures, such as producing fields. It allows for safe deployment of receivers close to obstructions where towed streamer deployment could be hazardous or impractical. The technology enables us to avoid many operational difficulties associated with telemetry systems such as radio frequency licensing problems, battery supply,
limited channel capacity, and manual pickup. The presence of buoys is eliminated decreasing the hazard from work and fishing boats since telemetry buoys also create additional obstacle for the source vessel.

Tool for reservoir monitoring
Since OBC operations are very controlled and enable us to place shots and receivers as near as possible to pre-plotted positions, the technique provides a practically repeatable method to accommodate time-lapse or 4D reservoir seismic monitoring technology. Thus the information from repeated OBC surveys could be integrated with associated geological, petrophysical and production information to produce a comprehensive reservoir description used in reservoir simulation. Typically, seismically enhanced reservoir descriptions are much better predictors of fluid movement.
within reservoirs than conventional descriptions based on production data alone (Beasley et al., 1997).

Comparison of dual-sensor OBC data with marine streamer 3D seismic data

Eric (1996) has clearly demonstrated the advantages of the OBC technology by comparing the results of a dual sensor OBC data acquired in 1996, with streamer data acquired in 1989 over the same area. This comparison is summarised in Table 1, while a comparison of the amplitude spectra for these cases is made in Figs. 4 and 5. Fig. 6 is a dual-sensor OBC data versus 1989 streamer data. A careful evaluation of this OBC data in comparison with the streamer data reveals further advantages of the OBC data over the latter as can be seen by examining Figs. 4-6.

From the seismic section on Fig. 6, it can be seen that:
- shallow gas anomalies are resolved better due to higher frequencies.
- lateral fault gap is much better constrained due to higher frequencies.
- small faults better defined due to better vertical and lateral resolution.
- unconformities, channels, and stratigraphy are much better resolved due to higher frequencies and higher fold.
- deeper potential (>3.0 seconds) much better resolved due to 6400m far offsets, continuous fold coverage (127 fold), and excellent offset distribution.

In terms of added reserves, bypassed areas of known reservoir can often be easily identified with the dual sensor OBC 3D data leading to the identification of new opportunities, e.g. in the deeper zones beneath 3.0 seconds on the seismic section.

Table 1. Comparison of dual sensor data of 1996 with streamer data of 1989

<table>
<thead>
<tr>
<th>DUAL SENSOR OBC</th>
<th>STREAMER</th>
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<tr>
<td>5 - 83 Hz frequency (-12db) range or a 48.7% improvement.</td>
<td>6-44 Hz frequency (-12db) range</td>
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<tr>
<td>127 fold (extremely continuous).</td>
<td>72 fold (continuity).</td>
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<tr>
<td>6400m far offset possible without feathering.</td>
<td>+3600m offset (dual boat case)</td>
</tr>
<tr>
<td>Single boat Dual Sensor OBC acquisition</td>
<td>Dual boat - less chance for navigation errors.</td>
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<tr>
<td>Vertical Resolution of VR . = 34 ft.</td>
<td>Vertical resolution of VR . = 72 ft.</td>
</tr>
<tr>
<td>Lateral Resolution of RL = 204 ft.</td>
<td>Lateral resolution of RL = 432 ft.</td>
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3D OBC seismic data acquisition in offshore Niger Delta

In late 1998 and during the first half of 1999, a 665 km² dual-sensor 3D OBC survey was conducted in the Niger Delta, offshore Nigeria (Ugbor, 1999). The water depth ranged from 4 to 20m. The area was live with both fishing and transit vessel activities with a vessel channel running approximately through the northeast-southwest length of the area. Dredging activity was also ongoing at the northeastern part of the area. The OBC technique was chosen for the survey in this area because the project objective could not tolerate shallow zones of missing data, which is inherent in multi-beat towed streamer acquisition operations.

The geometry used is similar to a land 3D cross array patch, yielding uniform coverage and eliminating the need for infill shooting. The prospect area was divided into several rectangular portions (called swaths) along which a recording template was rolled in cross array patch (Cross Spread) geometry. The method also provided for true surface consistent refraction and reflection statics calculation and high subsurface imaging. The problem of water column reverberation was taken care of by the simultaneous use of both pressure and velocity sensors (the dual-sensor method). The main vessels used in the survey included one recording vessel, two cable vessels, and two recording vessels. Drought vessels were also employed at the shallower water areas such as at depths below 6m. Some supply and other chase/utility boats were used for crew changes or equipment transfers.

Survey design and acquisition plan

The basic acquisition geometry was a 4-receiver line, asymmetric split spread patch with 2 orthogonal source lines 8 times the receiver line spacing in length. Each source line contributed to attenuate in-line direction and ran parallel to the coast. This patch was rolled 300m in-line and 24m crossline. By keeping the active swath fixed while the source pattern continued to roll, the reversal was achieved and the patch as a whole was rolled until the end of the swath. In this 3D OBC survey, about 7800m length of cables were deployed on the water bottom so that receiver groups lay within pre-planned bins. The cable vessel laid the cable on the sea floor by squirting the cable from the back of the vessel as the vessel passed through the predetermined traverse/swath arrangement. The recording vessel was dynamically anchored while the shooting vessel, which towed only the airgun array, shot a swath of lines parallel to the bottom-cables.

When the swath was completed, one bottom-cable was retrieved and re-deployed for the next swath. This process was repeated until the 3D survey was completed. Since the bottom-cables were stationary on the ocean’s bottom and the shooting boat towed only an airgun array as the seismic source, lines could be shot directly adjacent to obstacles, where encountered. A schematic of the OBC recording vessel and the 4-receiver line configuration used is similar to that already shown in Fig. 2.

Data quality evaluation and co-ordination

In this work, the Seismic Prospect Evaluation and Co-ordination System (SPECS) software package was used in the design, implementation and management of the OBC 3D seismic survey. SPECS includes a wide range of planning and QC functions which allows an in-depth analysis of all aspects of the seismic surveying. The system was primarily used in the field to check the fold coverage of shots during the job. Bad shots were edited out of the dataset during processing and therefore did not contribute to the fold as calculated by the SPECS software for the actual fold achieved on the ground. The grids were set up in the survey such that the cell size was 12.5m in the crossline or the shotline direction, and 18.75m in the inline or receiver direction. Onboard recording of the seismic operation and QC functions were performed by QC geophysicists in the recording room during the time of seismic data acquisition. This process monitored the data quality and provided onboard quality control to ensure strict adherence to the predetermined acquisition parameters and ensure high fidelity in the data obtained.

Summary and conclusions

The dual-sensor ocean bottom cable method of seismic acquisition deploys the sensors’ cables on the seafloor and the sensors record both the velocity and the pressure data from the propagating seismic waves. Higher bandwidth results in better resolution of gas anomalies and better definition of fault zones due to better vertical and lateral resolution. The OBC method results in better resolution of unconformities, channels, and stratigraphy due to higher fold and frequency. Other benefits include superior imaging by improving the lower frequency content of the seismic data, increased resolution of deeper targets due to possibility of far offsets, greater fold coverage, and excellent offset distribution. The method provides broad-band, high resolution reflection data without the potential contamination of water-column reverberations. As the cables and the source vessels are deployed directly adjacent to the obstacles, the method proves effective in generating high 3D data in the infill areas. The superior imaging of the dual sensor OBC seismic method was already evident in the preliminary results in the pioneer dual sensor OBC acquisition carried out in the Niger Delta. Though these local results are not being discussed here because the information is proprietary, the case for such surveys in our shallow water areas where fishing, oil production, and other economic and commercial activities are going on is already very clear.
Acknowledgements
We are grateful to the Shell Petroleum Development Company for approving Mr. C. Ugbor's attachment to the OBC crew during the data acquisition stage in 1999. We acknowledge the help of F. Akinbobola, then Head, DPE-UNI, Promise Egele, Austen Ezebilo and Leo Okara all of SPDC. We also extend our gratitude to Mr. Jim Roberts, the party chief of the Party 66 Atlantic Explorer crew of the then Western Geophysical that carried out the OBC survey. We are also thankful to the onboard seismic crew members especially Messrs. Craig Bowen, Cherry Lonoso, and Fabrice Mandraux, among others for the pains taken in clarifying some of the details of the OBC operation during the field work.

References