Full Azimuth imaging through consistent application of ocean bottom seismic

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Summary

In 1997 the world's first 3D ocean bottom seismic (OBS) surveys was acquired over the Statfjord field (Rognø et al., 1999). This survey was a dense, true 3D survey, which contained other 3D survey geometries as special cases. It was thus ideal for evaluating seismic azimuthal imaging versus acquisition geometries for both pressure waves and converted shear waves (Thompson et al, 2002).

Through extensive practical experience with the Statfjord survey, Statoil soon verified the benefits and took advantage of the full azimuth acquisition solution offered by 3D OBS. Since 1997, OBS surveys have been carried out over a large number of Statoil's geologically complex North Sea oil and gas fields, providing detailed, structural images of the disposition of fault-bounded compartments.
Through a discussion of geometric observations and studies from the Norwegian continental shelf, some of the benefit of using ocean bottom seismic for P-wave imaging will be demonstrated

Introduction

Standard towed-streamer seismic surveys are the first choice of technology for the geophysicist for reservoir imaging purposes, though this technical solution is not always suitable for obtaining the very best reservoir images, especially in geologically complex areas. The recording Ocean Bottom Seismic (OBS) data – although more expensive – offers the distinct advantage of flexible acquisition geometries. Virtually any pattern of sources (shots) and receivers is possible with the aim of imaging even the most complex reservoirs. True 3D data acquisition is realized by using a stationary seabed sensing system combined with a survey vessel shooting over a predetermined grid on the sea surface. Every subsurface point on the target can thus be illuminated from all directions and a large number of angles during an OBS survey.

In the late 1980's, Statoil developed the SUMIC (SUbsea seisMIC) technique whereby both shear and compressional waves were recorded by sensors implanted in the seabed Berg et al (1994). In 1992 a prototype SUMIC sensor array was developed and several extensive tests were carried out, with a full scale 2D acquisition carried out in 1993 over Statoil's Tommeliten structure in block 1/9 of the Norwegian sector of the North Sea. The principal objective of the 2D survey was to demonstrate the potential of the SUMIC technique to image subsurface structures through and below gas chimneys. During the 1997 planning of one of the world's first 3D-4C OBS survey over the Statoil-operated Statfjord oil field, straddling the border between the British and Norwegian sectors of the North Sea, the OBS advantages and technical benefits of high signal bandwidth, high spatial resolution, low noise, reduced weather dependence, versatile geometries, super-long offsets, super-wide aperture, and more, were investigated. This survey was a dense, true 3D survey, which contained other 3D survey geometries as special cases. It was thus ideal for evaluating seismic azimuthal imaging versus acquisition geometries for both pressure waves and converted shear waves
Through a discussion of geometric observations and a studies from the Norwegian continental shelf, some of the benefit of using ocean bottom seismic for P-wave imaging will be demonstrated.

Statfjord Acquisition geometry

The original Statfjord 3D OBS survey (Figure 1) consisted of four swaths of data, with each swath containing two receiver lines, 5km long, spaced 300m apart. Inline receiver spacing was 25m, whilst the source configuration consisted of dual arrays separated laterally by 50m, with a 25m (flip-flop) shot point interval. The maximum inline offset was 3000m, and maximum cross-line offset 3000m with the source lines separated by 100m, and aligned parallel to the receiver lines. The survey was a dip survey, orientated 120-300^{o}.

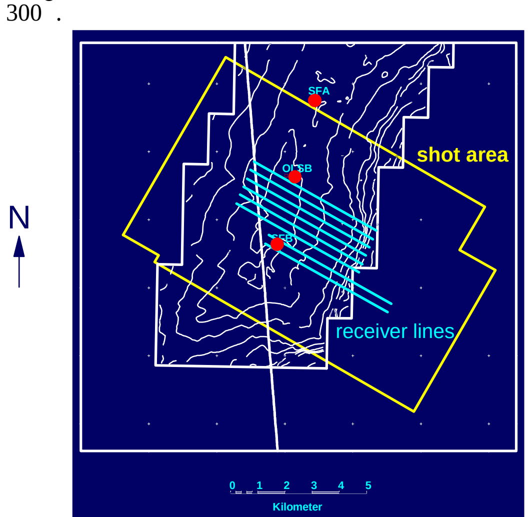


Figure 1. Acquisition Geometry for the original Statfjord 1997 3D OBS survey

Analysis of the geometry from the 3D OBS survey soon highlighted the benefits from the full azimuth and rich offset distribution that was possible with this acquisition technique. A large range of offsets were observed, but more importantly, a full azimuth range covering 360^o was evident (Figure 2).

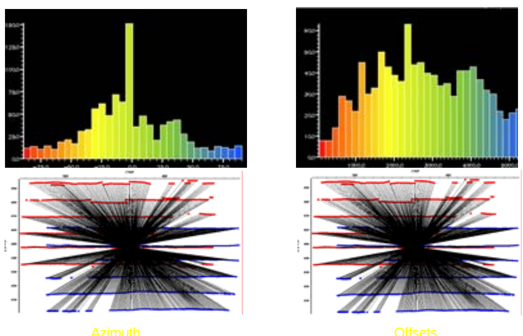


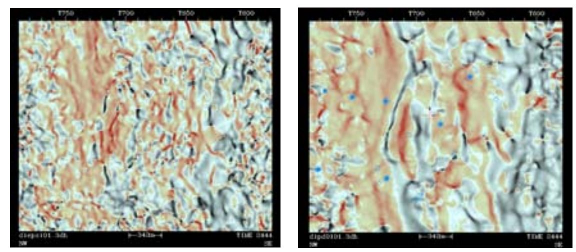
Figure 2. Analysis of azimuth and offset distribution for the original Statfjord 3D OBS survey

Studies into the importance of azimuth using advanced depth imaging techniques (Arntsen and Thompson, 2003), whereby both conventional 3D marine seismic and 3D OBS data were compared, again demonstrated the importance of azimuth. In this study the 3D OBS data were manipulated in such a manner that they simulated the acquisition geometry found in a conventional 3D marine seismic survey. A series of intermediate geometries whose cross-line offset was greater than a 3D marine survey but less than a 3D OBS survey were also emulated. From this study it was observed that cross-line offset was a critical factor governing image quality.

Statfjord Improved Imaging

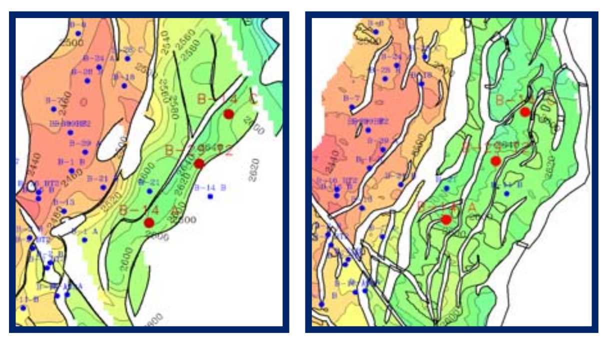
The 3D OBS data were extensively used in the 2001 reinterpretation of the fault pattern in the Statfjord East Flank, resulting in interpretation of one new internal East Flank reflector, and modification of another East Flank reflector. Dip volumes (Figure 3), highlighting the differences between conventional streamer seismic and 3D OBS, were generated and later used systematically when interpreting fault planes simplifying the fault mapping phase.

A part of the 3D OBS survey covered an area with two oil producers and one water injector. It was difficult to explain the production history of these wells with the existing interpretation in the area. The new interpretation (Figure 4), derived from the 3D OBS was more in line with the observed communication patterns identified from production data. A more reliable interpretation was considered essential when planning new wells in the eastern flank in the Statfjord B-area.



(a) 3D marine seismic (b) 3D OBS

Figure 3. (a) Dip volumes highlighting the differences between conventional 3D marine seismic and (b) 3D OBS.



(a) Geomodel 2000 (b) Geomodel 2001

Figure 4. (a) Comparison of Top Dunlin East Flank depth map based on streamer seismic and (b) 3D OBS

After the success of the 1997 3D OBS survey a larger 3D OBS survey was commissioned. This 3D OBS survey (Figure 5) was approximately 120km^2 in size and acquired in 2002 covering the rest of the east flank, and Statfjord East.

As with the earlier pilot a consistent uplift in image quality (Figure 6), compared to the earlier conventional 3D marine seismic, was achieved. Since the 2002 3D OBS survey several wells have been successfully drilled for which the 3D OBS was actively used for well planning.

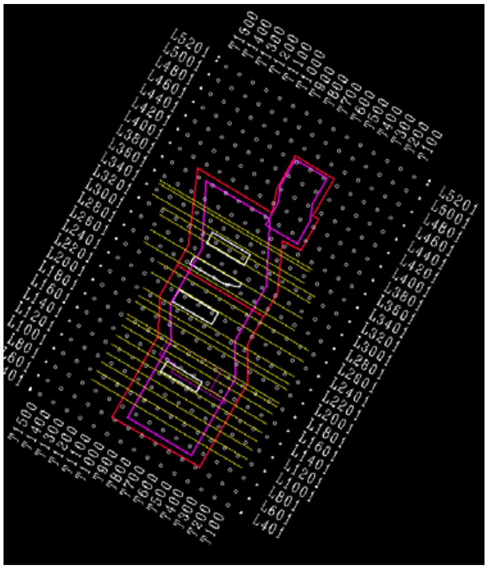
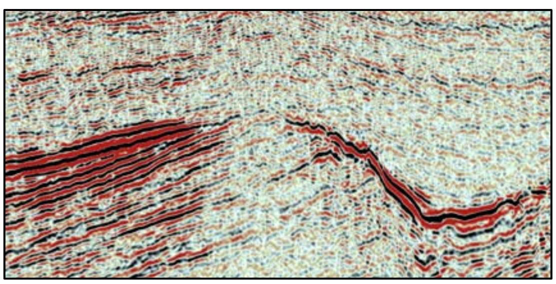
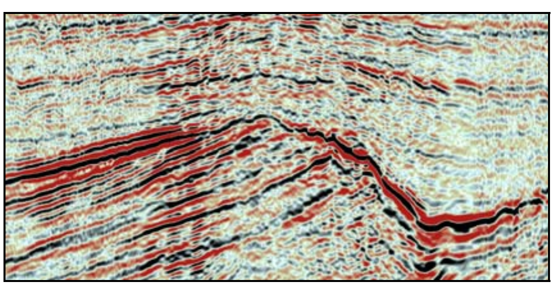


Figure 5. Areal extent of 2002 Statfjord OBS survey.



(a) 3D marine seismic



(b) 3D OBS.
Figure 6. (a) Comparison of 3D conventional marine seismic from 1997 and (b) 3D OBS from 2002 illustrating improved uplift of the Statfjord East flank structure.

Consistent improved structural imaging.

Since 1997, Statoil has consistently used OBS to improve structural imaging in challenging areas. OBS surveys have been carried out over a large number of Statoil's geologically complex North Sea oil and gas fields, providing detailed, structural images of the disposition of fault-bounded compartments. The OBS datasets by the company to date are illustrated in table 1. Approximately half of these are 3D OBS surveys designed to alleviate imaging problems associated with complex structures and difficult overburdens.

Gullfaks, 1989, SUMIC	Gullfaks South 3D, 2002
Gullfaks, 1993, SUMIC	Statfjord 3D, 2002
Troll, 1993,	Statfjord Øst 3D, 2002
Tommeliten 2D, 1993	Volve 3D, 2002
Gullfaks 2D, 1995	Gullfaks 3D, 2003
Statfjord 3D, 1997	Visund 3D, 2003
Block 24/12 (PL 204) 2D, 1997	Tyrihans 2.5D, 2003
Sleipner Øst 2D, 1997	Heidrun 3D, 2003
Faeroes/Shetland Basin 2D, 1997	Exploration 2D, 2003
Huldra 2D, 1998	Kvitebjørn 3D, 2003
MN4C98-2, Møre Basin (Bl. 6303)	Vigdis/Borg 3D, 2004
MN4C98-3, Fles (Bl. 6605)	Snorre 3D, 2004
MN4C98-4, Helland Hansen (Bl. 6505)	Kvitebjørn 3D, 2004
MN4C98-5, Modgunn Arch (Bl. 6403)	Gullfaks 3D, 2005
Gullfaks South 3D, 2000	Valemon 3D, 2006
Gullfaks 3D, 2001	Snøhvit 2.5D, 2006

Table 1. Overview of Statoil experience using Ocean Bottom Seismic

Success been achieved at several locations where 3D OBS has had a direct impact on field development especially when combined with other geophysical and petrophysical parameters.

Moreover, 3D OBS data have been used as the base survey for a complete re-interpretation of the whole Kvitebjørn field, and has contributed to recoverable reserves been upgraded by 50 percent in relation to the estimation in the

PDO. Further, based on the 3D OBS data seven HPHT wells have been successfully drilled and completed within two years - without any well control incidents.

At the Heidrun field the 3D OBS appears, in some areas, to be more robust with respect to imaging through the overburden and dealing with the ice berg scouring. Though still difficult to interpret the 3D OBS has, in some areas, de-risked the well planning process when incorporated with other data types such as sonic data in existing wells, and has actively been used in the planning of at least one well.

At the Snorre field the 3D OBS will be an important dataset regarding well planning in the southern area. The seismic data is now considerably more noise free, with significantly less remnant multiples, compared to the original streamer seismic. Vertical and lateral resolution is also improved leading to better event continuity and improved fault definition.

Uplift in data quality, at the Volve field, has led to increased confidence in interpretation, and reduced uncertainty in calculated volumes leading to the delivery of a plan for development and operation (PDO) in February 2005. The reserves for this field are estimated to be 12.4 million Sm3 of oil, and 1.3 billion Sm3 of gas. Production start-up is planned during the first half of 2007 using the world largest jack up platform, Mærsk Inspirer, with associated storage in tanker for shipping to the Sleipner-A facility for processing and export.

Conclusions

Through observation and analysis of ocean bottom seismic from the Norwegian continental shelf the offset and azimuth characteristics of 3D OBS have been demonstrated. The benefits of these characteristics have further been demonstrated by a series of short case studies where the uplift in seismic image quality was shown. Statoil have been aware of these benefits since the birth of marine 4C and has consistently used 3D OBS to improve seismic images for the last decade in areas where conventional acquisition techniques failed.

Acknowledgements

The authors wish to acknowledge the excellent work carried out at those fields where 3D OBS has been acquired and used to improve field knowledge. We wish thank Statoil, and the partners of Statfjord, Volve, Snorre, Kvitebjørn and Heidrun for their kind permission to publish these results.

EDITED REFERENCES

Note: This reference list is a copy-edited version of the reference list submitted by the author. Reference lists for the 2007 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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