Acquisition geometry versus 4C image quality. A study from Gullfaks South.

Mark Thompson, Borge Arntsen, Lasse Amundsen, Statoil ASA, Trondheim, Norway*

Summary

An evaluation into the effects of different acquisition geometries on image quality, for multi-component seismic data was carried out for both pressure wave (P-wave) and converted wave (PS-wave) data in both time and depth. This was achieved through decimation of source and receivers of existing seismic data, and through modelling of P-wave and PS-wave data for the Gullfaks South 3D pilot Ocean Bottom Seismic (OBS) data set acquired in 2000.

Introduction

Four-component (4C) ocean bottom surveys (OBS) have, in recent years, begun to play a vital role in field development, through detailed reservoir imaging, improved fault definition and time-lapse reservoir monitoring. This is evident by the increased number of published 'success stories' where 4C-OBS data has been a key element in the solution of imaging problems. This is in part due to the flexibility in survey design, which OBS surveys by their very nature allow, that was not previously possible with marine towed streamers. This flexibility in acquisition geometry, and the very nature of converted waves, however has led to more complex acquisition geometries. This complexity leads, even more so than before, to the necessity of using the appropriate acquisition configurations which optimise the final result and ultimate interpretation of the data.

Statoil have, over the years, acquired 4C-OBS data over the Statfjord field, (Rognø *et al.,* 1999), Gullfaks South field, (Næss *et al*., 2002), Gullfaks field, (Thompson *et al*., 2002) and Volve field, with the objectives of these surveys including time–lapse reservoir monitoring, improved reservoir imaging and improved fault definition, with an ultimate aim to have an impact on Improved Hydrocarbon recovery (IHR). The Statfjord 4C-OBS data set, acquired in 1997, has undergone extensive study into the effects of acquisition geometry for both P-wave data and PS-wave data on image quality, (Thompson *et al.,* 2002). The results of this study have strongly influenced the acquisition geometries and processing sequences of the subsequent 4C-OBS surveys. Expanding on the findings from the Statfjord 4C-OBS studies, the Gullfaks South pilot 4C-OBS data set, acquired in 2000, has been subject to similar studies, whereby elements of the survey configuration and processing sequence were assessed for their impact on the P-wave and PS-wave image quality and interpretation of the resulting data.

Field background

The Gullfaks South field, along with the fields Remakes and Galley, is a satellite of the Gullahs field, and is located in block 34/10 on the Norwegian continental shelf (Figure 1), in a water depth of approximately 135m. The production licence was awarded in June 1978 to Statoil, Norse Hydro and Saga Petroleum. Currently Statoil are the operator, owing 61% of the field, with Petrol and Norse Hydro owning 30% and 9% respectively.

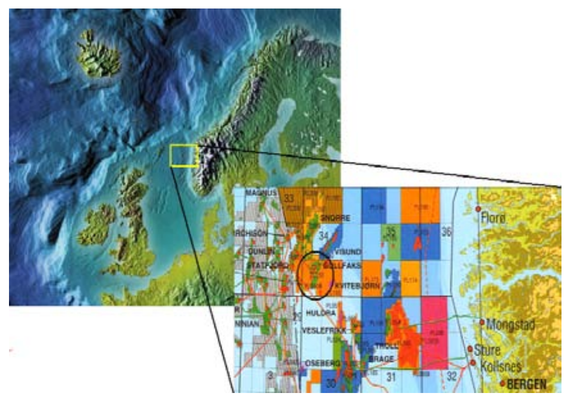

Figure 1: Location of Gullfaks Sør field.

Geological setting

The Gullahs South field occupies a westwards rotated fault block on the southern part of the Tampen structure (Figure 2). This structure is a result of two separate rift phases, a Permo-Triassic phase, and a late Jurassic – Early Createceous phase. Three structural domains from west to east, domino style fault block geometry, an accommodation zone, and a horst area separate the field. The domino style fault complex is characterised by repeated faulting dipping to the east, and reservoir layers dipping to the west. The horst domain to the eastern part of the field is defined by a structural high oriented from northeast to southwest, confined by eastwards and westwards dipping fault planes. Between the westwards complex and the eastwards area is the structurally complex accommodation zone, which has acted as a buffer zone between the domino fault complex and the horst area. The reservoir sands are from the early and middle Jurassic representing shallow marine to fluvial deposits. The main reservoirs are sandstones in the Brent, Dunlin and Statfjord formations.

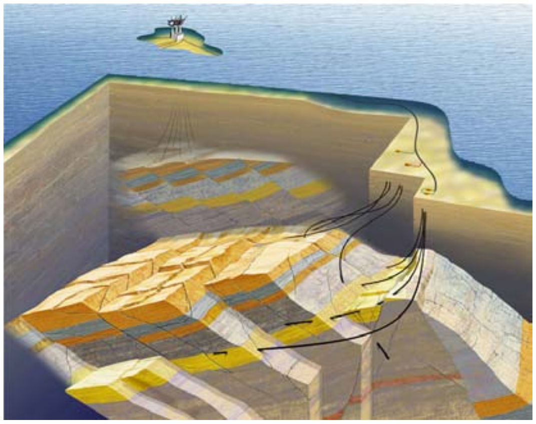

Figure 2: Gullfaks Sør Geological setting.

Production history

Gullfaks South has currently undergone two phases of development. Phase I encompassed production of oil and gas condensate through the Gullahs A platform driven by injection of gas, while Phase II encompasses production and export of gas reserves through the Gullahs C platform.

Acquisition Parameters

The acquisition geometry for the pilot 4C-OBS (Figure 3) consisted of one swath of data, orientated east–west, containing three receiver lines, 6km long, spaced 400m apart, with an in-line receiver spacing of 25m. The source configuration consisted of dual 3542 cubic inch air gun arrays, separated laterally by 50m, with a 25m (flip-flop) shot point interval. The maximum inline offset was 3000m, and maximum cross-line offset was 1000m. There were 28 source lines each separated by 100m, and aligned parallel to the cables. The water depths encountered were approximately 135m.

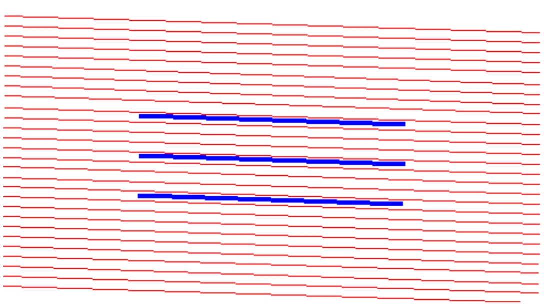

Figure 3: Acquisition geometry for Gullfaks South, with 28 source lines (red), orientated parallel to three receiver lines (blue).

Enhanced structural imaging

It was observed after the processing of the pilot 4C-OBS data set that the definition of the reservoir and structure was greatly enhanced when compared to the previously acquired conventional marine towed streamer 3D data set (Figure 4), which had already undergone extensive processing, including pre-stack depth migration, to improve image quality (Næss *et al*., 2002).

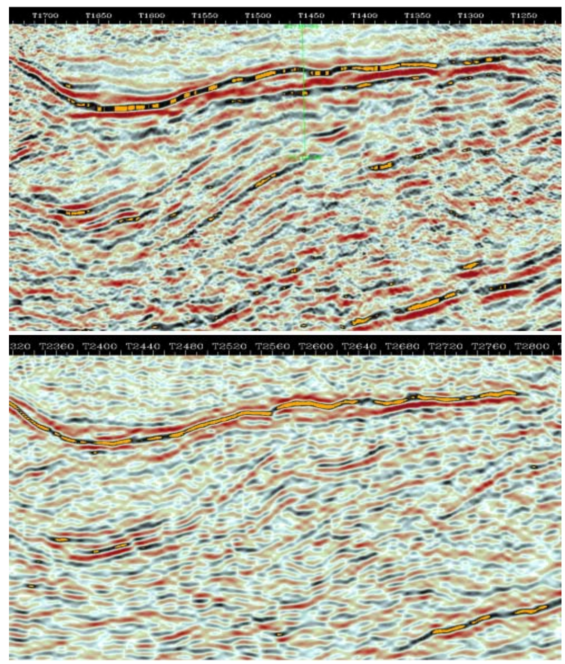

Figure 4: Enhanced structural imaging by the OBS data set (top) compared to the pre-stack depth migrated towed streamer data set (bottom). (Næss *et al*., 2002)

Acquisition geometry emulation

Acquisition geometry emulation was carried out through selective decimation of existing in both the source and receiver domains. A selection of 3D geometries, where receiver spread length, receiver spread positioning, and receiver spacing were emulated. Additionally tests were carried out into the effectiveness of 2D, 2.5D and node geometries. These experiments were calibrated against modelled data (Figure 5) using both finite difference and ray tracing schemes where the different acquisition geometries were investigated. All data, both P-wave and

PS-wave was processed through PSTM and PSDM, where the time and depth processing sequences were fixed.

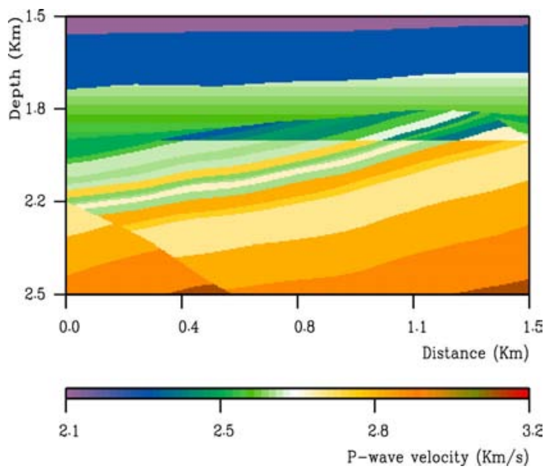

Figure 5: Model used to calibrate results from emulation, through data processing, of existing seismic data.

Evaluation of results

In the Gullfaks South pilot area, it was observed that even a 2D OBS geometry produced a better image than previous images from conventional 3D towed streamer survey. It was observed for both P-wave and PS-wave data that the image produced from a 3D 4C-OBS geometry was superior in detail to that produced by the 2D 4C-OBS geometry (Figure 6), though the differences between a 3D 4C-OBS geometry and a 2.5D 4C-OBS geometry were observed to be minimal. The differences between images derived from 3D and 2D geometries were attributed to the benefits of improved illumination achieved by 3D geometries. When evaluating receiver spread length, it was seen that this is an important factor, especially for the P-wave data, with the shorter lengths emulated failing to properly image the reservoir. The receiver spread length, though, was shown to have more localised influences on the image quality on the PS-wave data than the P-wave data. The receiver spread positioning was observed to be critical for the PS-wave data, more so than the P-wave data. Both spread length and positioning were related to the dip of the key events at reservoir level. The nodal geometries tested (Figure 7) exhibited a decrease in signal to noise levels for both P-wave and PS-wave data, though the PS-wave data was more somewhat sensitive to receiver spacing than the P-wave. The P-wave nodal data was still able to effectively image the reservoir.

Conclusions

It was concluded that 3D and 2.5D geometries were superior to 2D geometries, with receiver spread length and positioning being critical to successfully image the reservoir. Receiver spread length was considered to be more critical for P-wave data than PS-data, while receiver spread positioning was considered to be more critical for PS data than P-wave data. PS-data was seen to be more sensitive to receiver spacing than P-wave data. It is concluded that the flexibility of 4C-OBS geometries leads to improved illumination of sub-surface structures, with 3D geometries preferred over 2D geometries.

References

Hege Rognø, Åge Kristiensen, Lasse Amundsen, The Statfjord 3-D, 4-C OBC Survey: The Leading Edge November 1999.

Næss Ole E., Henden Jon O., A 3D test of ocean bottom recording: Expanded Abstracts, 64th EAGE Conference, Florence.

Thompson M., Digranes Per, Osmundsen Inger K., 2002, Ocean Bottom Seismic, A tool for improved hydrocarbon recovery in difficult areas: AMGE, Vera Cruz, Mexico, 3-6 Sept. 2002

Thompson M., Amundsen Lasse, 2002, Ocean Bottom Seismic, Acquisition geometry versus image quality, A study from the North Sea: AMGE, Vera Cruz, Mexico, 3-6 Sept. 2002

Arntsen Børge, Rosten Tage, 2002, Wave equation versus Kirchhoff prestack depth migration of OBC data, Society of Exploration Geophysicists International Exposition and 72nd Annual meeting, Salt Lake City 2002.

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Acquisition geometry versus 4C image quality

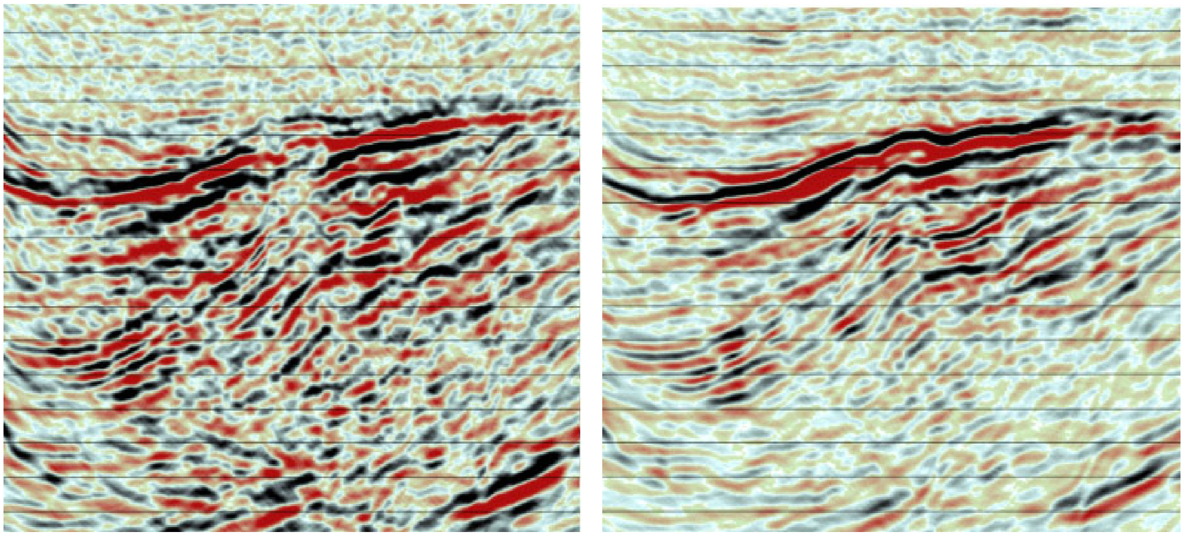

Figure 6: Improved structural resolution of 3D P-wave data (bottom), compared to 2D P-wave data (top)

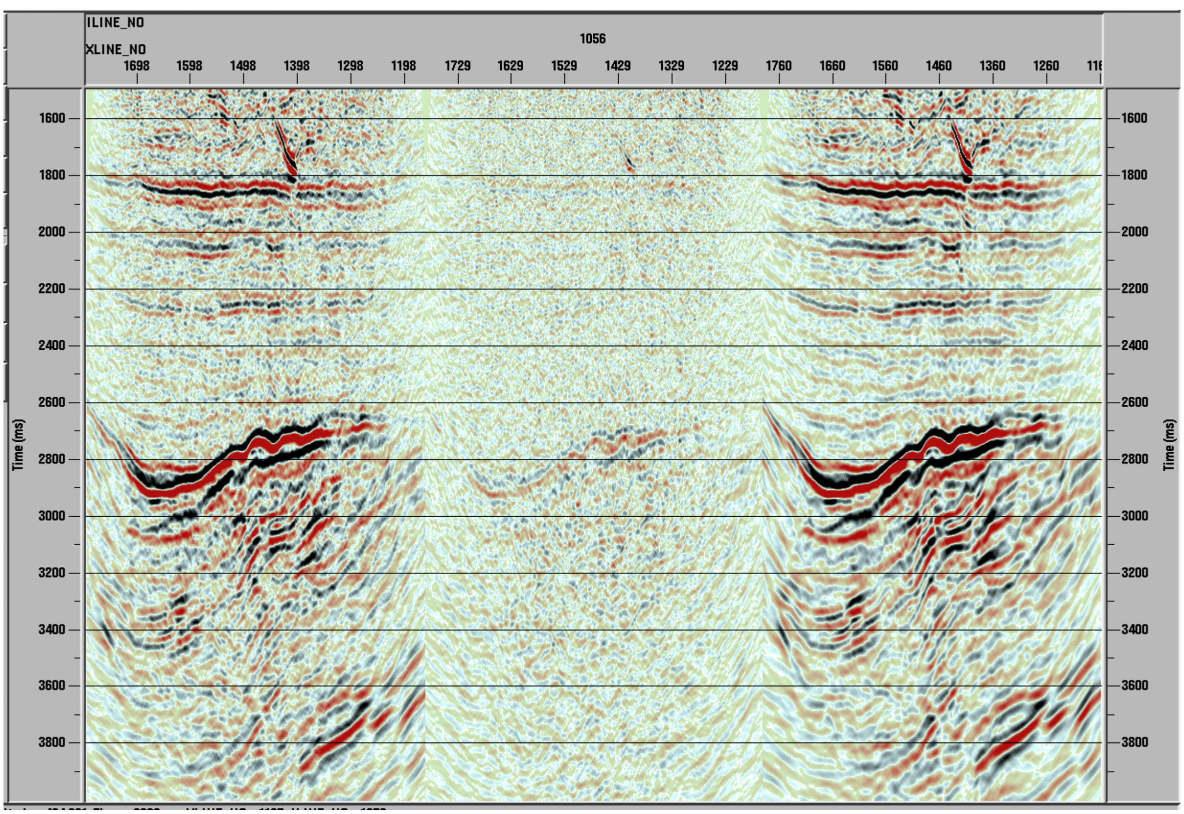

Figure 7: Nodal P-wave geometry (left) compared in a difference section (middle) to 3D P-wave geometry (right).