Focused Seismic Monitoring: From acquisition to interpretation in 48 hours.

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Summary

Focused Seismic Monitoring (FSM) is to monitor the reservoir in smaller, more focused areas than conventional time-lapse surface seismic would normally cover (Thompson, 2008). During 2008 a FSM field trial was carried out with the aim of achieving an insight into installation, acquisition and imaging procedures such that time-lapse seismic could be imaged in 'near time'.

Two 5km long multi-component seismic array cables, each containing 100 seismic sensor stations, were installed on the Snorre field and were connected to the Snorre A platform via an existing fibre tail. A data interrogation unit and data QC unit were installed on the platform and networked to a dedicated onshore support centre (OSC) and imaging cluster.

The pilot demonstrated 'real time' data transfer and quality control and imaging in 'near time'.

Introduction

The Snorre field was discovered in 1979 in blocks 34/4 and 34/7 of the Tampen area in the Norwegian North Sea. The field was sanctioned in 1988 and production started in 1992. It covers an area of approximately 200km^2 and lies in water depths from 300m to 350m. The field is currently producing from two platforms and a subsea template with reservoir pressure maintained by water, gas and alternating water-gas injection. Other field infrastructure is related to process facilities for the neighbouring Vigdis field and the export of oil and gas via the Statfjord field.

The field at Snorre is comprised of a series of sandstone reservoirs constrained structurally by large fault blocks (figure 1). The reservoir at Snorre is characterized by complexity, thin layers, sand connectivity and communication across faults. The production and injection history is complex and many of the injectors have been back-produced. Different reservoir levels are actively opened and closed to optimize the production and pressure support.

In order to be able to monitor and differentiate effects due to gas injection, water injection, pressure increase, pressure decline and OWC movement it must be possible to acquire, process and interpret 4D seismic in a much shorter time period than is currently used at Snorre. The Focused Seismic Monitoring (FSM) project identified the actions and technologies that could achieve this.

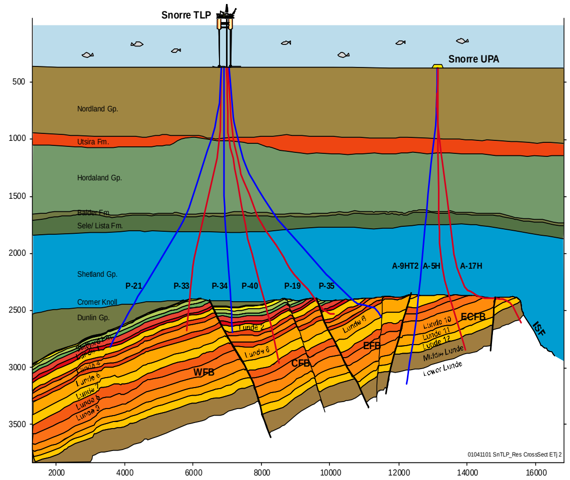

Figure 1. Snorre field model.

In 2008 a Focused Seismic Monitoring pilot was completed and proved that it was possible to install a fibre-optic multi-component ocean bottom cable (OBC) at Snorre and an onshore support centre (OSC) at the StatoilHydro Research centre and then demonstrated the delivery of a PP depth image within 48 hours of the completion of seismic acquisition.

FSM project

The Snorre field has an ambition to raise the recovery factor through an improved oil recovery (IOR) program. In view of the reservoir and production complexities and the success of ongoing time-lapse work at Snorre, an FSM project was initiated. The FSM project identified some of the actions required such that this ambition could be achieved. One action identified, with a large potential, was the use of frequent 4D seismic. More frequent 4D could potentially be achieved through the implementation of a permanent seismic solution.

The project also aimed to evaluate the need and the potential for seismic monitoring in smaller, more focused areas than a conventional time-lapse surface seismic survey would usually cover. The FSM project identified several potential locations and evaluated various criteria. These criteria included the size, location, the optimal interval between successive time-lapses surveys and the availability of potential seismic acquisition technologies. Location and size of a survey were evaluated based on the remaining reserves, expected drilling activity (including optimising drilling targets and reducing the need for side tracks) and expected value of increased understanding of the reservoir, optimising production/injection and increasing the understanding of the drainage pattern.

Early in the project two key locations were identified which would benefit from an FSM approach. The first location was a mature production area characterised by expensive wells. This location was in an infill phase of development where planning of a water-alternate-gas (WAG) production scenario was in progress. It was considered that an FSM scheme could contribute through the accurate monitoring of the direction of movement of the fluid fronts, and the reservoir zones contributing to production could be identified. The second location identified was an immature area, characterized by large uncertainties surrounding reservoir communication properties and with high drilling activity expected in the future. In this location the benefits included monitoring the direction of movement of the fluid fronts, and identification of the reservoir zones contributing to production.

During the FSM project several criteria were identified which were to be used in a technical screening process. Experience from previous time-lapse projects highlighted the requirement for a high level of data quality. The need to map small production effects, with short intervals between monitor campaigns, requires a high level of repeatability. Timing of results from time-lapse monitoring is also critical, with short turn-around times required from the acquisition, imaging and interpretation process. With future reservoir production the requirement for a robust long-term solution were also considered.

StatoilHydro's experience from other time-lapse projects has long highlighted the requirement for a high level of data quality, which can be achieved through a high degree of repeatability. This combined with the need for robust long-term solutions led to a collaboration project with Optoplan AS to develop a new fibre-optic based ocean bottom seismic technology suitable for FSM. This technology has been successfully field tested in a fjord in Norway at Trondheim (Thompson 2006) and later at the StatoilHydro facility at Tjeldbergodden (Thompson, 2007). Success with these field trials led to a full-scale field pilot at Snorre.

FSM pilot

A seismic array provided by Optoplan AS was installed with an east-west orientation on the Snorre field approximately 3km north of the Snorre A platform. It consisted of two fibre-optic seismic cables laid out 'back to back' giving a total array length in the order of 10km. Each cable contained 100 seismic sensor stations with an inter-station spacing of 50m and each sensor consisted of 3 orthogonal accelerometers and a hydrophone. These two seismic cables were connected to a lead-in cable and then up to the platform via a fibre tail available on the seabed. Cables were deployed and then trenched into the seabed at an average depth of around 1m (figure 2). A data interrogation unit was installed on the platform and connected to a dedicated sub-network within the already existing StatoilHydro infrastructure.

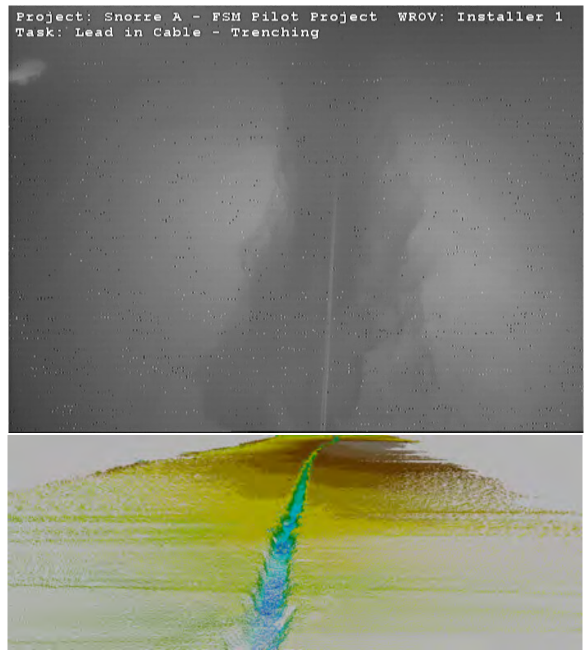

Figure 2. The fibre-optic cable was trenched into the seabed with an average depth of 1m. The top image shows the lead-in cable lying in its trench and below is a side-scan sonar image.

A conventional 3D seismic source and vessel were used to acquire a grid of shots over the cable area so that image quality could be assessed. This 3D source grid was then acquired again such that repeatability could be assessed. The average error between the two swaths was 4.9m (figure 3).

Through collaboration with Schlumberger an onshore support centre (OSC) and imaging cluster dedicated to the seismic acquisition were installed at StatoilHydro's research centre in Trondheim, Norway (figure 4). The OSC allowed the concept of integrated operations (IO) for seismic operations to be evaluated.

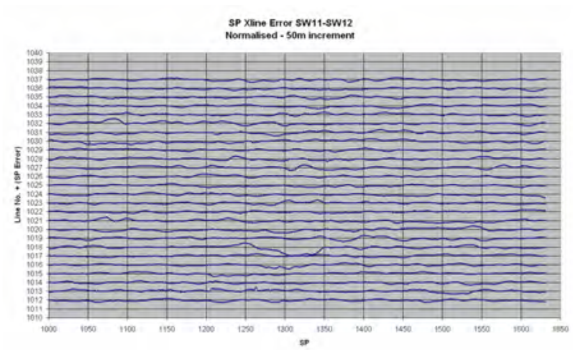

Figure 3. Cross-line source position differences between the original and repeat acquisition. The average difference in position is less than 5m.

During seismic operations quality control would normally be handled in the field by company representatives and reports sent to the company each day. For the FSM pilot, expert support and quality control functions were assembled in the OSC. Vessel and source positioning were made available in ‘real time’ and data transfer for seismic data allowed for quality control in ‘near time’. Constantly updated QC products were then made available to the FSM stakeholders who were situated at different geographical locations. Since the requirements for information were not identical for the different stakeholders, solutions to provide different levels of information were utilized. These ranged from full access of all QC material in the OSC to an abridged overview made available through a web interface that was accessible via a smart telephone solution.

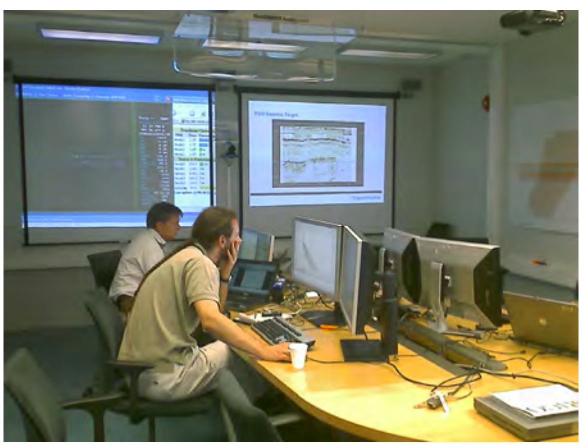

Figure 4. The Onshore Support Centre during acquisition.

A processing sequence has been devised on the dedicated cluster. The cluster forms the major part of a distributed processing system that included processing capability on the platform during acquisition that could, if necessary, have been operated remotely as a stand-alone system but more normally from within the onshore processing environment.

The processing sequence for the FSM data required the rotation of sensors where no orientation information other than that is held in the data is available. The sensor package is deployed in an unknown orientation on the seabed and the first break energy was used to derive the orientation of the accelerometers. The data were rotated into vertical, radial and transverse components (figure 5). Vector fidelity is required for this to be possible. Calibration filters were derived to sum the vertical and pressure components. The processing sequence included noise attenuation, PZ summation and pre-stack depth migration (Thompson, M., et al. 2008) with a P-wave velocity model available from the earlier processing of streamer data. With these processing parameters decided and the data from acquisition made available to the cluster on a shot-by-shot basis it has been possible to demonstrate a PP image produced in the depth domain within 48 hours of the end of acquisition.

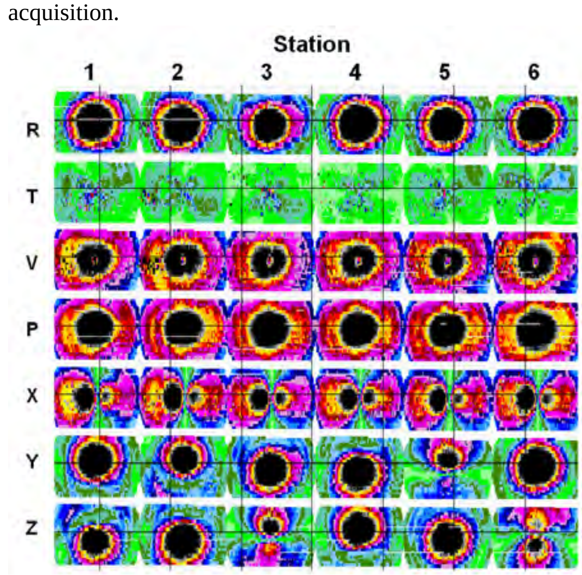

Figure 5. Orientation and rotation of fibre-optic 4C sensors based on first-break arrivals.

Conclusion

The FSM project identified key criteria for the long term future of reservoir monitoring at Snorre. These included high data quality, a high degree of repeatability, fast turn-around and short intervals between monitoring campaigns.

The FSM pilot carried out during 2008 demonstrated the concepts of Integrated Operations for seismic acquisition and ‘near time’ imaging for 4D monitoring.

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EDITED REFERENCES

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