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Grane PRM - From Acquisition to Interpretation in Record Time

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Summary

In August 2014 a full Permanent Reservoir Monitoring (PRM) system was installed on the seafloor at the Grane field; since going live, five PRM surveys have been acquired.

Efficient seismic operations and fast delivery of 4D data to the interpreters are essential components of the PRM solution.

The currently achieved time span for the Grane PRM acquisition and processing cycle is about one month; the 4D products are available to the interpreters typically 8 to 10 days after the last shot is acquired.

We first describe how a robust sequence has been designed and optimized, thanks to the successful collaboration between processing and interpretation teams.

Through a case study, we demonstrate the value of continuous fast delivery of 4D PRM seismic data; we also discuss a 4D processing flow designed to address the different acquisition geometries between vintage Ocean Bottom Cable (OBC) surveys and PRM surveys.

Grane PRM: from acquisition to interpretation in record time

Introduction

The Grane oil field is located in the Norwegian North Sea (Figure 1a), about 200 km NW of Stavanger, and contains heavy oil with no initial gas cap. The field was discovered in 1991 and came online in 2003; it is currently producing approximately 75,000 barrels of oil per day. The Grane field has an extensive seismic history: a first streamer survey conducted in 1993 was followed by two OBC surveys in 2001 and 2003, each one covering different parts of the field. In 2005, a 4D monitoring program was initiated in order to increase recovery by reducing uncertainties associated with the fluid distribution in the reservoir (Roy et al., 2011). Repeated towed streamer surveys were acquired every second year from 2005 until 2013. In August 2014, a permanent reservoir monitoring (PRM) system was installed over the Grane field to take over the 4D monitoring program (Thompson et al., 2015).

Since going live, PRM surveys have been acquired over the Grane field twice a year through autumn and spring campaigns. The requirements for frequent acquisition and high data quality have been achieved (Elde et al., 2016). Efficient seismic operations and fast delivery of 4D data to the interpreters are also essential components of the PRM solution.

The first part of this paper briefly describes the Grane PRM system and acquisition setup. We then present the PRM 4D processing sequence with its emphasis on processing turnaround. We discuss an example illustrating the value of fast delivery of up-to-date 4D PRM seismic data on a new producer well. Finally, an application of 4D processing between a pre-production OBC vintage from 2001/2003 and the first PRM vintage (2014) is presented to show that acquisition geometry differences can be successfully addressed within a short time frame. This allows the interpreters to bridge the gap between older datasets and recent PRM datasets, and then better understand the dynamic reservoir behaviour since production started in 2003.

Grane PRM system and acquisition

The permanent seismic recording system at Grane consists of 17 trenched cables covering about 48 km², using 3458 multi component sensors (13852 channels) and connected to the Grane platform; the cables are spaced 300m apart and the receiver station interval is 50m. The receiver array is shown in Figures 1b and 1c, overlaid on the map of infrastructures at the sea bottom (115m-130m depth).

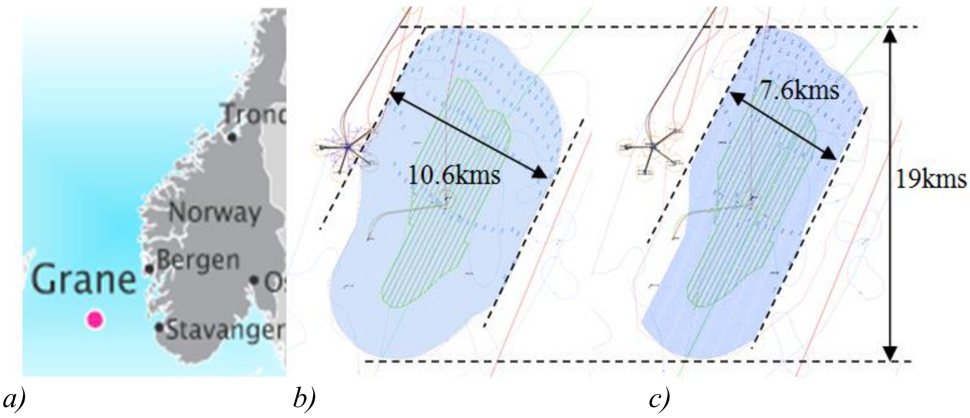


***Figure 1** a) Location of the Grane field - b) The Grane PRM receiver array (green) and PRM0/PRM1 shot lines (blue) - c) The Grane PRM receiver array (green) and shot lines acquired from PRM2 onwards (blue)*

The seismic acquisition is performed with a containerized dual seismic source. The source separation is 50m, and the shot point interval is 25m (flip-flop). For sake of smoother and more efficient acquisition operations, the original source used for Grane PRM0 was slightly redesigned before the

second acquisition to improve its robustness. Therefore the PRM1 vintage is considered as the baseline survey for all 4D PRM comparisons.
Saillines are acquired parallel to the receiver lines at 100m spacing. In order to reduce acquisition costs, the operator decided to reduce the initial source coverage of about 180km^2 (Figure 1b) to 135 km^2 after the PRM1 survey, by not acquiring saillines located further away than 1500m from the outermost receiver cables; this is illustrated on Figure 1c. A comparison between migrated datasets from the full and reduced source effort showed the success of such a strategy: the effect on the data quality is negligible within the receiver area where production effects need to be monitored. Table 1 shows the dates and durations of the five Grane PRM surveys acquired to date.

PRM survey	Acquisition period	Duration (days)
PRM0	Sept. 2014	30
PRM1	May 2015	24
PRM2	Sept. 2015	14
PRM3	May 2016	18
PRM4	Oct. 2016	19

Table 1 *Acquisition periods and durations of the first five PRM surveys (including downtime)*

PRM 4D processing sequence and turnaround

The early phase of the processing effort has been dedicated to setting up and optimizing a robust and repeatable sequence from the baseline and the first two monitor surveys. The optimized processing flow is applied to each PRM monitor (single monitor processing, Buizard et al., 2013): this avoids the re-processing of the baseline dataset (PRM1) every time a new monitor becomes available.

Minimizing data sorting steps is key to achieving the required swift processing turnaround (Buizard et al., 2013). Shot domain processing is performed at the same pace as the acquisition. Upon completion of the acquisition, full 3D receiver gathers are produced and 3D processing is applied. The Grane PRM data are finally migrated in both time and depth domains. Figure 2 shows the durations of the acquisition as well as the processing turnaround achieved for the four monitors (PRM0-PRM2-PRM3-PRM4) that have been processed to date. The final stacks from the fourth monitor acquisition (PRM4) were delivered to the Grane asset team 8 days after completion of the acquisition, without compromising on the 4D data resolution (median NRMS values of 5-6% in a long window centred over the reservoir).

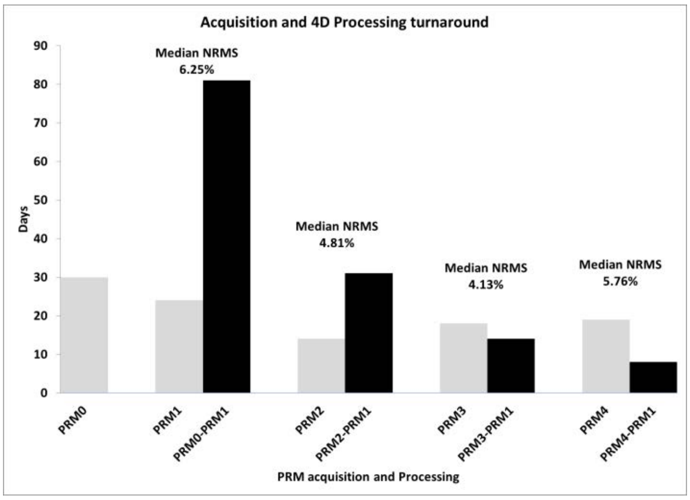


Figure 2 *PRM acquisition duration in days (grey histograms) and processing turnaround (black histograms). Once the sequence is defined (PRM0-PRM1) turnaround is consistently reduced, down to 8 days after acquisition completion on PRM4.*

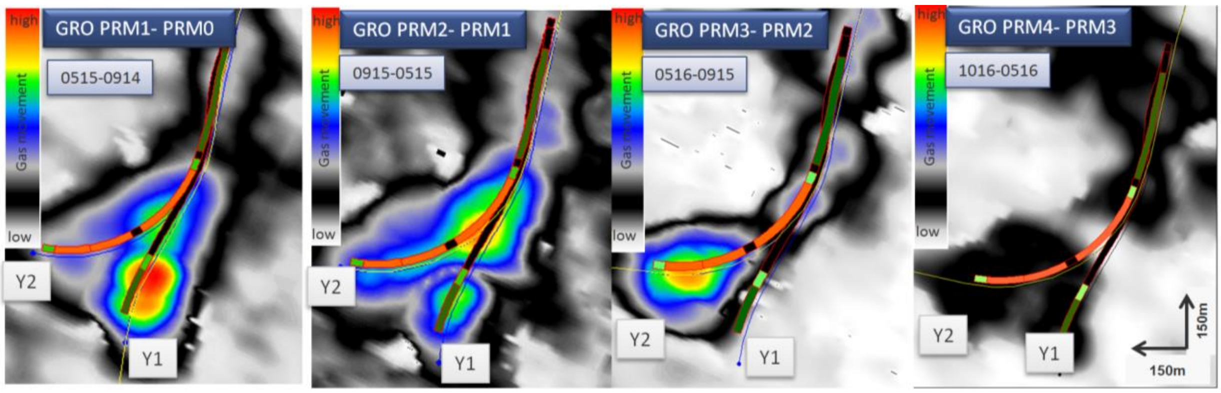
With this gain in operational efficiency, the time span of a Grane PRM acquisition and processing cycle is currently about one month, and the interpreters can now expect to get the fully processed 4D seismic volumes loaded on their workstations within three or four weeks after the first shot acquired. Co-location and coordination of acquisition QC, processing and interpretation teams in Statoil offices, as well as staff continuity, play a significant role in this achievement.

During the early development, intermediate volumes at key processing steps were delivered to the Grane asset team. In turn they inverted/interpreted them and gave regular feedback, thus contributing to the optimization of the processing sequence tailored for their needs.

Such an efficient communication link also allows continuous quick problem-solving on acquisition and processing related issues throughout the life of the project.

Observations from PRM 4D data for a new producer

An example of the value of frequent and up-to-date 4D data is illustrated in Figure 3. In this example, gas replacing oil is monitored from a new multi-lateral producer started up in September 2014, during the PRM0 acquisition. We can clearly observe how the gas replaces the oil in the two well branches Y1 and Y2 just a couple of days after the data delivery. Starting on the left, the PRM0-PRM1 map shows how the Y1 branch is affected by gas break, whereas no break is observed on Y2. Six months after (PRM2-PRM1), the Y2 branch was then affected by gas break in the middle section of the well. From PRM2 to PRM3 (Figure 3c), the gas movement is higher in the toe end of the Y2 branch of the well. Finally the 4D attribute map (Figure 3d), shows only minor gas movement. These observations can be used by the production engineers for them to better understand the well behaviour, and so extend the use of 4D seismic from well planning into well monitoring.



a) *b)* *c)* *d)*

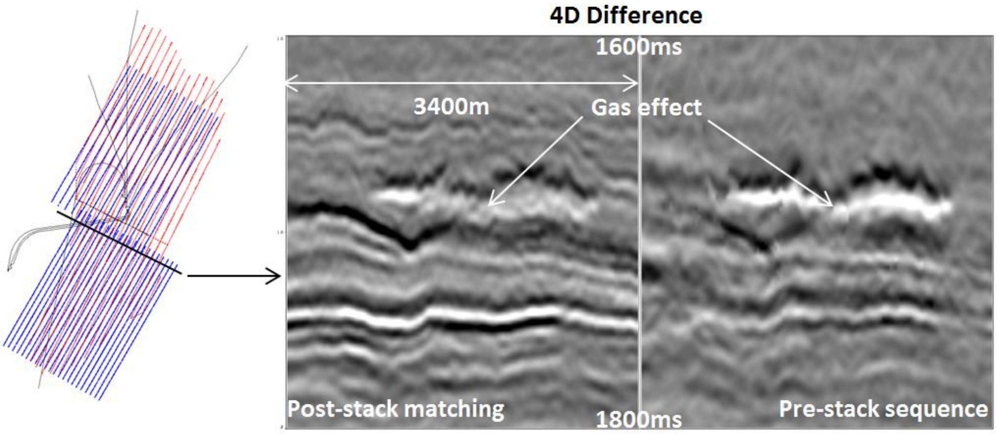
Figure 3 *G19 Well – Gas replacing oil attribute – Color scale is from black (low gas movement) to red (high gas movement) a) PRM1-PRM0, b) PRM2-PRM1, c) PRM3-PRM2, d) PRM4-PRM3*

PRM/OBC 4D processing

To get a better knowledge of the reservoir behaviour since production started, the interpreters need to be able to bridge the gap between PRM and older surveys acquired before production start-up. While the PRM / vintage Towed Streamer 4D processing is to start soon, the PRM / vintage OBC 4D project has recently been finalised. The 2001 and 2003 OBC surveys, covering different parts of the field, were merged and compared to the PRM0 dataset in an attempt to track 4D changes created by ten years of production.

The main challenges come from different acquisition geometries: OBC and PRM receivers are not co-located (see Figure 4a), orientation of the source and receiver cables slightly differ, and receiver and cable spacing are different. We have addressed the differences in acquisition geometry by using a multi-dimensional Fourier data mapping scheme to reconstruct the OBC dataset from their original positions to the target PRM geometry using pre-stack, post-demultiple OBC and PRM0 datasets as input. This allowed a fast delivery of the OBC/PRM0 4D difference as both vintages did not have to be re-processed from scratch following a more complex 4D co-processing route.

We compared the results obtained to a simple post-stack matching of OBC and PRM0 data and these are presented on Figures 4b and 4c. PRM and OBC data are now referenced to the same geometry; as a consequence a significantly improved 4D difference is obtained with the developed pre-stack sequence. It then gives better confidence in bridging the gap between PRM and older datasets.



a) b) c)

***Figure 4** a) OBC (blue) and PRM (red) receiver layouts, b) crossline 4D difference, with a post-stack matching sequence, c) crossline 4D difference with a pre-stack Fourier mapping sequence*

Conclusions

Five permanent reservoir monitoring (PRM) surveys have been acquired to date over the Grane field. The requirements for high data quality and frequent acquisition have been achieved, but they would be of limited value without the fast delivery of the 4D products to the interpretation team. The robust single monitor processing sequence designed and optimized for 4D PRM makes a very rapid turnaround possible: the 4D products are now available to the interpreters typically 8 to 10 days after the last shot. The time span for the Grane PRM acquisition and processing cycle is now about one month. Interpretation processes are also being optimized to keep up with this swift pace. The first example described in this abstract illustrates the value created by a fast delivery of up-to-date 4D products. In the second example, a 4D processing flow was designed to address the different acquisition geometries between vintage OBC surveys and PRM surveys. It allowed interpreters to successfully track the historical changes in the reservoir.

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