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Time-Lapse Seismic: A Multidisciplinary Tool for Reservoir Management on Snorre, Norwegian Continental Shelf

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Summary

4D seismic is a very important input to the multidisciplinary work at the Snorre Field. To get most value out of the 4D seismic data it is necessary to establish interpretation strategy and work processes. Both fluid and pressure changes are observed in the 4D seismic data and both differences in seismic amplitudes and timeshifts are used in the interpretation. However, the 4D responses are not unique and it is important to build confidence in the interpretation based on other relevant information as production and injection data, PLT and tracer information.

Introduction

Time-lapse seismic in the Snorre field has long been a key input to reservoir management. Since 1983 seismic data have been acquired with different time lapse frequencies. Today 4D seismic is still an important tool for monitoring the reservoir and de-risking the remaining opportunities.

Snorre, located in the Tampen area (Figure 1), is operated by Statoil and is jointly owned by Petoro, ExxonMobil, Idemitsu, RWE DEA, Total and Hess. The field was discovered in 1979, started production in 1992 from the Snorre A platform and in 2001 from the Snorre B platform.

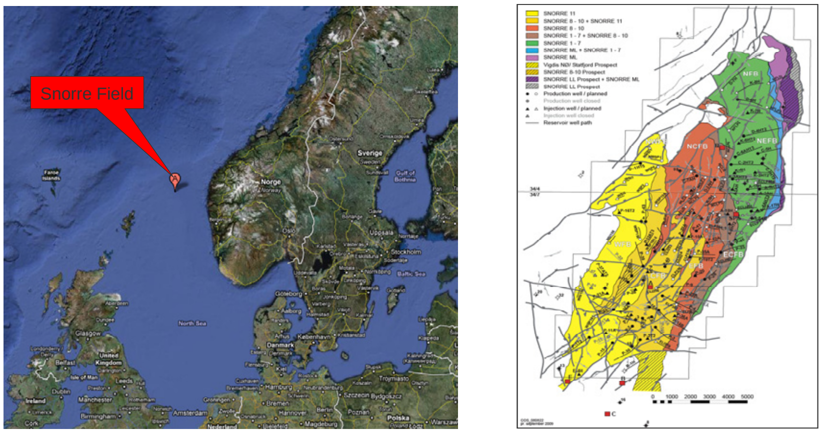


Figure 1: Snorre field location map (left) with Snorre field geological map highlighting the different geological formations together with the fault network.

The field produces from the lower Jurassic and Triassic sandstones of the Statfjord and the Lunde Fm. The reservoir (1000m thick) consists of alternating sequences of sandstones and shales, most of it are fluvial deposits (Figure 2). The individual sandstones and shales are relatively thin and below seismic resolution. The size of it combined with the depositional settings make the sandstone distribution difficult to predict. The field is pressure supported by water alternating gas (WAG) injection, resulting in complex drainage patterns.

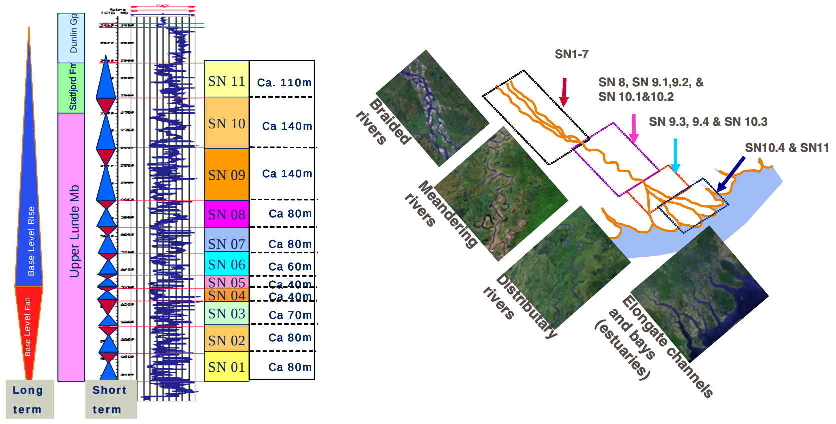


Figure 2: Snorre zonation and depositional environment

Interpretation strategy

4D monitoring reveals to be a challenging task on Snorre. The geological depositional setting (thin fluvial sand), the highly compartmentalised reservoir combined with the alternation of water and gas injection complicate the understanding of the reservoir flow behaviour. In addition, the large number of time lapse volumes is also adding some degree of complexity in the interpretation process.

During the interpretation, each time-lapse steps is looked at and not just the cumulative ones (for instance 1997-2001, 2001-2006, 2006-2009 as opposed to 1997-2001, 1997-2006, 1997-2009). It is also recommended to analyse all 4d seismic volumes: raw differences, time-shifted raw differences, absolute differences, etc.., as well as the static 3D seismic.

The project is performed stepwise: when seismic data are acquired and processed, the process starts with a screening phase, prioritizing, analysing, implementing and the final step reporting. This is achieved with a multidisciplinary team consisting of geophysicists, reservoir engineers, geologists, and production engineers to make sure all relevant data are incorporated in the interpretation phase.

Most of the screening and interpretation is performed using interpretation package such as Decision Space Desktop and Geoprobe. In Geoprobe, 4D data were visualized in 3D by use of geobodies and volume rendering, by filtering out the low 4D values. This is a very efficient way to quickly scan through the data. Seismic sections are also used extensively displaying 4D and 3D reflection data.

To take this further to the implementation phase, the 4D team need to work using a common platform and IRAP RMS has been chosen to integrate all relevant data. A workflow was established to upscale 4D seismic into the geological and simulation grid. This allows direct comparison with the reservoir geological and dynamic properties. It can also give information regarding fault sealing properties which is a valuable input for reservoir history matching.

4D expectation and interpretation

At Snorre, the fluid movements and changes in pressure can be observed both on the amplitude and velocity variations (in terms of time shifts). The time shifts are computed using Statoil’s proprietary method (Oen Lie, 2008). The results are used as a 4D attribute but also for correcting the monitor surveys for misalignment. The changes in amplitude are interpreted using raw and time-shift corrected differences and absolute differences.

All type of 4D responses is observed: amplitudes dimming and brightening, positive and negative time shifts. As a rule of thumbs dimming amplitude is related to increase in water saturation while brightening is related to increase in gas saturation. Positive time shift correspond to pressure decrease while negative time shift correspond to pressure increase. This interpretation is the most common but there are many local exceptions. Because of seismic interferences and tuning, non expected signal is complicating the interpretation. In addition, partly flooded reservoir zones and rise in the Oil Water contact can give opposite 4D response then expected. With so many combinations of 4D responses, it is therefore critical to build confidence in the time-lapse data by correlating the time lapse responses with other type of information such as production history, well logs, tracers, seismic inversion, etc..

Two different examples will be presented. The first example looks at the use of time shift attributes in the interpretation phase as shown in figure 3. 4D amplitudes are observed in the area and provide information regarding fluid changes: brightening in polygon 1 due to gas injection, dimming in polygon 2 due to water saturation increase related to P1. No strong amplitude is observed in the polygon 3. In the northern part of the field, a negative time shift was observed over a large extend. The negative time shift corresponds to an increase in velocity within the reservoir which is further linked to the I1 injector well. The I1 is a WAG injector which has been injecting some gas but mainly water during the 2006-2009 time-lapse. The increase in gas saturation combined with the increase in pressure resulted in a negative time shift. The extension of the time shift is an indication of the sealing potential of the surrounding faults. It extends further to the south meaning the I1 is giving pressure support to the southern producers.

The pressure changes interpreted on the time shifts led to a change of the completion strategy of well I2, opting for a DIACS (downhole instrumentation and control system) instead of a monobore completion design. It also confirmed the location the P3 producer and suggested a need for a geological resonation.

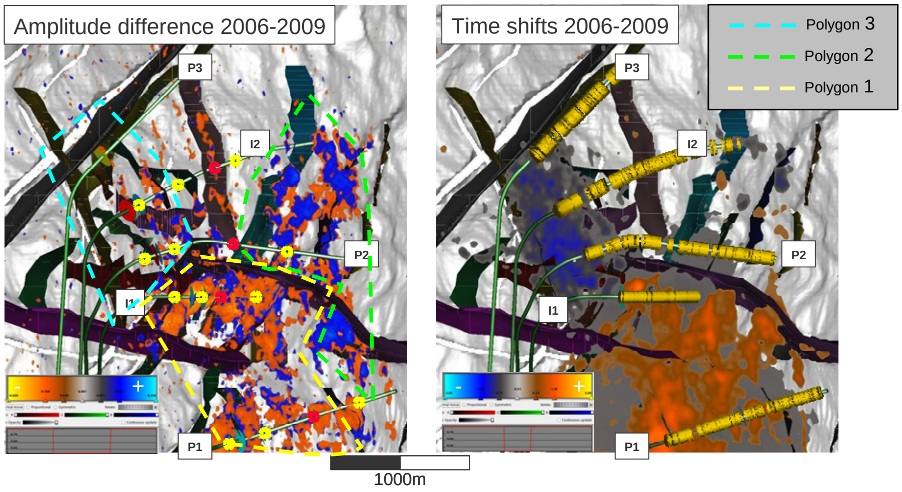
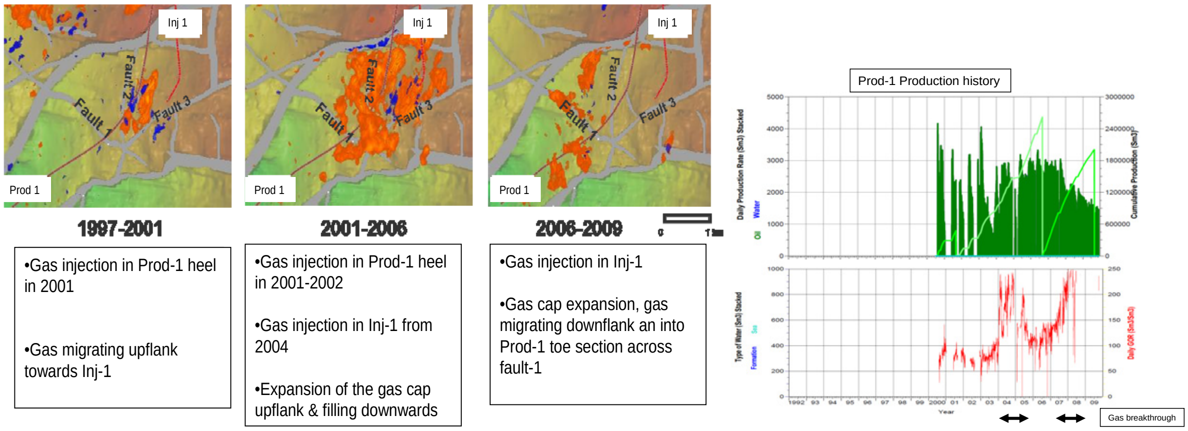


Figure 3: The display shows the time difference between 2006 and 2009 seismic vintages.

The second example is given from the southern part of the Snorre Field. In this segment there is one producer (prod 1) and one injector (inj 1). The production started up in 2000. The producer was temporally injecting gas during 2001-2002. This generated a small brightening response around the heel of the well as seen in the left 4D map in Figure 4 (1997-2001). In 2004 a separate gas injector was drilled (inj 1) generating a significant larger brightening response (red colour) shown in the middle 4D map (2001-2006). This part of the field is highly compartmentalised and it has been uncertain which areas have been drained or not. The production engineers were uncertain about the contribution from the toe section in prod 1 as the sealing potential of fault 1 was unclear. The 4D map from 2006-2009 seen to the right shows that the gas has migrated into the toe section during this time period. This correlated well to the observed increasing GOR in the prod 1. It has been very valuable to observe how the gas has migrated in the segment and across the faults for future drainage strategy.



1997-2001

- •Gas injection in Prod-1 heel in 2001
- •Gas migrating upflank towards Inj-1

2001-2006

- •Gas injection in Prod-1 heel in 2001-2002
- •Gas injection in Inj-1 from 2004
- •Expansion of the gas cap upflank & filling downwards

2006-2009

- •Gas injection in Inj-1
- •Gas cap expansion, gas migrating downflank an into Prod-1 toe section across fault-1

Figure 4: The 4D history from 1997 to 2009. To the left the 4D maps with red colour indicating increasing gas saturation and to the right the production history including the GOR from producer 1.

Conclusions

The 4D signal is challenging on Snorre due to the complex geology and the drainage strategy. The cross-discipline analysis of time-lapse data, involving production and reservoir engineers and geologists is necessary to understand the meaning of the 4D data. Since the original Snorre Plan for Development and Operation in 1987, several technological developments have contributed to the almost twofold increase in the expected recoverable oil reserves, which today represents a basis expected oil recovery of 46%. The field has a large IOR potential and an ambitious goal to improve the recovery factor to 55% has been stated. As the field is maturing with time, time-lapse seismic will become a major tool for achieving this goal.

Acknowledgments

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