FINAL TECHNICAL REPORT

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ACRONYM :ATLASS

TITLE :Analysis of time lapse seismic data for improved management of hydrocarbon reservoirs

PROJECT COORDINATOR :Norwegian University of Science and Technology

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1 Publishable Final Report

1.1 Executive publishable summary

Within a hydrocarbon reservoir and increase the hydrocarbon recovery rate by identification of bypassed reserves. Sub-objectives to achieve this goal are:

- to improve quantitative interpretation tools for time lapse seismic data
- to develop methods to reduce the number of un-necessary production wells and to identify undrained sections of hydrocarbons for drilling
- to improve placement of wells by using new time lapse analysing techniques
- estimate volumes of bypassed oil or gas
- provide guidelines on how to obtain precise information about production changes within a hydrocarbon reservoir
- ultimately to improve recovery factors and extraction of hydrocarbons.

Existing techniques for gathering information on how a hydrocarbon reservoir is being drained are based on a mathematical model simulation. This model is continuously being updated as new wells are drilled into the reservoir. Seismic data is the most efficient tool to obtain reservoir information between wells, and if the acquisition of seismic data is repeated after some years of production, it is possible to interpret seismic changes in terms of production related effects.

Some key results from the ATLASS project are:

- A new method for removing acquisition footprints from 4D seismic data
- Method for discrimination between velocity and compaction changes
- A new method for removing water layer multiples from 4D seismic data
- Development of laboratory equipment for acoustic monitoring of long core flooding
- Methodology for combined use of 4C and streamer data
- Guidelines for how to assess uncertainties in quantitative time lapse analysis
- New insight into key issues controlling the repeatability of 4D seismic data

Most of the above mentioned techniques have been tested on real field examples, with good results. This means that some of the key results obtained in the project already have been transferred into valuable results for the industry.

1.2 Publishable synthesis report

The project has been organized into 4 technical workpackages:

1. Using 4C data in 4D seismic studies
2. Discrimination between various production related effects from 4D seismic data
3. 4D repeatability

4. Rock physics measurements

A short description of key results from each activity is given below.

Using 4C data in 4D seismic studies

Various methods for matching conventional streamer data (for instance the baseline survey in a 4D seismic project) to 4C data have been tested, both in 2D and 3D. Since the number of 4C surveys is increasing, there is a need for such techniques.

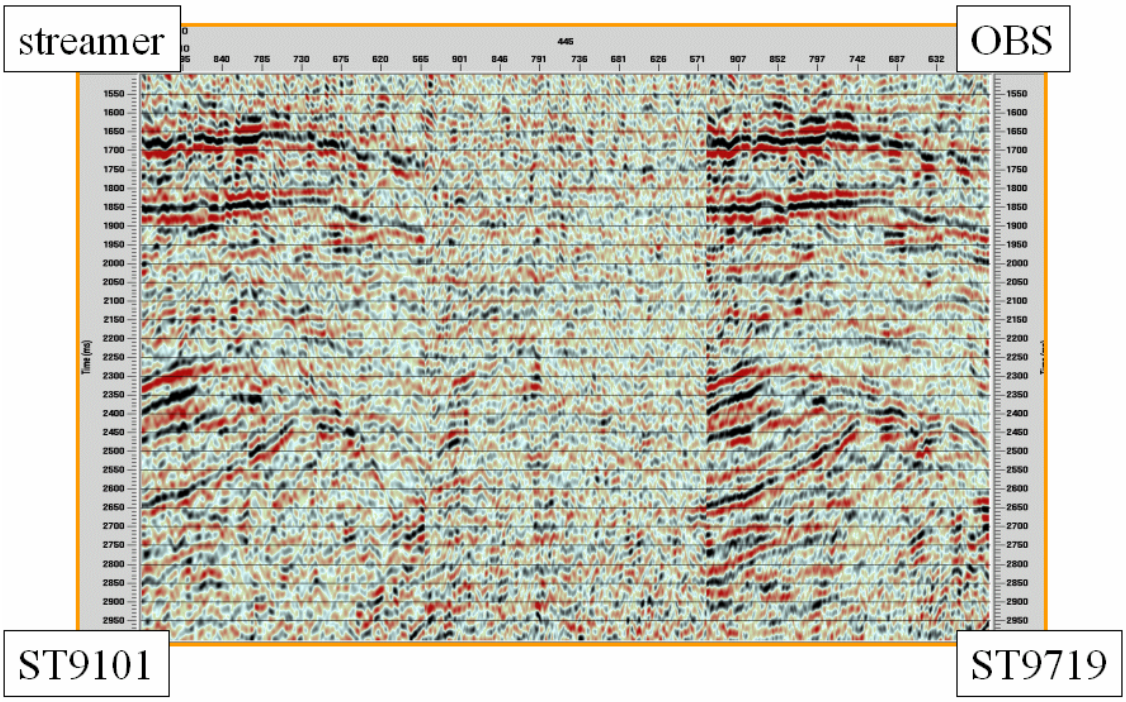

Figure P1: 4D reprocessed streamer dataset ST9101 (left), difference (middle), and 4C-OBS dataset ST9719 (right).

A 3D example of specially designed processing to achieve good matching between streamer and OBC data is shown in Figure P1. Improvements in repeatability after concurrent processing of both conventional streamer datasets and 4C-OBS datasets were observed, when compared to the original processing schemes implemented on this data. These improvements were seen through the attenuation of structural/geological events both inside and outside the reservoir, which are known not to be production related effects. Furthermore, 4C data are often used to cover areas beneath permanent field installations, and as a result of that we are faced with the challenge of how to combine streamer and seabed seismic data. One field example demonstrating how 4C data is used to fill in areas beneath a platform is given. Comparison between full azimuth and partial azimuth stacks show that multi-azimuth imaging improves the structural image. Guidelines for how to tie PS seismic data to a well have also been developed.

Discrimination between various production effects

Recommendations for acquisition and processing for optimal discrimination abilities are given. A deterministic procedure for how to assess uncertainties in quantitative time lapse seismic analysis is presented. The methodology relates uncertainties in the input time lapse seismic data to the overall uncertainty of the estimated pressure or saturation changes. The effect of anisotropic rocks on the discrimination process was found to be relatively small, but not insignificant. In some cases, changes in anisotropy might be used for improved discrimination. It was also shown that combined use of PP and PS time lapse seismic data will reduce the overall uncertainty when using such data to discriminate between for instance pressure and saturation. Although traveltime shifts and amplitude changes are very different seismic properties, various ways of combining such measurements to obtain a better 4D interpretation were presented. Figure P2 shows an example of estimating saturation changes from near and far offset amplitude changes. For this example, a combination of seismic traveltime and amplitude changes gave less stable results. However, in other cases, it was found that the added value of traveltime changes could be used to determine how various production related parameters varied with depth.

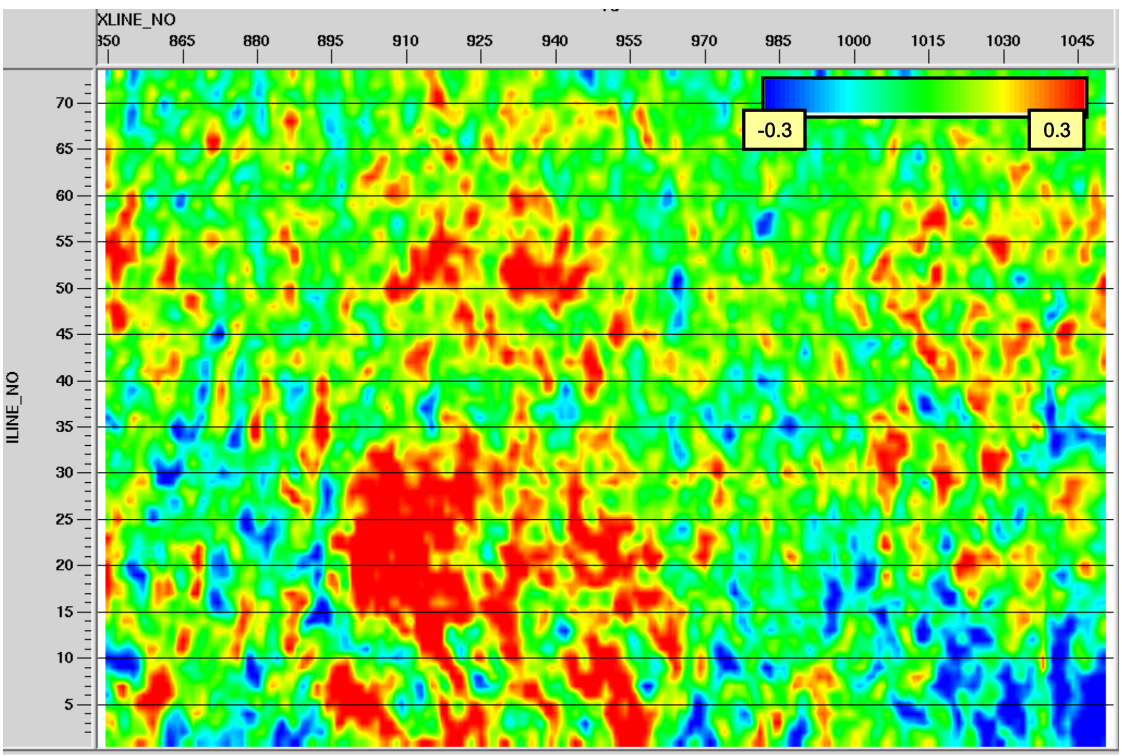

Figure P2: Estimated saturation changes, based on near and far offset amplitude changes.

A new method exploiting near and far offset travel time shifts was developed for discrimination between compaction changes and velocity changes in a given rock. An example of a statistical, quantitative method for estimation of saturation changes at the Gullfaks Field, showed results that agreed well with the well observations. Figure P3 shows the results of this analysis, presented as water saturation probability maps.

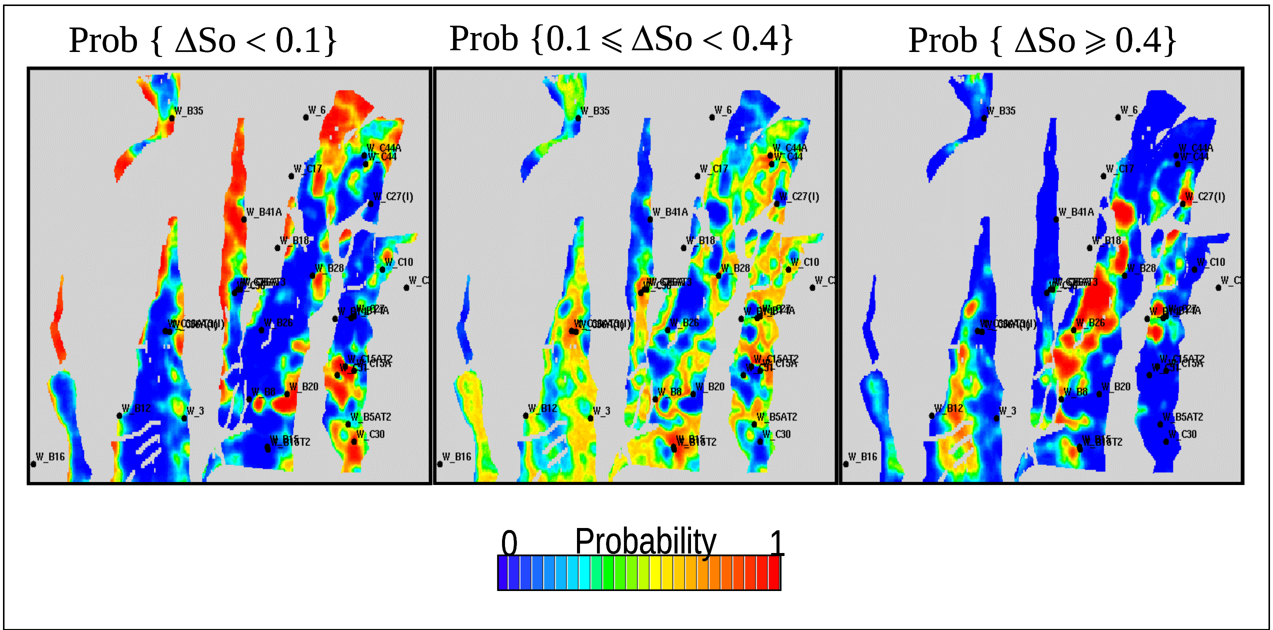

Figure P3: Probability maps for the upper part of the Tarbert Formation being undrained (left), partly drained (middle) and drained (right), 1985-1999. Based on regression with ΔRS and Tarbert oil column height.

For the Troll West oil province a method based on 1D modeling was used to estimate the movement of the gas-oil contact.

4D repeatability issues

A detailed study for various caused of non-repeatability in a seismic time lapse study has been performed. Some of these causes are hard to circumvent (especially position-related issues), but for some causes we have suggested some cures. A separate report for handling of environmental noise has been delivered. An automatic method for removal of spatially organized noise has shown a good potential for use on 4D seismic data. An example of applying this statistical method on a land data set is shown in Figure P4.

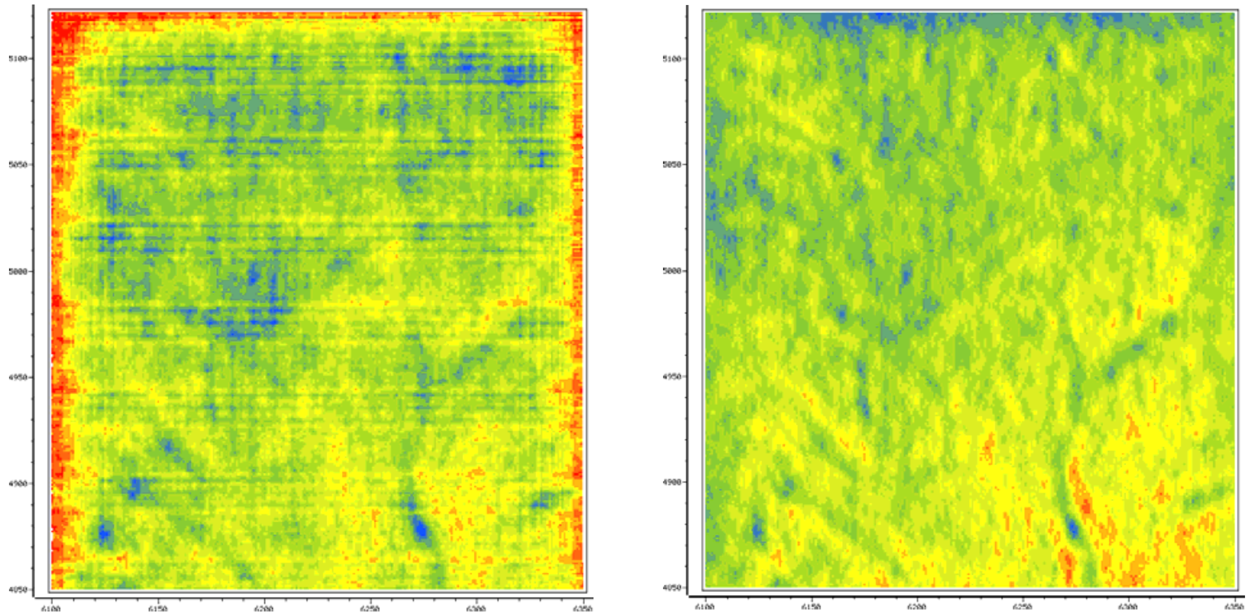

Figure P4: Land acquisition imprint removal with Factorial Kriging. Notice that the acquisition imprints on the left amplitude map is strongly attenuated after application of the factorial kriging algorithm (right).

This method is now being offered as a routine service to the industry. For 4D purposes, removal of acquisition imprints is probably more important than for conventional seismic data. This will lead to an enhancement of the final time lapse seismic data set. It was recognized early in the project that varying tides will lead to non-repeatability on the 4D seismic data, and that one should correct for such variations prior to 4D analysis. Realizing this sensitivity for tidal variations a new method for removal of water layer multiples was developed, and tested on a real data set from the North Sea, showing good results. A synthetic data example demonstrating the method is shown in Figure P5, where we clearly observe that both the first and second order water layer multiples are strongly attenuated.

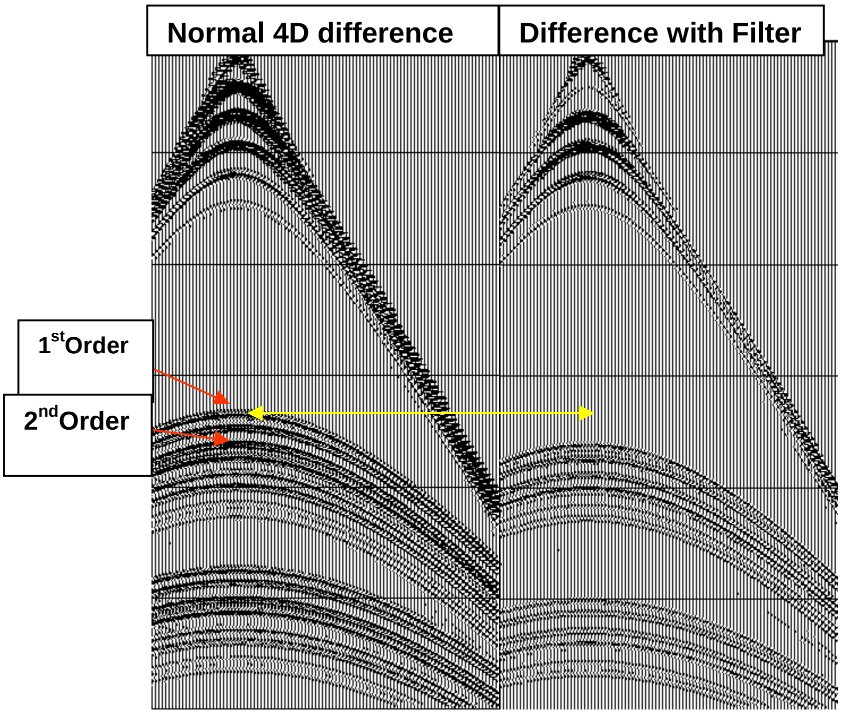

Figure P5: Comparison between normal 4D differences and differences after application of the proposed de-multiple filter.

Rock physics measurements

Ultrasonic core measurements describing how various rocks respond acoustically to variations in pressure and saturation have been performed. Both carbonate and sandstone rocks have been analyzed, and thoroughly described. A new apparatus for monitoring the fluid flow inside a long core has been developed (Figure P6), and shows very interesting results, when combined with X-ray imaging of selected cross-sections along the core.

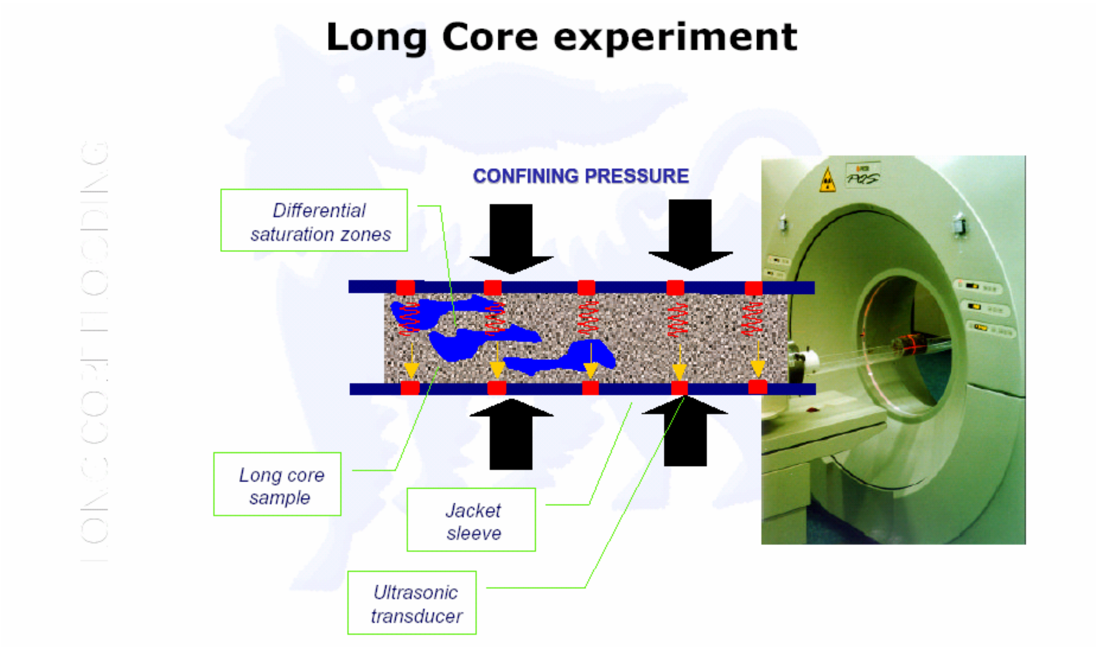

Figure P6: Experimental setup for the long core flooding experiment.

We found that the seismic velocities were changing due to the flooding within the core, and that we were able to follow the flooding by a set of 4 transducer pairs attached to the core (Figure P7). The various curves in this figure correspond to various pairs of transducers. Methods for determining anisotropic parameters as well as permeability distributions within a core sample have been developed. A separate report on how to upscale and integrate rock physics measurements with well and seismic data gives useful guidelines that can be used in most 4D projects.

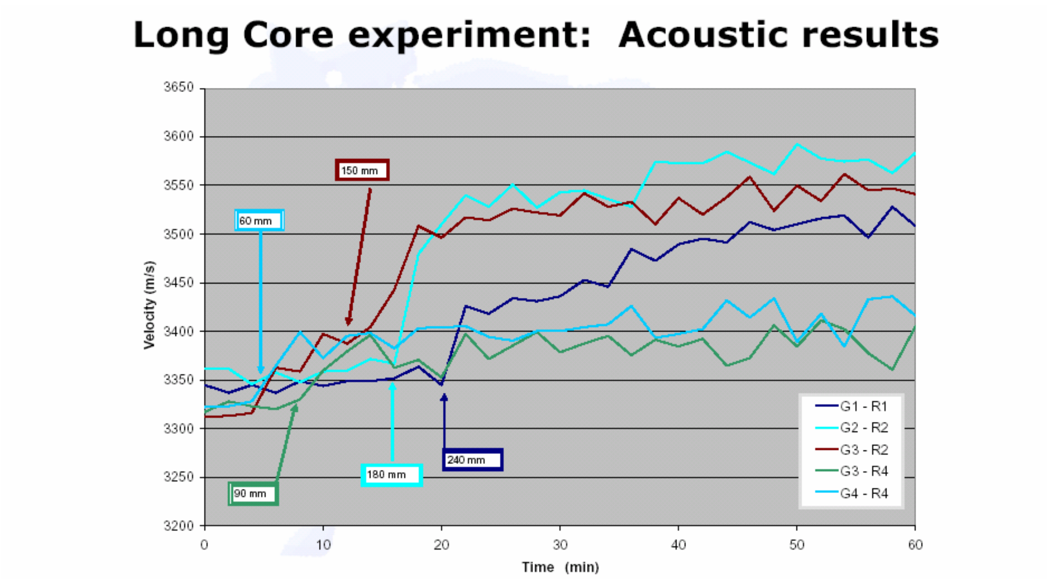

Figure P7: Measured ultrasonic P-wave velocities versus time and horizontal position (color labeled) obtained from the long core flooding experiment.