Annual Report 2012

# SBBU – Centre for Drilling and Wells for Improved Recovery

sfi Centre for Research-based Innovation
Established by the Research Council of Norway

IRIS International Research Institute of Stavanger
SINTEF
UiS
NTNU – Trondheim Norwegian University of Science and Technology

# Introduction

The Centre for Drilling and Wells for Improved Recovery (SBBU) is an industry-driven initiative with the industrial partners funding, prioritizing and directing R&D efforts towards their requirements and challenges focusing on both short-term goals that tackle daily problems and long-term ones that address the need for step-change developments.

Furthermore, the Centre has been approved and designated by the Research Council of Norway (RCN) as a Centre for Research-based Innovation (SFI), thus receiving additional funds for a 5 to 8 year time frame.

The Centre was fully established and became operational in June of 2011 with several R&D activities undertaken by the research partners which cover the main designated research areas of the Centre.

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# Vision

Unlock petroleum resources through better drilling and well technology.

# Objective

The Centre's objective is to **improve drilling and well technology** providing **improved safety** for people and the environment and **value creation** through better **resource development** and **reduced cost**.

## Significance for the business sector

The industry challenge is to improve oil recovery from existing and new reservoirs (improved oil recovery – IOR) using smarter, safer and more environmentally friendly technologies. The petroleum industry also faces a critical challenge to locate and develop new petroleum resources effectively in order to avoid declining production and increased cost per oil and gas unit. Improved and newly developed drilling and well technology will provide a significant contribution to achieving these challenges.

Both operators and society face the continuous challenge of developing drilling and well technologies that can deliver safer, environmentally friendly and more effective solutions. Fields are often developed in technically challenging environments which place limits on existing technologies and often need improved and innovative solutions outside of the established comfort zone. The Norwegian Petroleum Directorate (NPD) and the operators are united in identifying drilling and well technology as the main target area in their focus for improving efficiency and resource development.

The area of drilling and well technology for improved recovery has an important upside potential and is of a strong commercial interest. It also represents business opportunities for the oil companies as well as the supply industry and creates a considerable added value for the society.

Presently approximately 33% of the available resources on the Norwegian Continental Shelf (NCS) have been produced. The expected average recovery rate in the NCS oil fields is about 46%. A significant focus area for improving the recovery rate will be drilling and well technology. Drilling and wells represent about 50% of the entire cost on the NCS, reaching the 60% mark in subsea fields. Ref. NPD. In general, these figures also reflect the international picture.

Improved efficiency, problem avoidance and cost reduction will in itself allow more wells to be drilled. In addition technology innovation in well architecture, smart wells and smart-well completions will improve the recovery rate significantly.

Based on latest figures, the industry reports approximately 25% of non-productive time in drilling operations. In addition, about the same potential remains by avoiding operational problems and improved use of existing technology.

## Technology gaps

Predicting and maintaining the control of formation and well integrity, both on the short- and long-term are critical issues for safety and efficiency of operations as well as for ensuring uninterrupted oil production.

Currently, the potential of real-time drilling and well data utilization is not fully exploited. There is a need for standardization and quality assurance. Surface data should be integrated with subsurface data and models. The aim is to provide better information for improved decisions.

Improved imaging ahead-of and around the wellbore has a significant potential for improved safety and value creation. The challenge is to apply the new information for live-updating of the earth model, making improved prognoses of pore pressure and wellbore stability, identifying potential new targets, and modifying the well placement and well path according to an updated and enhanced field drainage strategy.

Monitoring and control of pressure, temperature and multiphase flow along horizontal and multilateral wells is important. Intra-field well monitoring should be established to optimize field drainage, increase the recovery rate and the well integrity.

Low cost well intervention technology is needed to secure a high recovery from subsea wells. This applies to all concepts for well intervention.

Innovative solutions are needed for cost effective and safe well plugging and abandonment (P&A). P&A will become a substantial activity on the NCS as fields are being shut down. This will represent a significant time and cost if existing technology is used. There is considerable potential for improvements by introducing lighter and simpler P&A solutions.

## Collaborative environment

The Centre is based on a collaborative environment between the oil industry and the R&D community. Specialists from the participating oil companies and the research partners cooperate to form the basis for the innovation process. The focus and activities will evolve during the life of the Centre.

Special attention is given to careful coordination of the Centre's activities in relation to the other R&D activities at the four R&D partners. All open R&D results from the current portfolios will be systematically made available to the SBBU.

## Way to the market

To ensure that the developed technology and solutions will be commercially available in the market, the realisation of R&D results is intended to be performed through associated projects. These associated projects will be developed outside the Centre`s activities, and aim at a targeted development and qualification process in cooperation with the service industry and smaller companies (SMEs) in order to produce commercially available products/services.

## SBBU partners

**Research partners**

SINTEF

NTNU – Trondheim
Norwegian University of
Science and Technology

IRIS
International Research Institute of Stavanger

**Industry partners**

Statoil

ConocoPhillips

TOTAL

DETNORSKE

TALISMAN ENERGY

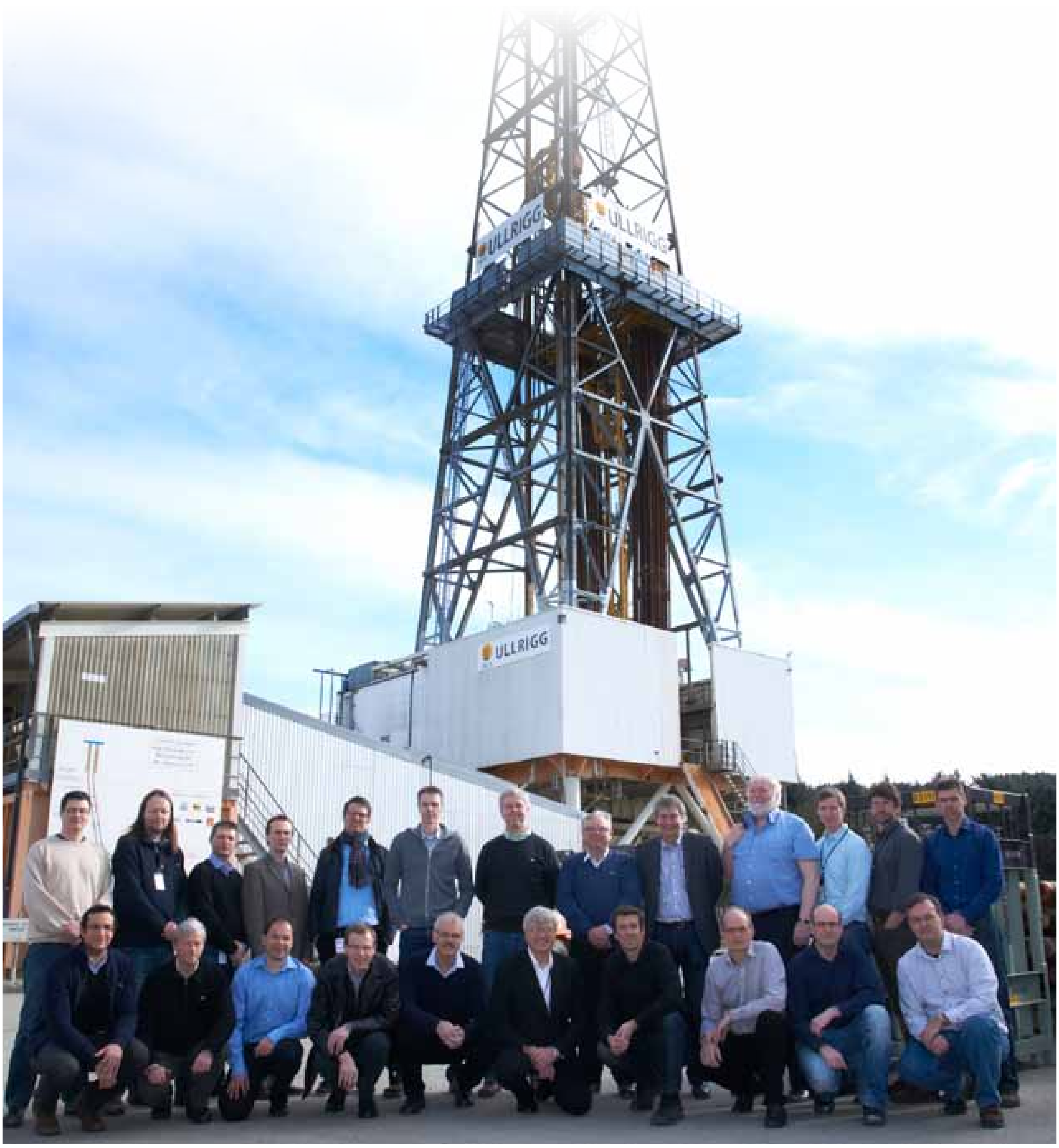
wintershall

The Research Council of Norway

Centre for Research-based Innovation

## SBBU – Centre for Drilling and Wells for Improved Recovery

| Program 1 – Safe and efficient drilling operation | Program 2 – Drilling solutions for improved recovery | Program 3 – Well solutions for improved recovery |
|---|---|---|
| • Rate of penetration management and improvement<br>• Formation integrity<br>• Managed pressure drilling<br>• Nanoparticle-based drilling fluids | • Geo-steering and deep imaging<br>• Flexible earth model | • Slender well technology<br>• Well integrity<br>• Plugging and abandonment<br>• Water shutoffs and intelligent well completions |



# Program 1 – Safe and efficient drilling operation

Program 1 addresses technologies and methods to improve safety and drilling performance and avoid drilling related problems. In 2012, the Program 1 projects were related to:

- Rate of Penetration (ROP) management and improvement
- Formation Integrity
- Managed Pressure Drilling (MPD)
- Nanoparticle-based drilling fluids

The diversity of these projects not only reflects the broad knowledge among the partners, but also a variation in project objectives spanning from fundamental research to industrial prototypes.

One project that has produced promising results on a prototype level is that of "ROP management and improvement" where a new dynamic cuttings transport model has been developed and implemented in software for real-time drilling analysis.

## Rate of Penetration (ROP) management and improvement

### Motivation

*Ability to optimise the rate of penetration while drilling is essential to reduce the drilling cost while avoiding well problems. A significant potential for improvement exists.*

When drilling a well the ROP is mainly affected by (1) bit properties, (2) weight that is exerted on the bit, (3) rotational speed of the bit, (4) formation properties, and (5) pressure difference between well and formation.

As the well is drilled deeper, the ROP is greatly limited by the ability to transport the cuttings out of the well. The drilling mud has several purposes of which one of the most important is to transport the cuttings. If cuttings are not removed sufficiently, the movement of the drillstring will be obstructed and may result in a situation where the drillstring eventually may get stuck. This increases the well drilling cost due to lost productive time and loss of equipment, if one does not succeed in freeing the pipe. A so-called pack off due to improper hole cleaning may also result in a situation where drilling mud is lost to the formation. In some cases this may cause underbalance above the depth of the fracture and might aggravate to a severe loss of well stability or an influx of formation fluids.

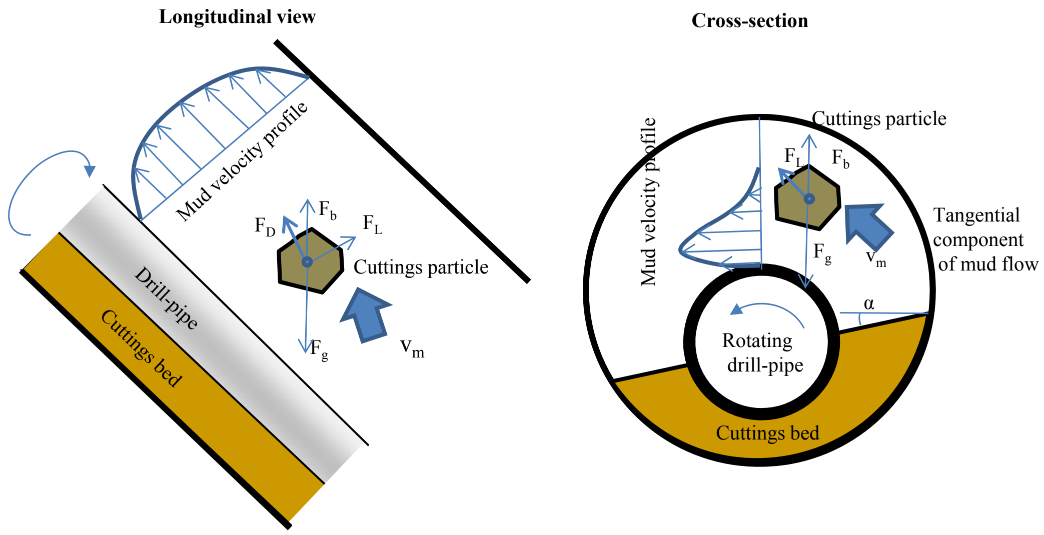
The problem of finding the optimum flow rate can be very challenging. On the one hand, the frictional pressure loss caused by the mud flow cannot be too high in order to prevent formation fracturing; this sets an upper constraint on the flow rate. On the other hand, the flow rate needs to be sufficient to transport the cuttings. These two constraints are contradictory, especially for long wells with highly inclined sections.

### Project description and results

The project has produced an advanced system for ROP optimization based on real-time analysis of surface and downhole measurements. In this software a transient cuttings transport model has been developed by integrating closure laws for cuttings transport into a transient hydraulic model that accounts for both fluid transport and drillstring mechanics.

This software makes it possible to predict the downhole conditions accurately since it includes phenomena that evolve over time such as the building and removal of cuttings beds. Effects related to changes in operational parameters are taken into account so that the predicted well status is as realistic as possible. The model is calibrated against real data by adjusting parameters such as cuttings size and cuttings bed erosion factor using the measured cuttings rates at surface as the best fit criteria.

The model has been used to analyse the cuttings transport conditions for two situations taking place in a "Designer Well" in the North Sea. In the first case, a drill out cement operation was analysed. The operation took place in an inclined part of the well. During the operation, several pack off incidents occurred which were probably caused by cuttings bed avalanches that led to a total obstruction of the annulus. Simulations verified that for the given drilling parameters, cutting beds were evolving over time. It was seen that the annular velocity was too small in parts of the well, leading to a continuous build-up of a cuttings bed that most probably developed into a cuttings avalanche, which then




Force acting on a cuttings particle in suspension. From SPE 163492 "Real-Time Evaluation of Hole Cleaning Conditions Using a Transient Cuttings Transport Model" by Eric Cayeux et al., presented at the SPE/IADC Drilling Conference and Exhibition held in Amsterdam, the Netherlands, 5–7 March 2013.

resulted in the subsequent pack off situations. The main operational recommendation was that a higher flow-rate could have been used, since there was no risk of fracturing the formation as the operation took place in a cased hole.

In the second situation, an MPD (Managed Pressure Drilling) operation was analysed. Here the rate of penetration was relatively high, leading to a situation where cuttings were accumulating in the well. Simulations were performed to reproduce the well conditions and it was seen that the flow-rate used was too low. Since the well was operating in MPD conditions, there was an opportunity to increase the flow-rate and compensate for the increased downhole pressure by changing the settings of the MPD choke. It was also confirmed by simulations that an increase in RPM (drillpipe Rotations Per Minute) would have been beneficial, to decrease the risk of having cuttings accumulations by actively stirring the cuttings beds. Simulations have also shown that material transport could happen due to cuttings bed erosion, thereby explaining why the reduction of the ROP stabilized the downhole conditions.

### Conclusions

*The simulations performed confirmed that a transient cuttings transport model is able to recreate the downhole well conditions, and that it can be a valuable tool for planning operations and providing real-time operational support.*

## Formation integrity

### Motivation

*Formation integrity is essential to avoid drilling problems in open hole and to avoid formation related problems during the production phase.*

### Project description

The project is in the start-up phase, and is coordinated with related work outside SBBU. Preliminary work has revealed that it will be valuable to obtain improved extended leak off testing (XLOT). Improved modelling will be the objective in the next project phase.

### Conclusions

*The project work will focus on modelling for improved extended leak off testing.*

## Managed Pressure Drilling

### Motivation

*Managed Pressure Drilling (MPD) is a drilling process that offers the ability to control the well pressure faster and more precisely than conventional drilling in order to compensate for pressure variations. The intention is to prevent influx from the formation, losses to the formation, or any hole instability problems. MPD techniques can assist drilling by allowing smaller margins between pore pressure or collapse pressure and fracture pressure.*

## Project Description and Results

In 2012 a pre-project focused on MPD in long wells and when drilling from floaters. In long wells, typically drilled with oil-based or synthetic-based mud, pressure control is very challenging because of the compressibility of the mud and the long distance. When drilling from floaters, the drillstring is exposed to heave movements causing surge and swab pressures when the heave compensator is turned off (during connection).

A report has been produced with special focus on long wells and MPD from floaters. The different factors which influence the annulus pressure are explained in detail to underline the challenges with MPD in long wells and from floaters. The speed with which these factors change has been analysed in order to understand if, and in that case how, it is possible to control the downhole pressure using a back pressure MPD or dual gradient MPD method. Based on this analysis, a set of requirements has been proposed for a generic annular back pressure or dual gradient MPD solution on how to obtain safe and reliable pressure control during drilling with MPD from a floater or in Extended Reach Drilling (ERD) wells. Some of the requirements are related specifically to dual gradient drilling or back pressure MPD.

## Conclusions

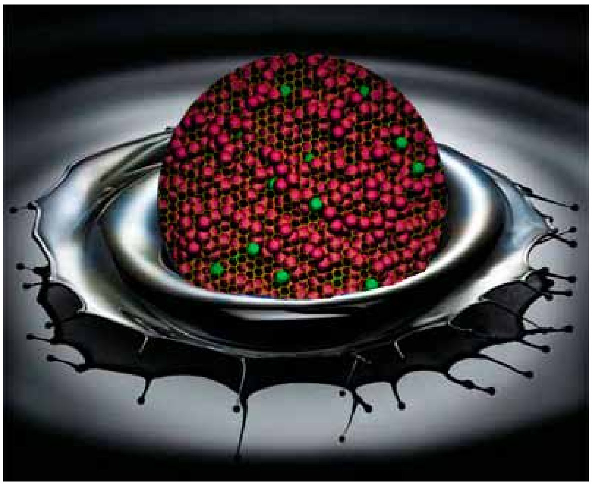
*MPD is a valuable tool for drilling wells with reduced pressure margins. This will allow wells to be drilled which might otherwise not be possible. In the next project phase the focus will be on drilling extended reach wells.*

# Nanoparticle-based drilling fluids

## Motivation

*Nanotechnology, based on recent experiences from other industry areas, might open for step change in drilling fluids technology.*

In the past decades, nanotechnology has been a constantly evolving discipline and driven by a variety of industries, such as electronics, biomedicine, pharmaceuticals, materials and manufacturing, other than the oil and gas industry. One of the exciting developments in nanotechnology is the discovery of smart nanofluids — a base fluid with suspended nanosized particles, which have novel thermal conductivity and fluidic properties that make them useful in various applications such as heat transfer, grinding, and space technology. Nanofluids shed a light on the development of a new generation of drilling fluids for improving the drilling process, in



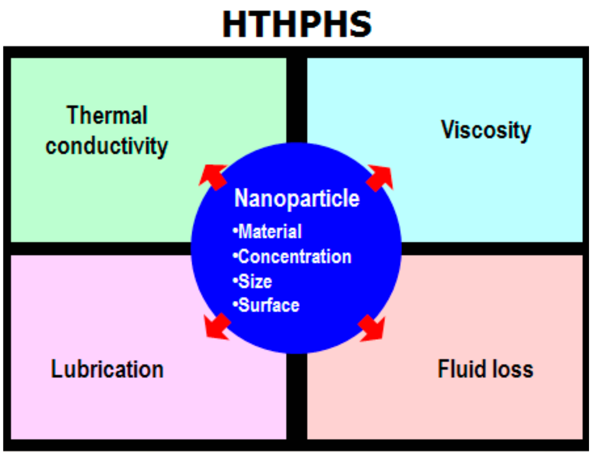
terms of modifying the rheological properties of a drilling fluid, improved drilling cutting transport, decreasing friction for reduction of drillstring torque and drag, mitigating wear on drillstring and casing, optimizing filter cake properties for reduced drilling fluid loss, reduced formation damage, and improved conditions for cementing (better bonding between cement and formation).

## Project description and results

A literature survey has been carried out to gain the state-of-the-art understanding of the potential and challenges of nanofluids for drilling applications. In the next step, we plan to develop and test nanoparticle-based drilling fluids with required rheological and filtration properties for application in challenging HTHP drilling operations by the integration of experiments and multiscale modelling methodologies.

## Conclusions

*The literature study concluded that basic research should be performed to obtain new knowledge for the application of nanotechnology for improving drilling fluid properties.*



# Program 2
# – Drilling solutions for improved recovery

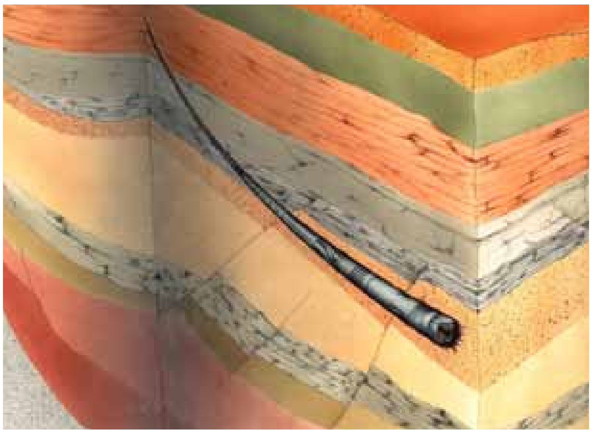
Program 2 addresses optimal well placement and well design for improved recovery of oil and gas.

High capacity transmission and real-time interpretation of data acquired during drilling, in combination with work processes for updating earth models, will secure improved safety and optimization of the well placement and design while drilling.

## Geo-steering and deep imaging

### Motivation

*High resolution deep imaging and geo-steering have the potential to significantly improve oil recovery by providing the tools and data to optimise well placement in the reservoir.*



### Project description and results

#### Geo-steering

Various logging-while-drilling (LWD) and seismic-while-drilling (SWD) tools offer opportunities to obtain geological information near the bottom-hole-assembly during the drilling process. These real-time in-situ data provide relatively high-resolution information around, and possibly ahead of, the drilling path compared to data from a surface seismic survey. The use of the in-situ data offers a substantial potential for improved recovery through continuous optimization of the remaining well path while drilling.

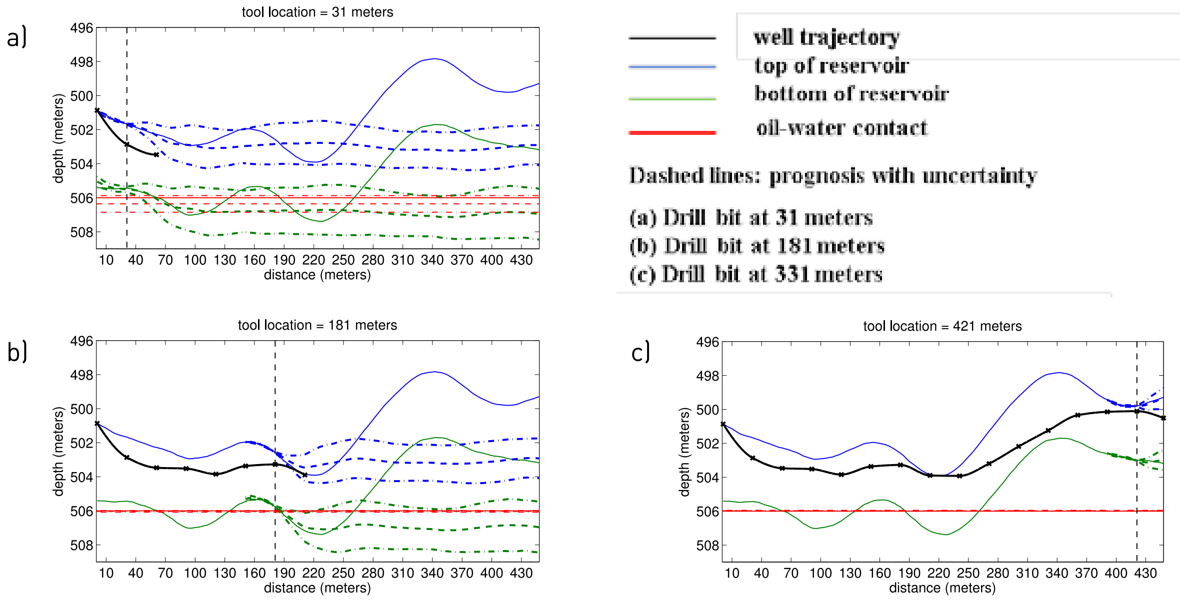
The project demonstrated an automated workflow for optimizing the steering of a well using data from logging-while-drilling (LWD). The Ensemble Kalman filter (EnKF) is used for continuous model updating and uncertainty propagation, and a robust optimization is used to compute the well position that minimizes the average cost function evaluated on the ensemble of geological models estimated from the EnKF. Directional resistivity measurements were considered and a simplified model was used to simulate the log responses. In real situations, multiple LWD measurements are collected, and the simulated log responses will be provided by multiple numerical simulators. Since in the EnKF, the data model-relationship is treated as a black box, the EnKF is well-suited for model updating in an integrated workflow that involves multiple software packages for simulating different data-model-relationships.

#### Deep imaging

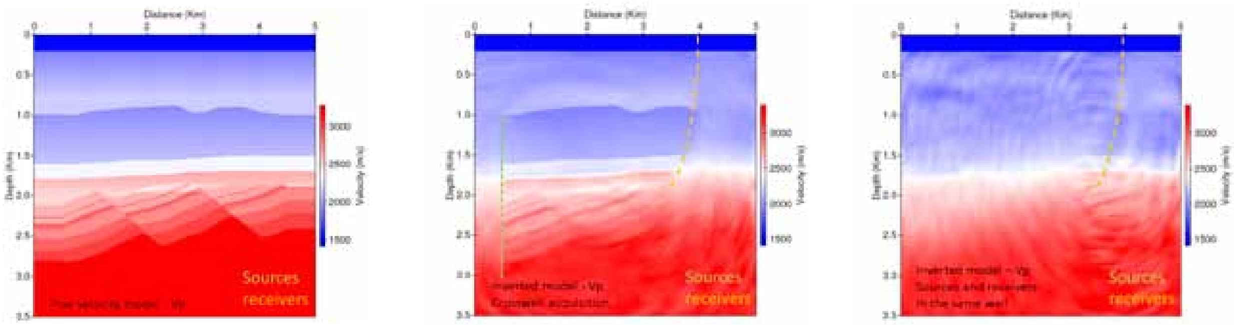
Avoiding geo-hazards is a major concern in drilling operations. The identification of drilling targets and the initial well plan are usually based on surface seismic data acquired during the exploration phase. These data provide low resolution models with significant uncertainties in the lithology model, well tops, and the prognoses for the location of potential geo-hazards such as faults and fractures. Seismic data acquired during drilling can be used to improve imaging ahead of and around the wellbore. Surface to wellbore seismic, well-to-well seismic or in wellbore seismic with sources and receivers placed in the drillstring, can be used to provide a local update around the well.

Among the seismic imaging methods, full waveform inversion (FWI) has the greatest potential in terms of resolution power to quantify the medium properties by reunifying the model building and migration tasks, and exploiting the whole information contained in the seismic signal.

The project investigated the potential of FWI to provide an update of the subsurface image during drilling. The main objective consists of evaluating the ability of the method to detect geological features ahead of and around the drill bit for different acquisition configura-




Well trajectory at different times during drilling. Uncertainties in location of top and bottom of the reservoir are reduced using log data recorded during drilling.




True model and examples of models derived from FWI using seismic-while-drilling data in cross-well configuration and with both sources and receivers at the borehole. The initial model is a smoothed version of the true one.

tions: surface to wellbore seismic, well-to-well seismic and wellbore seismic with sources and receivers placed along the drillstring. For these different cases, the final velocity models obtained provided clear indications about the presence of the fault ahead of the drill bit, the quality of the resulting models depending on the acquisition geometry which has a substantial imprint on the quality of the outcome from imaging or FWI.

## Conclusions

*Well trajectory optimization methods have been established utilizing an ensemble Kalman filter-based method. Detailed inversion of seismic data recorded while drilling has been performed using a Full Waveform Inversion-based method. Different source-receiver configurations have been studied and illumination analysis has been initiated. This initial work has shown that there is a large potential for improved geo-steering by combining advanced modelling with new hardware developments coming from the industry. A significant improvement will be possible both with respect to improved resolution and deeper penetration.*

# Flexible Earth Model

## Motivation

*The increased amount of measurements available in real time while drilling with wired pipe opens new possibilities for optimisation of well placement. The project aim is improved support for decision making processes while drilling, by using the most current and precise information obtained during the drilling operation.*

The continuous stream of new information reduces uncertainty and allows revisions of the geological interpretations made prior to the drilling operation. This requires effective interpretation, integration and utilisation of the new information within the timeframe set by the on-going drilling operation. Current three-dimensional earth modelling tools have limited capabilities for local alterations that enable effective integration of newly acquired information. Model modifications are complex and labour intensive, and the time needed for updating the model often exceeds the time available during drilling operations.

## Project description and results

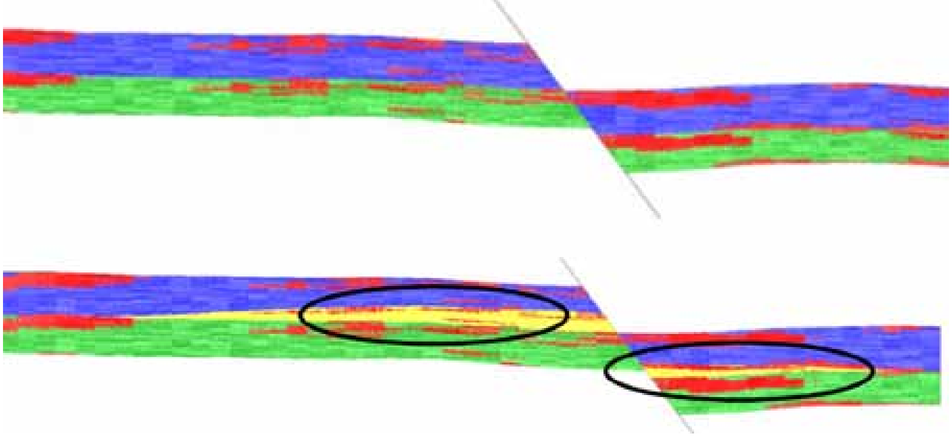
The project objective is to develop methods for more effective earth model management, particularly aimed at supporting decisions for optimal well placement in real-time based on the most recent information received during the on-going drilling operation. The complexity when managing existing earth models is mainly a result of the application of a single and globally defined grid for storing physical properties. This approach implies that even local modifications of the geological structure (fault network and layering) or the resolution of the properties dictate a time consuming global update of the numerical representation.

When a geological interpretation is locally updated within a closed region, e.g. around a well, a local modification of the numerical model requires that only a minimum of its data structures needs to be updated to re-establish a complete earth model, independently of the complexity of the geological configuration and the type of update. This requires that all data structures and algorithms in the numerical model support local alterations so that no part is globally re-constructed when only a local modification is needed.

Existing earth modelling strategies manage the subsurface as a single global region. In contrast, in our newly developed approach we split the volume into separate sub-regions which are handled individually and independently of the other sub-regions. This is enabled by the application of a set of flexible mathematical transformations which link the sub-regions in the geological structure with associated functions used to represent the properties within each sub-region. This allows separate management of the geological structure and the properties, as well as the individual handling of each property within a sub-region. As a result, local updates of the geological structure (both fault network and stratigraphy) and properties are enabled. Moreover, the resolution of each property within each sub-region can be separately controlled and adapted to the requirements of each property.

## Conclusions

*The current developments aim at enabling effective decision support while drilling, and the new technology also supports earth modelling in general. The present focus is on the validation and demonstration of the fundamental principles, as well as on exploring new functionalities that capitalise the advantages offered by the new approach.*



The figures show how the earth model is locally updated when inserting a new layer (in yellow): Only the top layer (in blue) is modified, the bottom layer (in green) is retained. Using existing earth model technologies, such updates dictate a global re-construction of the entire numerical representation.

# Program 3
# – Well solutions for improved recovery

Wells are an invariable prerequisite for the recovery of hydrocarbons. Any technical progress that makes it technically and financially possible to drill more wells and ensure effective, reliable, long-lasting functionality of existing wells is therefore a valuable contribution to improving oil recovery.

## Slender well technology

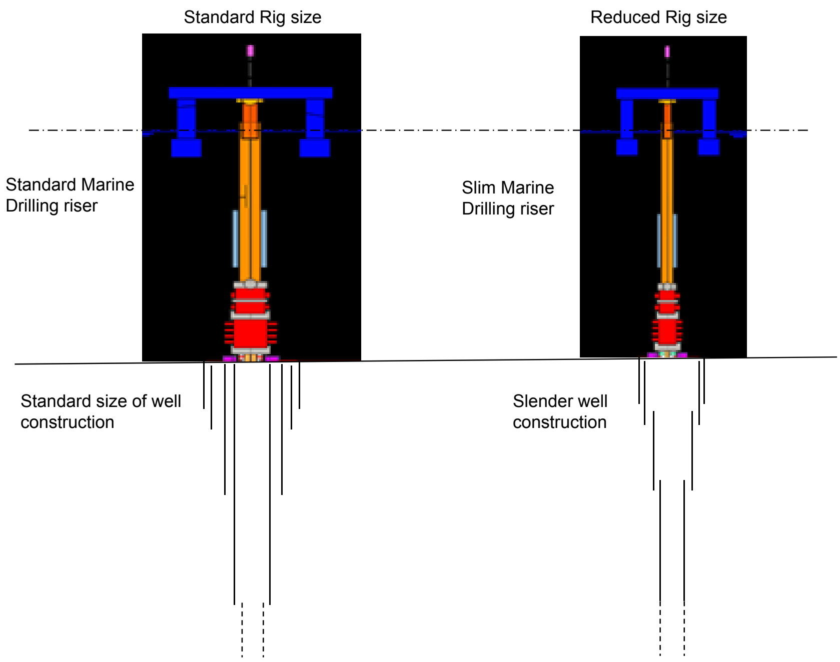
### Motivation

*Drilling costs represent more than 50% of total field development cost; hence a significant reduction of drilling costs will also have a major impact on the profitability of the field development.*

Offshore wells that are being constructed to date have large well volumes and are drilled with large, high-cost drilling units. There is a significant potential for cost reduction by starting the well with a substantially smaller diameter, which implies reduced casing dimensions and costs, reduced mud volumes and costs, reduced Blow out Preventer (BOP) size and costs, in addition to the possibility of using lower-cost drilling units. The potential for cost reduction is greater for subsea wells and more significant with increasing water depths.

### Project description and results

In this pre-project, the main focus has been on well construction. Reduced hole diameter allows higher pressure rating of well tubular and the well design may be based on an extensive use of liners. Liners may also simplify permanent plugging and abandonment (P&A) of the well. Expandable liner hangers, with an expansion cone remaining in place after setting, allow for relevant pressure rating. Enabling technologies like Managed Pressure Drilling (MPD) for control of Equivalent Circulation Density (ECD) and expandable casing/liner will allow for a reduced number of casing points and/or slimmer well completion. Centralization of casing/liner may cause restriction due to small radial clearances, and stepwise under-reaming may be applied to achieve proper cement bonding. The final hole size considered as minimum for both exploration and production wells is 5 7/8". This allows full logging and coring capabilities and a standard 3 ½" drill string can be used. When reducing the diameter of the marine drilling riser to 13 ¾" (21" standard) and the BOP size to 13 5/8" (18 ¾"




Slender well versus standard well size.

standard), the weight and riser volume will be reduced by approximately 45% and 55%, respectively.

Wellhead fatigue life will be increased using slender wells. Using a 13 ¾" (12 ¾" ID) riser and a 13 5/8" BOP in 500 m water depth, initial simulations indicate that the mean and alternating loads on the wellhead are reduced by 30% and 40%, respectively.

### Conclusions

*In spite of the potential for well cost reduction using slender wells, there are still challenges to implement this technology. The main reasons may be that presently most drilling units have a standard size of BOP and riser installed, rig utilization is high (hence no low cost rigs are available in the market), and the well construction time and rig rate constitute the main cost element. The risk of drilling a slender well, and the potential for cost reduction, has also to be balanced against a standard well.*

## Well integrity

### Motivation

*Well integrity implies maintaining leak-free and functioning wells. Apart from the economic loss related to a leaking well, such incidents may jeopardize personnel safety and the environment. Following some recent accidents, there is a strong interest in the industry for well integrity.*

### Project description and results

Well integrity concerns all mechanical elements in the well, and also the integrity of the immediately surrounding formation and the intervening cement placed to support the casing/liner and establish the sealing barrier element towards the formation. So far the project has focused on the integrity of downhole cement. Portland cement is the most commonly used cement in oil wells, due to its availability, low price and the fact that a long-term experience has been established on the use of this material.

Cement sheaths are among the well barrier elements that most frequently fail, resulting in well integrity issues. Cement failure is attributed to the formation of preferential leaky paths. These develop at the cement-casing or cement-formation interfaces, as cracks in the cement volume, or as results of increased permeability of the cement.

In this project, the pore structure of well cement has been studied by means of micro computed tomography (μ-CT) and focused ion beam scanning electron microscope (FIB-SEM). The findings can be used as a basis for estimating leak rates through set cement. The study also illustrates how this combination of microscopy techniques may be used to resolve many questions relevant for well integrity.

The study reveals that the size and number density of the pores can be very sensitive to the water-to-cement ratio applied during mixing of the components. A low water-to-cement ratio, which produced a thick cement, resulted in much larger pores than a thin cement produced with high water-to-cement ratio, as shown in Figure 1, whereas the porosity remained largely unaffected. The differences in pore size and number density are likely to arise from hydration interactions in the cement. Mechanical testing showed higher stiffness and higher strength – both tensile and compressive – for the thick cement. This may be due to a larger density of hard unhydrated cement grains (Figure 2), which act as obstacles impeding dislocation flow through the material.

The combination of μ-CT and FIB-SEM has a large potential for characterization of cement, and may answer several critical questions related to pore geometry (Figure 3) and distribution of solid phases. This may among others lead us to a better understanding of the processes that degrade the cement and how they can be stopped.

Results from this work was presented at the SPE International Symposium on Oilfield Chemistry, Woodlands, TX, USA, 8-10 April 2013 (Torsæter et al., 2013).

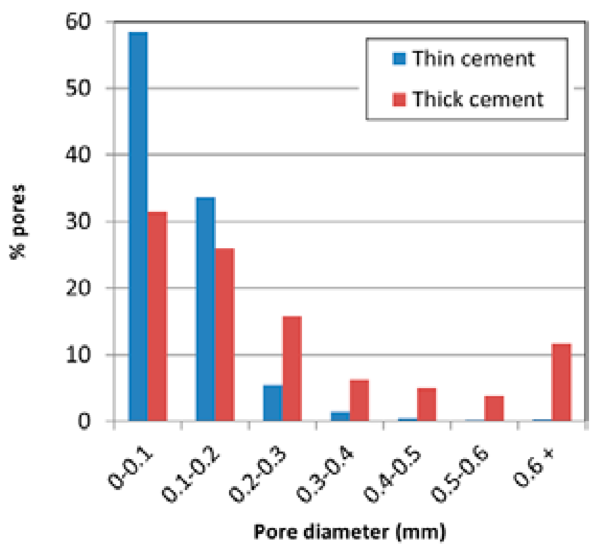



**Figure 1. Distribution of pore diameters in thick and thin cement, as revealed by M. Torsæter et al. (2013).**

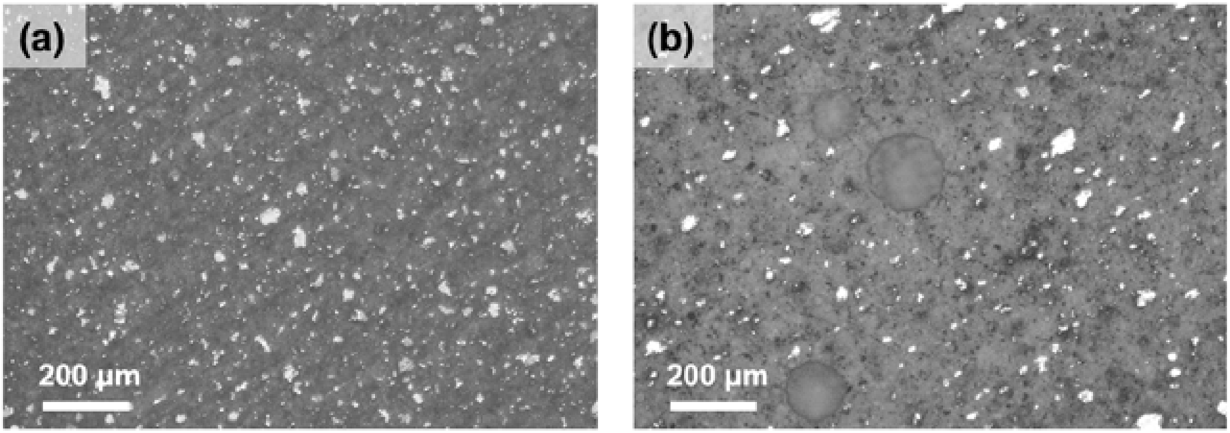



Figure 2. Light optical microscopy images of thick (a) and thin (b) cement, showing the occurrence of unhydrated cement grains (white particles). Torsæter et al. (2013).

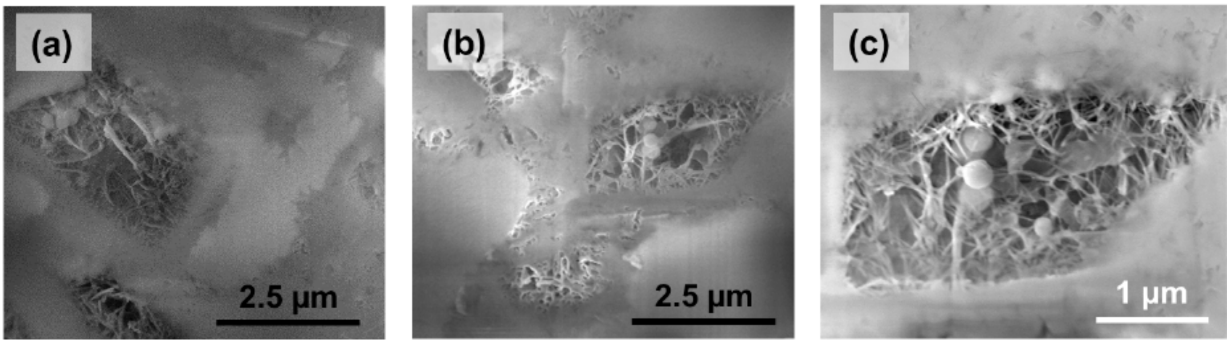



Figure 3. Micro- and nano-porosity observed in thick (a) and thin (b) cement. (c) is a close-up of one of the pores in the thin cement.

## Conclusions

*There is a pressing need for improved technology and materials to secure well integrity in both existing and future wells. The initial work is a basis for the next project phase focusing on cyclic and thermal loads on tubing and cement, cement/formation bonding and the influence of drilling on long-term well integrity.*

# Plug & Abandonment

## Motivation

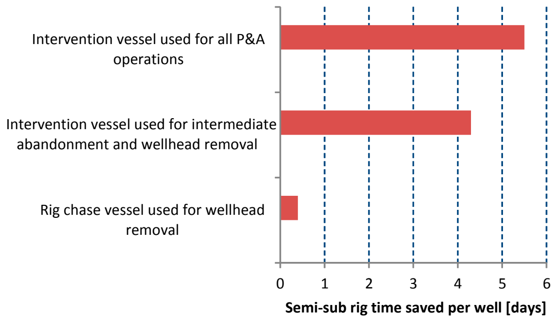
*Plug and abandonment (P&A) (of the present wells) at the Norwegian continental shelf will require 200-300 rig-years, representing a cost of several hundred billion NOK. A significant reduction in the costs related to P&A will allow for more wells to be drilled, and hence contribute to improved recovery. Important work has been done by the Norwegian Oil and Gas Association and is used as a basis for the present project.*

## Project description and results

In relation to this project, the cost picture for plugging of an exploration well has been evaluated for four different scenarios using a probabilistic approach. Different combinations of rig and vessel technologies are applied for four cases. The reference case is a situation where a semi-submersible rig is used for all operations, while for the remaining cases other vessels are used for all or parts of the P&A operations.

Using a rig chase vessel for wellhead removal instead of the semi-submersible rig to complete all the P&A work on its own is found to be slightly more expensive for a single exploration well. However, using a dedicated vessel for the wellhead removal operation releases the semi-submersible rig for drilling new wells, which is of major value. The estimated rig time saved per well for the semi-submersible rig is shown in the figure below.

Results from this work was presented at the Offshore Technology Conference, Houston, TX, USA, 6-9 May, 2013 (Saasen et al., 2013).




Comparison of semi-submersible rig time saved per well, as compared to the case when the semi-submersible rig is used for all the P&A work (Saasen et al., 2013).

## Conclusions

*There is a considerable need for improved technology to reduce time and cost for P&A. The initial work is a basis for the next project phase focusing on rig-less P&A, optimized barrier materials, long-term testing of P&A barrier materials and planning of large scale tests on cement sealing when tubing is left in hole. Critical elements are the ability to establish barriers behind one or more tubular(s) (preferably without a rig) and afterwards to be able to verify the integrity of these barriers.*

# Production Optimization through the use of Water Shutoffs and Intelligent Well Completions

## Motivation

*There is great potential for improving oil recovery by (a) a controlled reduction of the produced water cut from individual zones in oil producing wells and (b) an effective utilization of deployed smart (or advanced) wells.*

Secondary and tertiary (EOR) applications require the use of fluids which are injected to displace formation oil, accelerate oil production, reduce residual oil saturation, and increase oil recovery. The injected fluids (water, chemicals, gas, etc.) should be utilized efficiently to achieve these objectives, and produced fluid composition should be optimized with respect to the quantity and quality of the unwanted (water and/or free-gas) fluids.

This project aims is designed to address means to control/minimize the production of the unwanted formation/injection fluids and maximize oil production through the use of chemical and mechanical means in existing and newly drilled wells.

## Project description and results

### Chemical Water Shutoff Technology

Laboratory experiments were conducted to examine the bulk fluid behaviour of the available polymer samples. Following that, core floods of several chemical systems were also carried out.

The tests included: gelation time, filterability / injectivity, permeability reduction in both matrix (sandstone) and fracture (sandstone and chalk). They have been performed with commercially available chemicals.

SEM (Scanning Electron Microscopy) was engaged to characterize the core sample material and the matrix / fracture interface. Procedures for the SEM visualization of polymer distribution in the rock matrix were developed to evaluate how the matrix pores may be affected when artificial fractures are introduced in the core sample. Figures 1 and 2 illustrate examples of the use of SEM to identify polymer in the porous space and detect potential damage to the core during the core flooding.

Among the core tests conducted was also the evaluation of whether injected chemicals (polymers) block water imbibition into matrix. Three experiments were conducted in fractured Liege core samples and involved the injection through the core fracture of Syntetic Sea Water (SSW), high molecular weight (Mw), and low Mw polymers. For all experiments the oil production was monitored versus time and some results are displayed in Figure 3. According to the lab experiments, the final oil recovery from the three tests was similar, but the rate of oil recovery was quite different between the two polymer and SSW cases. Both polymers did not penetrate into the carbonate matrix with the water imbibition delayed but not blocked by the molecular weight polymer.

### Intelligent Well Completions

A tools/equipment reliability survey related to smart wells was carried out as a parallel activity with the modelling initiatives. A 1,600,000 grid cell and 24 layer extended Brugge Eclipse model was extracted from Petrel. The model was modified to include several layers of different geological origin as well as three deviated and horizontal producing wells completed in several producing zones, and 10 injection wells. Figure 4 illustrates the oil saturation distribution in two layers, after 10 years of production.

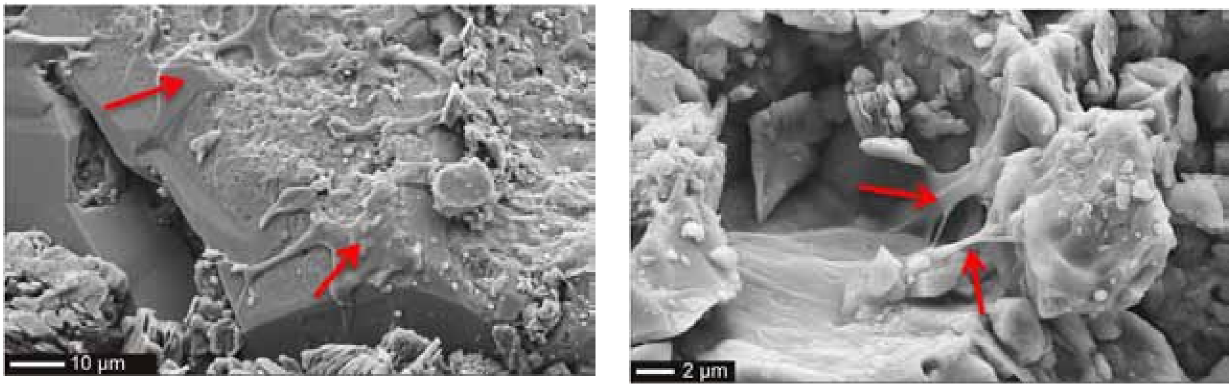



Figure 1. Half of the core dried in drying cabinet. Collapsed polymer structures, mostly outspread as coatings on the pore walls.

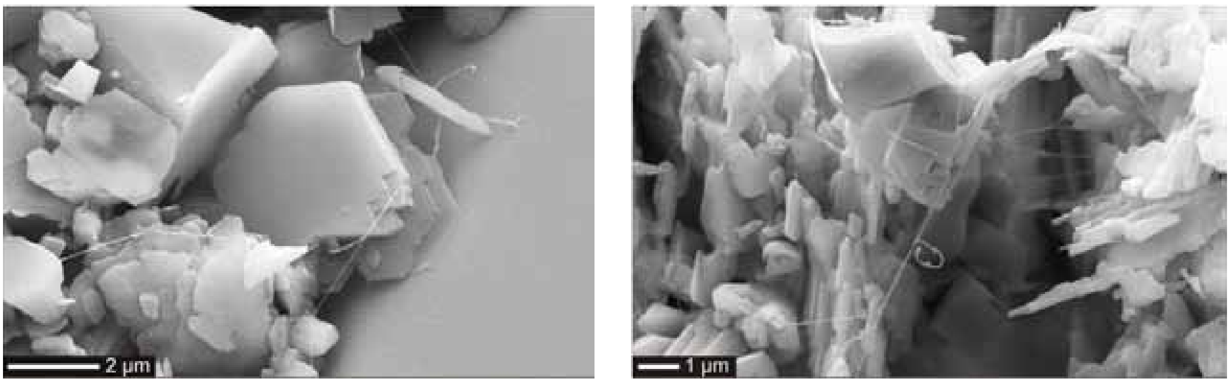



Figure 2. Half of the core freeze-dried. Inlet side. Well-preserved structures, with – partly network forming – polymer chains intact.

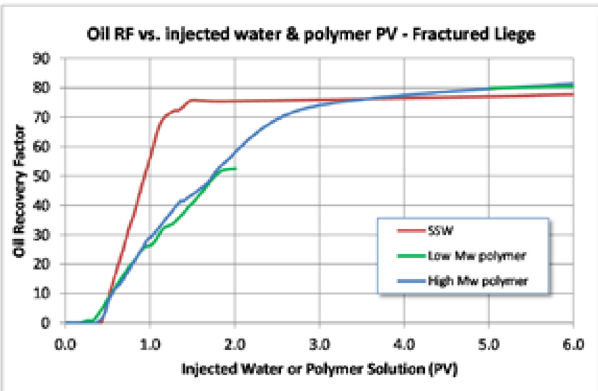
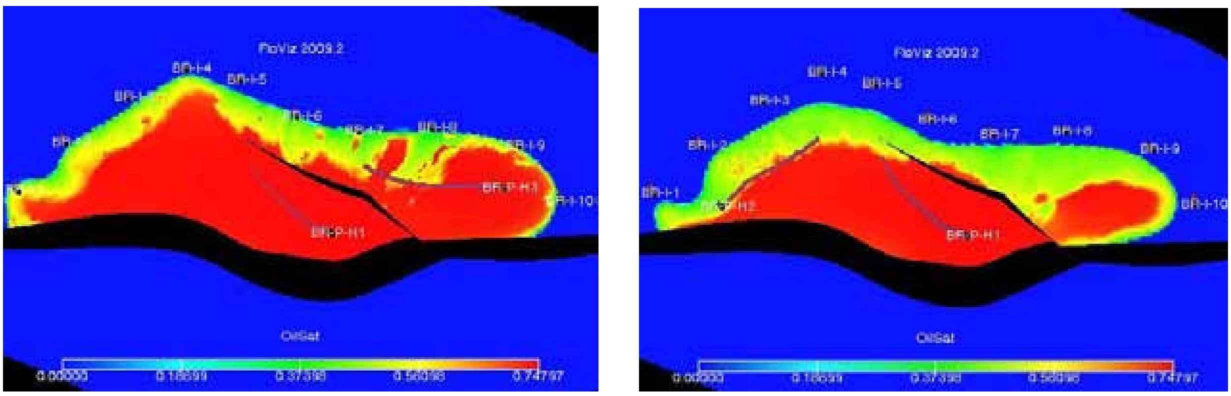



Figure 3. Oil recovery vs. injected water or polymer PV in a fractured Liege core sample; SSW, low and high molecular weight polymer injection through the core fracture.

Figure 4. Simulated oil saturation after 10 years of production, in layer 3 (left) and layer 15 (right) of a model reservoir; preliminary simulation runs.



### Conclusions

*Effective, cost-based and environmentally friendly solutions and improved technology could provide significant boosts in the produced oil volumes while reducing water production from oil producing wells.*

The initial project work forms the basis for the next project phase that is focusing on

- the deployment of the appropriate water blocking chemicals with deep penetration depending on the prevailing well/reservoir conditions, and
- the development of methodologies and a prototype model for (a) making full use of all existing downhole measurements to manage smart-well production, (b) predicting fluid (oil, water) volumes to proactively manipulate installed downhole devices and thus increase the ROI for smart (advanced) wells, (c) providing the means to assess the value of smart-well installations prior to installation, (d) directing future developments on what type of data will be needed and its frequency to further increase the value of smart (advanced) wells, and (e) evaluating the value of various existing or to-be-developed downhole hardware.

# Academy

The Centre organizes projects for MSc and PhD students to work on industry defined topics.

PhD students and post-doctoral fellows are employed by the University of Stavanger and NTNU.

Seven PhD students have been engaged, three of these are female. During 2012, six MSc students were involved in the research projects.

The Centre will also include structured competence development in collaboration with and for the oil companies.

# International cooperation

## University of Texas at Austin

*Deep imaging and geo-steering, a Bayesian Framework for Real-Time Optimization of Well Placement*

Cooperation between SBBU and the University of Texas at Austin was initiated in 2012. The PhD advisor, Professor Reidar B. Bratvold at UiS, will spend the academic year 2012-13 in a sabbatical at the University of Texas at Austin (UT). The plan is for the PhD student Kanokwan Kullawan to spend two semesters at UT during this period. Bratvold will continue his advisory duties during his sabbatical as a part of the sabbatical arrangement with UiS.

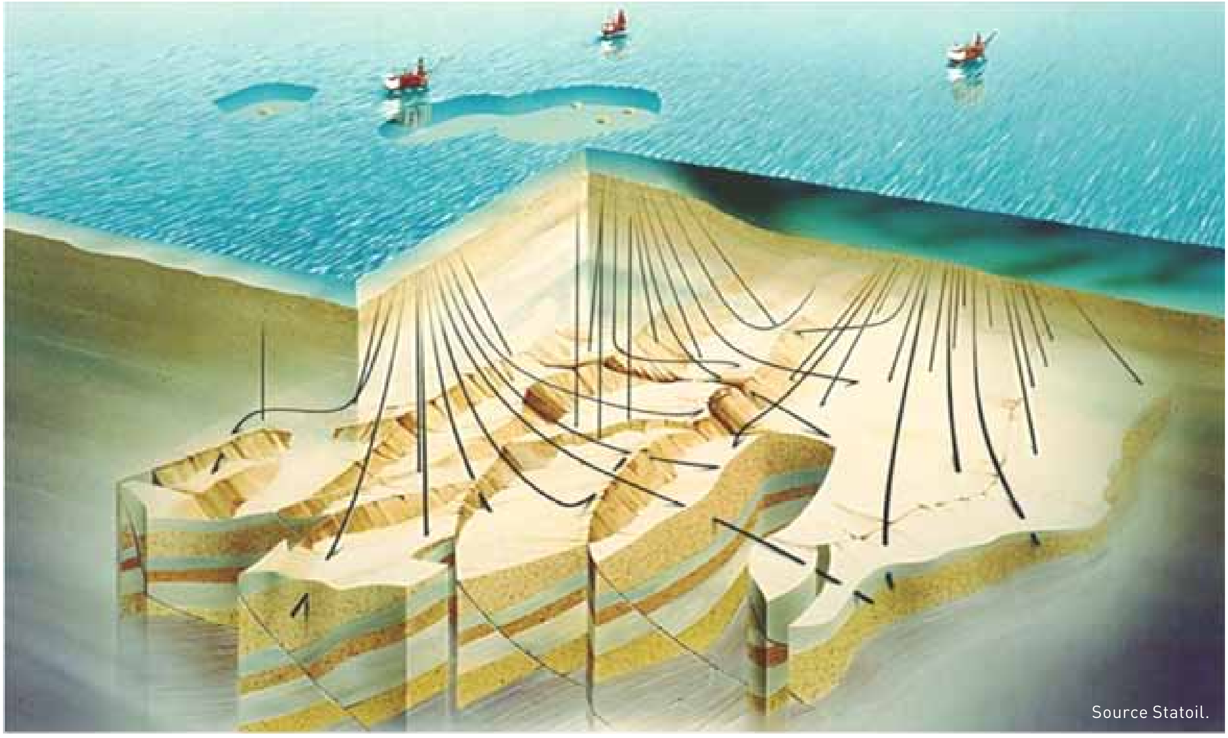
**From left Prof. Eric Bickel, Prof. Reidar B. Bratvold and PhD student Kanokwan Kullawan.**

UT has a number of research areas that are relevant for this project, including reservoir engineering, under Professor Larry Lake in the Department of Petroleum and Geosystems Engineering, decision analysis and optimization, under Professor Eric Bickel in the Graduate Program in Operations Research, and real option and dynamic programming under Professor Jim Dyer at the McCombs School of Business. The fact that Bratvold will spend an extended time period at UT provides an excellent opportunity for enhancing the international collaboration at SBBU. The PhD work is focused on collaborative research with Professor Eric Bickel.

The PhD student will focus on the development of suitable operational decision supporting analysis for operational geo-steering purposes and the creation of framework to quantify the value of geo-steering. The PhD project will be aligned with the earth model update project. A statistical inference model framework will be developed which provides a consistent and practical means of updating geological and fluid flow uncertainties in a 3D earth model conditioned to real-time data and interpretations.

***University of Houston***

The University of Houston (UH) has been involved with the SBBU activities from 2011. Through a long-term and fruitful collaboration with IRIS, UH has contributed with expertise in various fields. In drilling, Professor Dr. Michael Nikolaou, Department of Chemical Engineering, has contributed with his expertise on process control. In 2012, Professor Nikolaou visited SBBU for one month and his knowledge has been invaluable especially for the Managed Pressure Drilling project in Program 1.



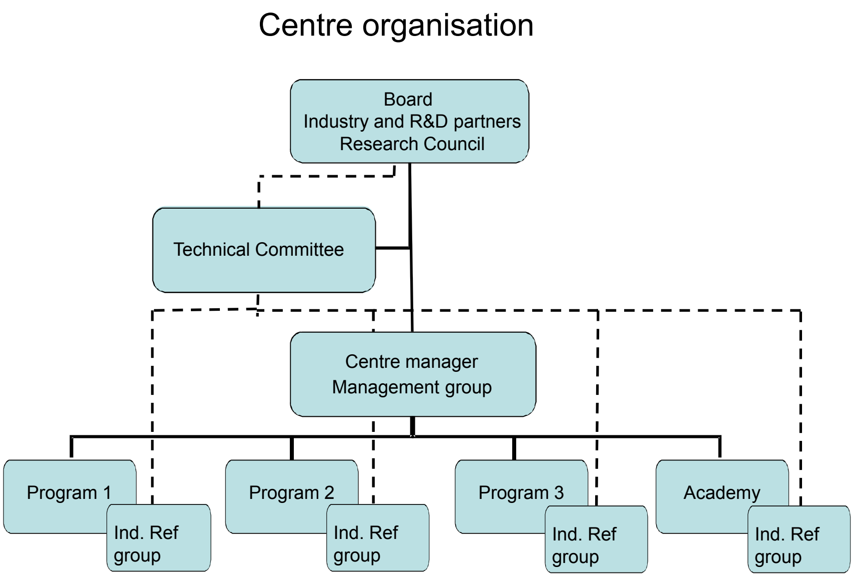

# Governance

The Board has representatives from the Industry partners as well as the Research partners. The Chair of the Board is elected from industry and industry governance is secured through voting rules giving one vote to each industry member and one joint vote to the research partners. The Research Council joins the Board as observer. A Technical Committee (TC) is an advisory body to both the Board and the Centre Manager, and has a coordinating responsibility across programs and projects.

Project based Reference Groups (RG) with technical specialists from the oil companies are established and provide advice and project supervision.

The industry involvement through the Board, the Technical Committee and the Reference Groups is essential for the innovation process.

Project research management and coordination is provided by both Program managers and Project managers.



## Budgets and financial matters

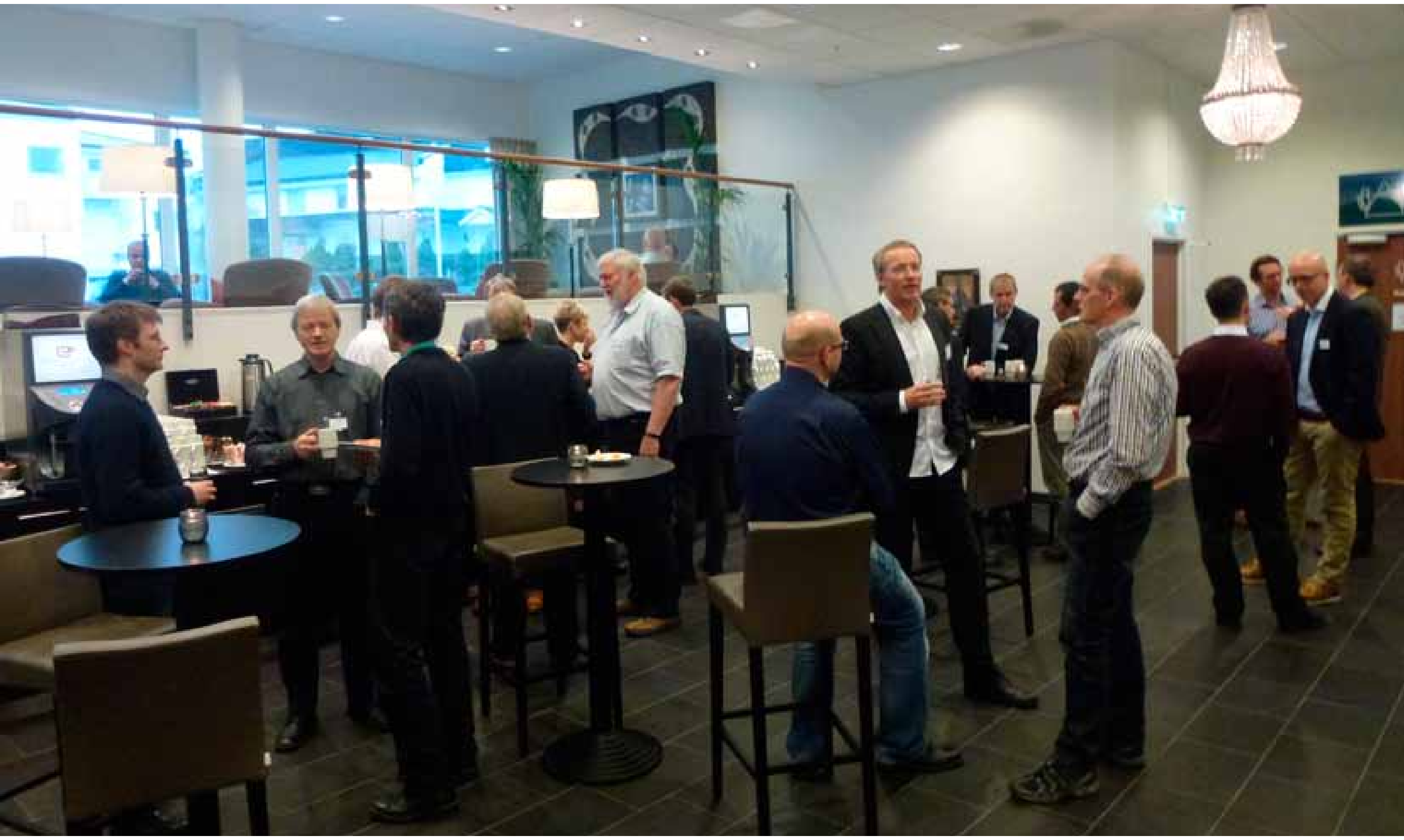
The Centre has a budget of NOK 42 million per year, funded by NOK 10 million from the Research Council of Norway, NOK 30 million by the participating oil companies and NOK 2 million by the Research Partners.
Operating cost 2012: NOK 44.2 million.

## Seminar and conference presentations

A seminar with 70 participants from the participating oil companies and the Research partners was successfully organized at Sola Strand Hotel, near Stavanger. A similar seminar will be arranged in 2013, while a conference with external participation is planned for 2014.

The UiS PhD student Kanokwan Kullawan was the winner of a scholarship for the best Norwegian presentation at the Transatlantic Science Week in Houston in November 2012.

Four papers have been prepared for presentation at international conferences.



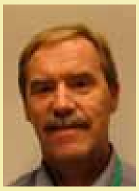
# People in SBBU

## – Centre for Drilling and Wells for Improved Recovery

### Board and Technical Committee

**Board members:**


**Brage Sandstad,** ConocoPhillips, Chairman


**Hans Konrad Johnsen,** Det norske


**Halvor Kjørholt,** Statoil


**Harald Blikra,** Talisman


**Rune Teigland,** TOTAL


**Torgeir Larsen,** Wintershall


**Øyvind Veddeng Salvesen,** Research Council


**Jon Kleppe,** NTNU


**Hans Borge,** UiS


**Kjell Arne Jacobsen,** SINTEF


**Aina M. Berg,** IRIS

**Technical Committee members:**


**Harald Nevøy,** ConocoPhillips, Chairman


**Arild Saasen,** Det norske


**Arne Torsvoll,** Statoil


**Vigdis B. Holst,** Talisman


**Johan Kverneland,** TOTAL


**Torgeir Larsen,** Wintershall

### SBBU management

**SBBU Manager:**


**Sigmund Stokka,** IRIS

**Program managers:**


**Program 1: Jan Einar Gravdal,** IRIS


**Deputy: Thor Ole Gulsrud,** SINTEF


**Program 2: Hans Martin Helset,** SINTEF


**Deputy: Erlend H. Vefring,** IRIS


**Program 3: Erling Fjær,** SINTEF


**Deputy: Jostein Sørbø,** IRIS

**Advisers:**

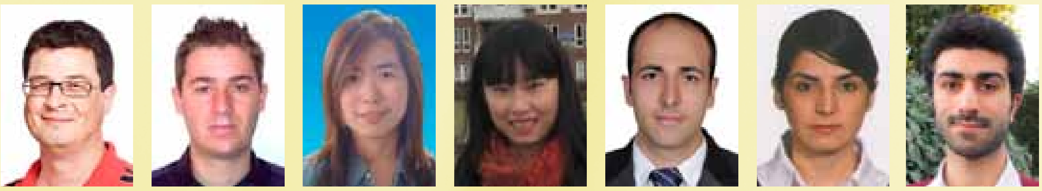

**Sigbjørn Sangesland,** NTNU


**Kjell Kåre Fjelde,** UiS


**Arild N. Nystad,** IRIS/SINTEF


**Tor Stein Ølberg,** IRIS/SINTEF

## PhD students



**Erich Suter,** UiS

**Jesus Alberto De Andrade Correia,** NTNU

**Kanokwan Kullawan,** UiS

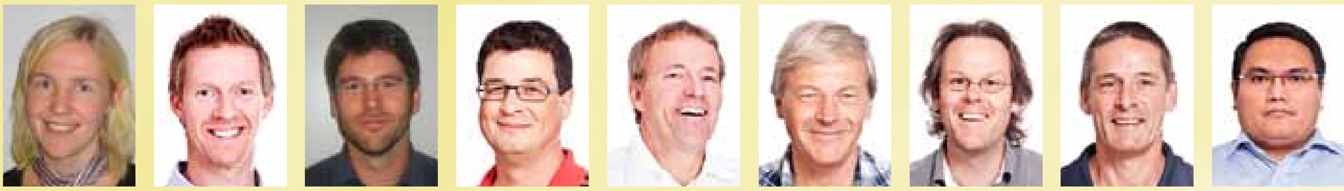
**Yi Liu,** NTNU

**Mahmoud Khalifeh,** UiS

**Fatemeh Moeinika,** UiS

**Reza Askarinezhad,** UiS

## Research Scientists



**Helga Gjeraldstveit** IRIS

**Jan Einar Gravdal** IRIS

**Fionn Iversen** IRIS

**Erich Suter** IRIS

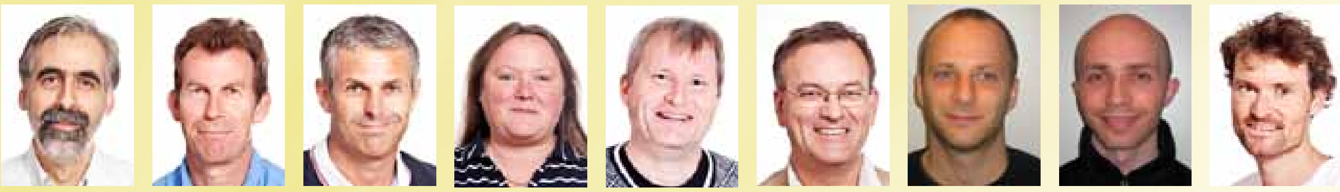
**Erlend H. Vefring** IRIS

**Jostein Sørbø** IRIS

**Øystein Lund Bø** IRIS

**Dave Gardener** IRIS

**Jimmy Baringbing** IRIS



**Dimitrios Hatzignatiou** IRIS

**Arne Stavland** IRIS

**Nils H. Giske** IRIS

**Tania Hilde-brand-Habel** IRIS

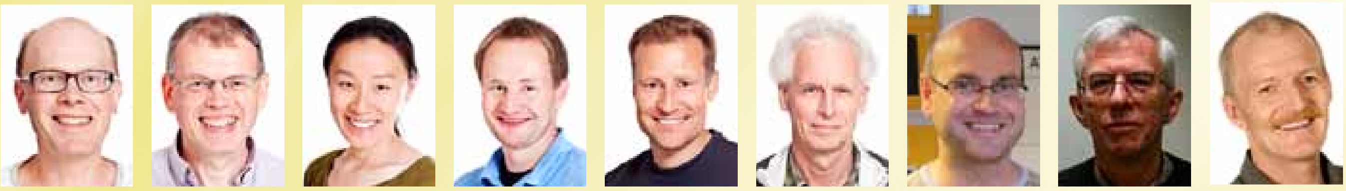
**Ove Sævereid** IRIS

**Eric Cayeux** IRIS

**Benoit Daireaux** IRIS

**Erik Dvergsnes** IRIS

**Steinar Kragseth** IRIS



**Helmer André Friis** IRIS

**Geir Nævdal** IRIS

**Yan Chen** IRIS

**Eric Patrick Ford** IRIS

**Øystein Arild** IRIS

**Bjarne Aas** IRIS

**Kjell Kåre Fjelde** UiS

**Helge Hodne** UiS

**Reidar Bratvold** UiS

**Terje Kårstad** UiS

**Hans Martin Helset** SINTEF

**Bård Bjørnevik** SINTEF

**Knut Steinar Bjørkevoll** SINTEF

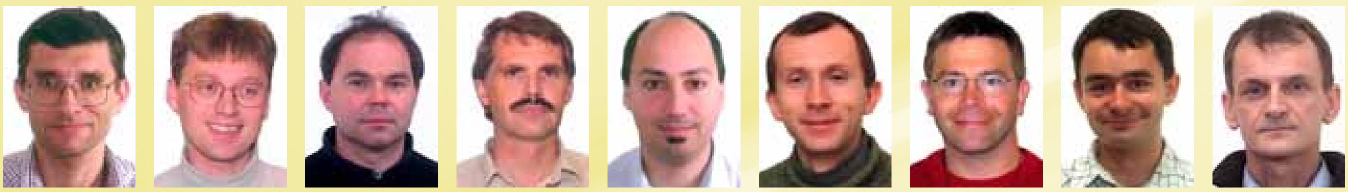
**Szczepan Polak** SINTEF

**Torbjørn Vrålstad** SINTEF

**Nils Totland** SINTEF

**Malin Torsæter** SINTEF

**Velaug Myrseth Oltedal** SINTEF



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**Erling Fjær** SINTEF

**Pierre Cerasi** SINTEF

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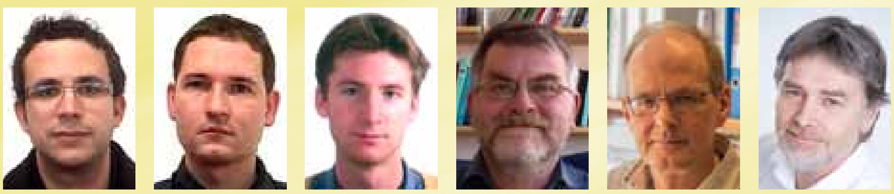
**Jørn F. Stenebråten** SINTEF

**Roar Nybø** SINTEF

**Michael Jordan** SINTEF



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**Børge Arntsen** NTNU

**Sigbjørn Sangesland** NTNU

**Pål Skalle** NTNU

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**SBBU - CENTRE FOR DRILLING AND WELLS FOR IMPROVED RECOVERY**

The Centre was established in 2011 by leading oil companies, academic institutions and the Research Council of Norway, with the objective to improve drilling and well technology providing improved safety for people and the environment and value creation through better resource development and reduced cost.

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IRIS International Research Institute of Stavanger

SINTEF

NTNU – Trondheim Norwegian University of Science and Technology