successful news
SUbsurface CO2 storage- Critical Elements and Superior Strategy

Newsletter from the SUCCESS centre – December 2016 – no. 23

Snapshots from the SUCCESS seminar and Brumunddalen field trip. All photos by Marit Hommedal

Maria giving an opinion

Nick making a point

Rock singing Per with "He ain't heavy – he's my sandstone"

Arvid finds a stone

Fall Seminar among the red sandstone

The SUCCESS Fall Seminar 2016 was held at at Scandic Ringsaker Hotel north of Hamar, October 19th to 21st, back to back with the CLIMIT PhD Seminar.

Many good and interesting presentations were given at the seminar on Wednesday.

Peter Zweigel from Statoil presented the storage part of the Norwegian full-scale CCS possibility study, with positive prospects for future CCS technology development and demonstrations. Statoil points to Smeaheia reservoir east of the Troll field, as the preferred candidate for storage of CO_2 in the planned government demonstration project.

Volker Oye from NORSAR shared results from several microseismic monitoring studies, and showed that new methodology enables much more precise determination of microseismic focal points in the horizontal and vertical domain.

Alf G. Melbye from SINTEF Petroleum presented the ECCSEL research infra structure for CCS. ECCSEL can provide access to test facilities e.g. at Svelvik CO_2 field laboratory.

Remy Agerborg from SUCCESS partner Octio gave a talk about Octio's 4D Gravitude technology for monitoring the reservoirs at Troll, Mikkel and Ormen Lange. High-precision instruments and processing algorithms allow detection of overall gas/water front movement down to less than 1 meter.

Covering the SUCCESS activities, **Maria Elenius** summed up results so far from the integration activities on Skade. Performed simulations indicate that pressure buildup is a key limitation with regards to achieving targeted injection rates.

Sarah Gasda then presented results from the PROTECT project on experiments, modeling and simulation of caprock integrity in North Sea aquifers.

Arve Rein Sleveland from the COPASS project talked about sedimentology of an aeolian to marginal marine succession, presenting results from investigations of an exhumed natural CO_2 reservoir in Jurassic sediments in Utah, USA.

Nazmul Mondol gave several snapshots of SUCCESS PhD research at UiO, before **Arvid Nøttvedt** wrapped up by talking about the plans for the final reporting of the SUCCESS Centre.

On Thursday, there was a guided field trip to study the Brumundal sandstone. This sandstone reservoir represents an analogue to relevant reservoirs for CO_2 storage offshore. The field trip was enthusiastically guided by **Johan Petter Nystuen** (below) and **Per Aagaard**, who demonstrated extensive knowledge about the local geology and the Brumundal sandstone in particular.

At the CLIMIT Seminar on Friday, **Kari Lise Rørvik** from Gassnova talked about CO_2 Storage in general and how it can help solving global warming challenge. She summed up the conclusions from the feasibility studies. **Maria Elenius** gave some examples of SUCCESS key findings. Then followed ten interesting presentations from the PhD students.

All the SUCCESS SAC members participated at the SUCCESS seminar and two of the members also participated at the CLIMIT PhD seminar, where they gave valuable feedback on the presentations from the PhD students.

Kari Lise Rørvik made everyone happy at the SUCCESS seminar promising access to new Gassnova data.

The Scientific Advisory Committee (SAC) on the go: Nick Riley, Auli Niemi, Marte Guiterrez and Sylvain Thibeau.

The Björkén Prize to Auli Niemi

The SUCCESS centre is happy to congratulate Auli Niemi, member of our Scientific Advisory Committee, with being awarded the prestigious Björkén Prize, one of the most prestigious prizes at Uppsala University. It has been awarded since 1902.

SUCCESS to investigate Smeaheia

Smeaheia is the recommended site for storage of carbon dioxide from Norwegian onshore sources. This was the result of Statoil's feasibility study, which was approved by Gassnova 1 July 2016. SUCCESS has therefore decided that next year's work on storage capacity will be on the Smeaheia case. For that purpose we have received Statoil's Petrel model on Smeaheia from Gassnova. However, the objective of our study will be different from Statoil's objective. In the feasibility study, Statoil's objective was to study injection of 1.3 Mt CO_2 per year over 25 years. Our objective will be to investigate the storage capacity of the field and evaluate the injectivity and risk of leakage.

IAa

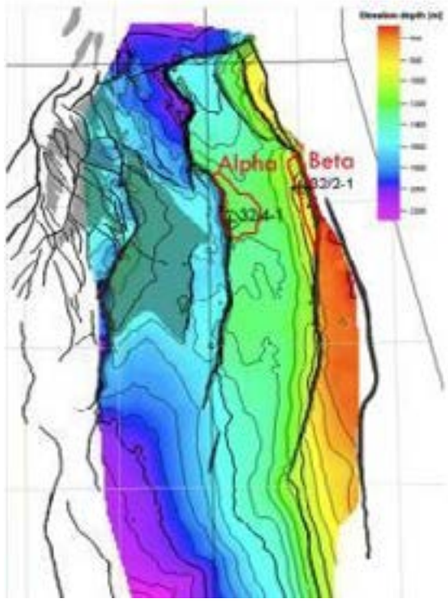


Figure: Location of possible injection structures in the large fault block of Smeaheia.

SUCCESS at GHGT

In November the biannual GHGT conference on greenhouse gas technology was staged in Lousanne. Several SUCCESS researchers were involved. We have noticed the following presentations and posters:

- *Movement of reducing fluids in low permeabilityrocks during progressive structural deformation – Modelling CO_2 migration in the Carmel Formation, USA*
  Anja Sundal, Rohaldin Miri, Ivar Midtkandal, Valentin Zuchuat, Per Aagaard, Alvar Braathen, University of Oslo; Helge Hellevang, Jan Tveranger, University of Bergen
- *Pressure induced deformation and flow using CO_2 field analogues, Utah*
  Elin Skurtveit, Guillaume Sauvin, Norwegian Geotechnical Institute (NGI); Alvar Braathen, Eivind B Larsen, University of Oslo
- *CO_2 leakage detection technology – Industry needs, government regulations, and sensor performance*
  Ann E. A. Blomberg, NGI & University of Oslo; Ivar-Kristian Waarum, Espen Eek, Per Sparrevik, Joonsang Park, Gerard Cornelissen, Mike Carpenter, Delphine Laborde, Jock Brown, Torleiv S. Grimsrud, DNV GL
- *2.5D inversion and joint interpretation of CSEM data at Sleipner CO_2 storage*
  Joonsang Park, NGI
- *Simulation of CO_2 storage into methane hydrate reservoirs, non-equilibrium approach*
  Khadijeh Qorbani, Bjørn Kvamme, University of Bergen
- *Vertical equilibrium flow models with fully coupled geomechanics for CO_2 storage modelling, using precomputed mechanical response functions*
  Odd Andersen, SINTEF ICT & University of Bergen; Halvor Nilsen, University of Bergen; Sarah Gasda, UNI Research, CIPR

New PhD on rock physics and CCS

On December 12th Javad Naseryan-Moghadam at University of Oslo defended his PhD thesis «Investigation of petrophysical and rock physical aspects of CO_2 storage in sandstone reservoirs – An experimental study».

In this PhD study the main focus was to investigate the CO_2 storage potential in the Knorringfjellet formation in Svalbard area, recently considered as a potential site for a pilot CO_2 sequestration project. In order to address the petrophysical aspects associated with CO_2 storage a series of fluid flow experiments were conducted at Department of Geosciences (UiO) and Norwegian geotechnical Institute (NGI) on the Knorringfjellet sandstone core plugs. The sensitivity of the core plugs to the applied confining stress and pore pressure in terms of the effective stress coefficient for the permeability (αk) was studied and the dependency of αk to the contrast between elastic moduli of quartz and clay minerals has been modelled. The modified Clay Shell model proposed in this study was successfully utilized to predict the αk values by means of spherical pore geometry. The significantly low relative permeabilities of CO_2 in the tested sandstones were attributed to inefficient sweeping of the in-situ water due to the domination of capillary forces over viscous forces, especially in case of gaseous CO_2. The significant role of residual trapping in immobilization of a great portion of CO_2, especially in the early stages of sequestration, has been experimentally documented. Geophysical monitoring of the CO_2 plume movement inside the target aquifer is crucial for fully addressing the security issues associated with CO_2 leakage into the surrounding environment. The obtained results in the rock physics part suggest that the seismic response of the CO_2 saturated sandstone under different temperature and pressures, representing different CO_2 phases (gas, liquid, or supercritical), can be utilized for tracking the CO_2 phase transition inside the storage reservoirs.

SUCCESS integration work on the go

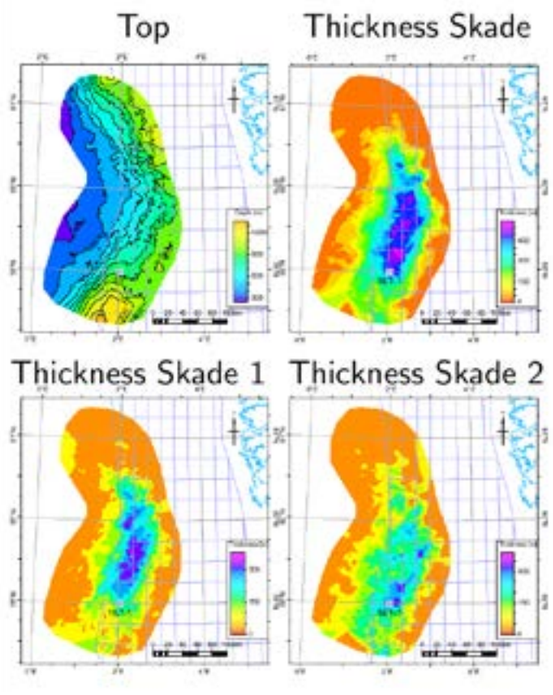
The SUCCESS centre is soon entering its last year, and an important task just now is to summarize and integrate the results we have obtained. For this an extra work package has been established – WP Zero. WP leader Maria Elenius reports:

WP 0.1 investigates storage capacity, leakage risk and injectivity for the Skade formations. Recently, the Smeaheia was chosen for WP 0.2 in favor of the Johansen formation, because there is an aim from Norwegian authorities to store 1.5 Mt CO_2 per year in the Smeaheia.

In 2016, the main focus has however been on Skade. Our simulation results show that pressure buildup is often the limiting factor for storage capacity. Although CO_2 migration is limited to tens of kilometers near injection wells, the surrounding pore water can propagate the injection pressure pulse more than a hundred kilometers away. The magnitude of the overpressure is reduced with distance from injection wells, but parts of the aquifer that are closer to the surface have lower tolerance to overpressure. Therefore, the risk of caprock failure is examined also in shallow regions far away from injection wells, and includes the post-injection period.

In addition, the pressure tolerance may be further reduced in the presence of existing faults. The evaluation of storage feasibility is therefore pending on reliable data on formation depth, stress regime and presence of faults. In addition, the permeability, compressibility and porosity affect propagation of the overpressure and must be evaluated. Challenges then appear in terms of reliable data and simulation capabilities in formation volumes that can be an order of magnitude larger than those examined for hydrocarbon exploration.

Data density is low for CO_2 applications in untested aquifers such as Skade, often with no core samples and unconfirmed seismic interpretations. In WP 0.1 and WP 0.2, experts on geology, geophysics, geomechanics, simulation technique and statistical analysis collaborate to optimize the use of existing data in an efficient simulation framework. Based on improved seismic interpretation, analysis of formation tests, testing of wellbore cuttings and examination of leakage pathways, probability density functions are developed and used as input to simulations. The sensitivity of parameters and safe injection rates are evaluated based on a large number of simulations.



All photos in this newsletter are by Marit Hommedal

What we've done ...

WP 1: RESERVOIR

The main targets for WP 1, development of new reservoir models and evaluation of injectivity of the Skade and Johansen Formations, have been partly completed. A new model with top and bottom surfaces of Skade has been made, improved from the earlier available models from NPD. The model has been delivered and utilized in assessing the storage capacity for Skade (WP 0).

Due to lack of resources a large scale model has not been made for Johansen Formation. This work will be cancelled and resources will be allocated to evaluate Smeaheia (Troll Kystnær) instead, using already existing reservoir models.

The first synthesis report, on the long term delivery of understanding CO_2 injecvtivity, has been finalized, with some minor adjustments to be done. The final report will be delivered first tertiary 2017.

A large work on the potential of CO_2 forming shallow hydrates during a leakage has been finalized by the group of Bjørn Kvamme. This work has resulted in a much improved understanding of the stability of CO_2 and CH_4 hydrates in cold and seawater in sediment pores. The group has also provided new models and data showing that CO_2 corrosion of the steel-cement interface may potentially cause local pathways for CO_2 leakages along abandoned or active wells.

Helge Hellevang, leader WP 1

WP 2: CONTAINMENT

WP 2 is focused on identifying and quantifying the processes that may affect storage integrity and long-term containment. In 2016, there have been three main activities: (1) hydro-chemical-mechanical experiments on shale samples, (2) identification of leakage pathways, and (3) application of advanced hydromechanical modeling. All three activities are continuation of past activities, with the first two involving a post-doc and PhD student who are both in their final year.

After the wrap-up of activities, methods and data delivered in WP 2 will be integrated into WP 0 to demonstrate how leakage risk estimates can be improved for candidate storage sites in the North Sea.

In 2016, a new experimental set-up was completed and used to make permeability measurements on intact shale samples from the Longyearbyen CO2Lab. The measurements (pulse and flow-through) were made under different confining pressures (5–15 MPa) with different permeating fluids (argon, water, CO_2). Water causes swelling and pore blocking, resulting in reduced permeability that does not rebound with decreased confining pressure.

In contrast, dry supercritical CO_2 increases permeability to a greater degree than seen with inert argon. This suggests that water evaporation into the CO_2 causes the hydrated shale minerals in the shale to shrink, altering the pore geometry. Alternatively, evaporation may result in the opening of pore throats. The effect of confining pressure is on dry shale permeability limited.

Although the experiments were performed on intact shale, swelling and shrinking of the shale with exposure to CO_2 would close or open existing fractures in the shale. This work will help us understand if CO_2 leakage along fractures in shale will be enhanced or hindered by exposure to CO_2.

Sarah Gasda, leader WP 2

Current work is focused on the effect of clay swelling, confining pressure and CO_2 on permeability using tablets of compressed montmorillonite. Similar tests are planned for the Draupne shale samples obtained from the CO2Seal project, funding permitting.

WP 3: MONITORING

WP 3 has established three activities for the center integration/synthesis deliverables. Each of these three will contribute with respect to shallow-focused marine environmental monitoring, deep-focused geophysical monitoring, and reservoir-to-seabed leakage scenario, respectively.

Joonsang Park, leader WP 3 (behind)

It is planned to link the deep-focused and shallow-focused monitoring activities and provide realistic leakage scenarios This activity is expected to have a unique and novel contribution to the CCS society. NIVA and IFE are involved. This activity is, at the same time, rather challenging and we expect that a spin-off project will be desired among the SUCCESS partners in the coming years. In addition, some activities in STEMM-CCS might be related to this and we should try to collaborate.

In addition, there was a fruitful discussion between STEMM-CCS (H2020) and CCS LEAD (Gassnova pre-project led by NGI), whose intention was to initiate a good collaboration between the two projects.

Other activities have been revised in order to take into account the budget situation. For example, we will focus, first, on the Skade case study and see the progress. The Smeaheia case study will be done later and is expected to be minimized Finally, it is planned to deliver two synthesis reports.

During a workshop in April each institute presented their plans. Industry partner Octio was also involved in the discussion. Several follow-up meetings have been staged. At the moment, NGI is producing a set of synthetic data of seismic, EM and gravity, which will be inverted by UniCIPR.

SUCCESS wishes you all a sandstone filled with yuletide happiness and a merry new year!

SUCCESS (Subsurface CO_2 Storage – Critical Elements and Superior Strategy) is one of several Norwegian centres for environment-friendly energy research, funded by the Norwegian Research Council and industry partners. For more info and contact address: *www.fme-success.no*.

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