successful news
SUbsurface CO2 storage- Critical Elements and Superior Strategy
Newsletter from the SUCCESS centre – December 2017 – no. 25

FME SUCCESS – the closing

Final conference in March

As the last of the first generation FME centres, SUCCESS is now finalizing its deliverables and coming to an end. The research staff is busy summing up their findings in a series of seven reports.

And everything will be neatly wrapped up March 6–8, 2018 in a final conference held at "Gamle Museet" in the centre of Oslo. Save the dates!

The first day will be a conference on **Future perspectives on CCS**, and will be by invitation only.

The second day will be the **SUCCESS Centre day**; a semi-open presentation summing up the main findings in our Centre – injectivity, capacity, monitoring and more. All current partners, former industry partners, PhDs, postdocs as well as researchers involved throughout the eight year period are welcome to join us on this day. More info will follow regarding tentative program and registration etc.

The third day will be a closed session where the industry and research partners in SUCCESS will focus on **further cooperation** in the CCS field.

We wish you all a pleasant holiday season and a SUCCESSful new year.

And don't let this CO_2 calculation discourage you from making someone special happy:

Of seals and polar bears
– and digital geology in the high Arctic

In early September, four geoscientists from UNIS headed out on a mission to Deltaneset in central Spitsbergen. Their task was simple – to bring the outcrops of the Longyearbyen CO2 lab home with them – as digital outcrops opening up research possibilities with significance well beyond the Svalbard archipelago.

In recent years, advances in photogrammetric software revolutionized the construction of digital outcrop models solely from photographs. In the past, achieving such high resolution and quality required costly Lidar acquisition campaigns, which also often took several months to process. Nowadays, taking a lot of photos is all you need to digitize your outcrops using open-source or commercial 3D modelling software. The photos need to contain sufficient overlap for optimal results – 80 % overlap is a good start – and should preferably be taken with a fixed zoom lens.

We have tested everything from high-end consumer DSLRs to compact cameras and smartphone/tablet cameras, and to our surprise found that the smartphone often works best – high MP cameras typically result in models too large to handle.

Ground-based and drone-based photographs can be merged for processing. In the ideal case, camera locations are known from a built-in GPS though positioning and scale are only important for geometrical measurements of features' orientation and dimensions. Differential GPS of points on the outcrop can provide ground control points where mm-scale precision is required.

What makes such virtual outcrops useful?

For a start, it allows us to share the outcrop with those not fortunate to be able to travel to Deltaneset (or any other remote location for that matter...). It serves as a backup when a field excursion must be cancelled due to weather or polar bear visits, both of which happened to me the last year ...

More importantly, however, it allows us to conduct detailed and quantitative analyses of the outcrop, in contrast to the 2D approach of using solely field photographs. Fracture and fault orientations can be mapped manually or semi-automatically, and fed directly to discrete fracture modelling workflows. Stratigraphic logs can be correlated laterally, especially in areas with steep topography. Key parameters such as sand body dimensions can be extracted.

The project group prior to departure to the field in the Zodiac. From left to right: Paul Lubrano-Lavadera (researcher at UNIS), Peter Betlem (MSc student at UNIS and University of Reykjavik), Tom Birchall (PhD student at UNIS) and Kim Senger (Associate Professor at UNIS). Photo taken by Lilith Kuckero

Such models also serve to define the geometrical framework on which to construct reservoir models or start models for geophysical inversions. Last but not least, the digital outcrop provides a chance for planning the next targeted field campaign.

View eastwards along the slopes of Janusfjellet, illustrating the typical nature of shale-dominated outcrops. Note the people on the ridge for scale. Photo taken by Peter Betlem.

So what did we "scan" at Deltaneset before the dark season descended on us?
Firstly, we focused on the normal faults exposed on the western side of Konusdalen. These occur within the upper part of the Kapp Toscana Group sandstone-siltstone aquifer targeted by the Longyearbyen CO2 lab project, and represent the main evidence for structural compartmentalization of the target aquifer.

This is important, as water injection tests in the CO2 lab well park clearly indicate lack of fluid communication between relatively closely spaced wells. Seismic acquired in Adventdalen does not indicate that such features are present but they could very well be beyond seismic resolution. Paul Lubrano-Lavadera is currently investigating how these features would "look like" on seismic, using the virtual outcrop to define their geometry.

Once done with the reservoir we moved on to the seal – or cap rock as we call it. In Adventdalen we know it is robust – the severe underpressure below it testifies the cap rock integrity – but we also know that cap rocks can fracture and leak following CO2 injection. This is likely to happen along pre-existing zones of weakness such as faults. What do we know about cap rocks though? Very little! Offshore wells rarely core the shale dominated cap rocks due to cost issues, and shales are often poorly preserved in outcrops, especially where faulted.

On Svalbard, however, we are fortunate to have four wells fully penetrating the the Agardhfjellet formation cap rock and relatively good outcrops. One of these is at the informally named Maaykedalen just west of Konusdalen on the north slopes of Janusfjellet. Here we observe several faults cutting the lower part of the cap rock succession, and have generated a digital outcrop model as well. This Paul uses to model a hypothetical scenario in which CO2 migrates along a fault zone and how this impacts seismic imaging.

In addition, the "from outcrop to geomodel" workflow utilized on Svalbard with respect to fractured reservoirs will form the backbone of a presentation by Senger et al on "Characterization and modelling of a naturally fractured reservoir-caprock unit targeted for CO2 storage in Arctic Norway" at the Fourth EAGE Workshop on Rock Physics to be held in Abu Dhabi in mid-November.

And what about the title?
Well, beforewe were looking at the seal in the mountainsides some creative polar bears managed to enter our humble cabin at Deltaneset and make a big mess inside…

Kim Senger

Simulations on new seismic dataset show ...

Influence of CO_2 migration on pressure buildup

The SUCCESS Centre has selected two CO_2 storage locations in the North Sea for its final studies: Smeaheia (a deep, confined reservoir) and Skade (a shallow, saline aquifer). They allow testing of the learnings and knowledge from the Snøhvit and Sleipner field pilots and may potentially confine the range and use of methods and models developed.

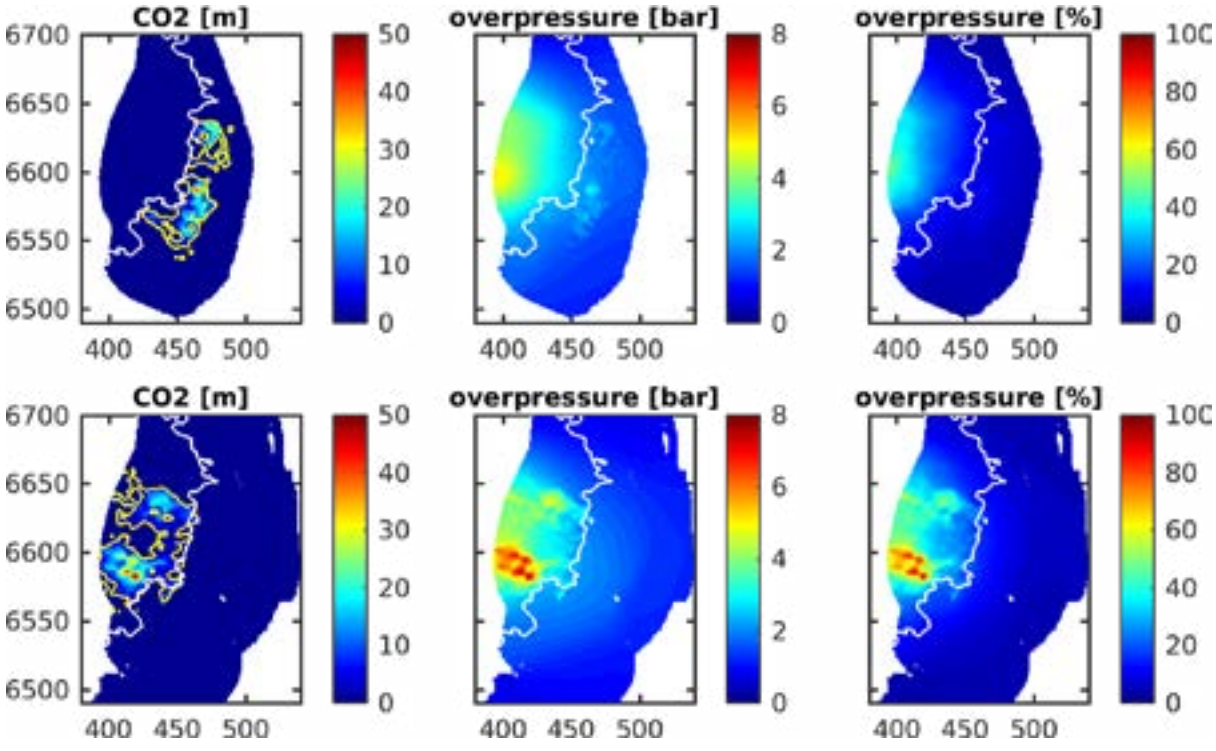
Large North Sea aquifers of high quality are the likely major target for 12 Gt of European CO2 emissions that should be stored in the subsurface until 2050. This involves an upscaling of today's injection rate by more than two orders magnitude, which requires careful examination of the storage feasibility.

Many aquifers are closed or semi-closed, with storage capacity mainly constrained by consideration to failure criteria for the caprock. Because the induced pressure can propagate to sensitive regions far from the injector, the risk of caprock failure must be examined in volumes and for long times.

SUCCESS work on the Skade formation points to the fact that Skade and Utsira are connected in the western extent of the aquifer system (to the west of the white contour in the figure below). The caprock in this region is shallow with low estimated tolerance to overpressure (8 bars).

In addition, as CO2 migrates to this region it transitions from liquid to gas, whereby the volume expands and the pressure is enhanced. This pressure increase together with the buoyancy pressure exerted from gaseous CO2 on the caprock is in some cases the limiting constraint for storage in the aquifer system.

Maria Elenius



Skade (top) and Utsira (bottom) with coordinates in km northing and easting. Left pane) CO2 plume thickness 500 years after CO2 injection in Skade. The extent is marked with a yellow contour. Middle and right panes) Overpressure in Utsira and Skade expressed as bars and as percentage of the allowable overpressure.

Skade facts

- Part of the larger Utsira/Skade aquifer system
- Assessed in NPD Storage Atlas together with Utsira (16 Gt in total storage capacity)
- Relatively shallow (average depth 900 m) and good permeability
- Considered lower leakage risk than Utsira (Skade lies below Utsira)
- Interesting geology, with turbidite layering, but very little is known about the characteristics of heterogeneity

New SUCCESS paper

The Strength of Skade Mudstones

SUCCESS PhD student Mohammad Nooraiepour and co-workers have just published a paper on "Compaction and mechanical strength of Middle Miocene mudstones in the Norwegian North Sea – The major seal for the Skade CO_2 storage reservoir" in *International Journal of Greenhouse Gas Control* (http://dx.doi.org/10.1016/j.ijggc.2017.10.016). We cite the abstract:

This study has investigated petrophysical, acoustic and geomechanical properties of Middle Miocene mudstones in the Norwegian North Sea as the primary caprock for Skade CO2 storage reservoir. To evaluate the seal properties, we analyzed collected drill cuttings and measured well logs from well 16/4-1, in addition to an extensive well log database in the Northern North Sea. The studied caprock was identified as siliceous ooze-rich mudstones with low bulk density, high shear wave velocity, and low Vp/Vs ratio. The abundance of siliceous skeletal material resulted in a significant shift from the overall trend of mudstones within the Hordaland Group. The estimated scenarios for S-wave velocity depicted that the ooze-rich mudstones have the highest brittleness of the Hordaland Group semi-consolidated rocks. The brittleness indices in well 16/4-1 illustrated that the mineralogical composition-based indices significantly overestimate brittleness compared to the elastic-based indices. While the caprock for Skade CO2 storage reservoir showed an overall ductility, the bottom 30 m demonstrated an increased brittleness profile. The more brittle ooze-rich mudstones also indicated the lowest estimation of fracture pressure compared to other scenarios. The research outcomes emphasize on the influence of mudstone type and microstructure on the macroscale physical properties of shallow semi-compacted CO2 caprocks.

Symposium on CO_2–hydrocarbon interactions for CO_2 storage with EOR/EGR

The SIAM Conference on Mathematical and Computational Issues in the Geosciences was staged in Erlangen September 11th. As part of this, a minisymposium was held focusing on two relevant processes, convective mixing and wettability alteration, along with their analytical and numerical solution strategies. Density-driven convective mixing of CO2 in oil increases mixing and alters the oil mobility. Wettability may change dynamically with CO2 exposure, impacting the capacity of the rock to trap CO2. Recent studies have shown compelling results that may have a significant, yet still largely unknown, impact on field-scale fluid flow (recovery) and trapping (storage). Chairing the minisymposium were SUCCESS WP leaders Sarah Gasda and Maria Elenius.

How to store CO_2 subsurface forever

Aftenposten, the largest Norwegian newspaper, carries a regular popular science column "Viten" (Knowledge). On October 24th the topic was CO_2 storage and safety.

Authors were SUCCESS/UiO postdoc Anja Sundal and researcher Odd Andersen of SINTEF Digital. Over one and a half page they explained "how we may store CO2 sub-sea forever". They write:

"Although we now have both the theoretical knowledge and the practical experience with how CO2 may be stored safely, fear of complications is one of the reasons why it has been hard to get a break-through for carbon storage many places in Europe – people just don't like the idea that gas should be injected under the ground where they live, if it is ever so deep. With storage on the Norwegian continental shelf, however, this is a minor problem. Large and suitable storage formations far at sea, in areas already well-mapped, can make the geological formations under the North Sea a well-functioning common storage site for CO2 from industry across Northern Europe – if there is political willingness. Norway's advantageous geology and our long technological experience as an oil and gas nation have contributed to giving geological CO2 storage a high national priority."

Read the full story (in Norwegian) at https://www.aftenposten.no/viten/i/ORkd1/Slik-kan-vi-lagre-CO2-under-havbunnen-for-alltid.

12 Tirsdag 24. oktober 2017 Aftenposten

VITEN GEOLOGI

Berggrunnen under Nordsjøen har et stort potensial som felles lagringssted for CO_2 fra industri i hele Nord-Europa.

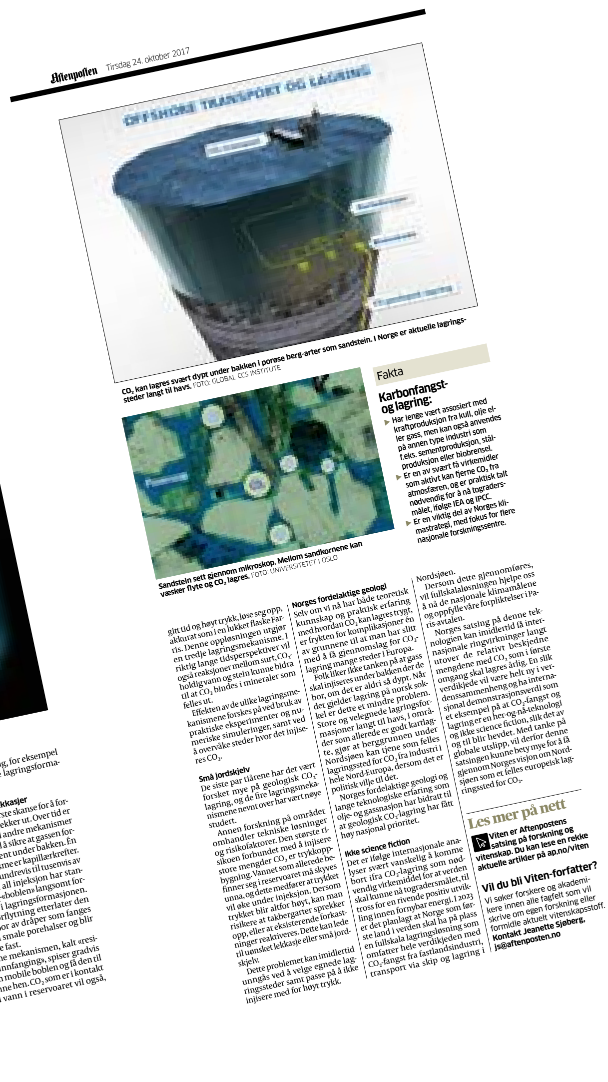
Slik kan vi lagre CO_2 under havbunnen for alltid

På Utsira-høyden i Nordsjøen har Statoil lagret CO_2 i en geologisk sandsteinsformasjon siden 1996. FOTO: OLAV OLSEN

Odd Andersen forsker, Sintef Digital

Anja Sundal geolog og postdoc, Universitetet i Oslo

Geologien i Nordsjøen består i stor grad av sedimentære bergarter som har bygget seg opp over flere hundre millioner år.



Aftenposten Tirsdag 24. oktober 2017

CO_2 kan lagres svært dypt under bakken i porøse berg-arter som sandstein. I Norge er aktuelle lagringssteder langt til havs. FOTO: GLOBAL CCS INSTITUTE

Sandstein sett gjennom mikroskop. Mellom sandkornene kan væsker flyte og CO_2 lagres. FOTO: UNIVERSITETET I OSLO

Fakta

Karbonfangst- og lagring:

- Har lenge vært assosiert med kraftproduksjon fra kull, olje eller gass, men kan også anvendes på annen type industri som f.eks. sementproduksjon, stålproduksjon eller biobrensel.
- Er en av svært få virkemidler som aktivt kan fjerne CO_2 fra atmosfæren, og er praktisk talt nødvendig for å nå togradersmålet, ifølge IEA og IPCC.
- Er en viktig del av Norges klimastrategi, med fokus for flere nasjonale forskningssentre.

Les mer på nett

Viten er Aftenpostens satsing på forskning og vitenskap. Du kan lese en rekke aktuelle artikler på ap.no/viten

Vil du bli Viten-forfatter?

Vi søker forskere og akademikere innen alle fagfelt som vil skrive om egen forskning eller formidle aktuelt vitenskapsstoff. Kontakt Jeanette Sjøberg, js@aftenposten.no

SUCCESSFul coursing

This summer the first suite of High North CCS courses was run in an international collaboration funded by the Norwegian Centre for International Cooperation in Education (SiU).

Communicating the essentials of CO2 capture and storage to the next generations of CCS researchers has been an important part of FME SUCCESS. We have talked to children at the Forskningstorget research fair as well as to students at the universities.

In 2014, the University Centre in Svalbard (UNIS) and University of Oslo, together with Colorado School of Mines, were awarded the project "Carbon Capture and Sequestration in the High North – CCS-HN", with the aim to establish a suite of CCS courses at the three institutions, thus providing exchange of teaching staff, students, and CCS knowledge. The project provides travel grants for student and teacher mobility between Svalbard, Oslo and Colorado.

After some planning (including some failing in realizing the administrative complications of international collaboration) the three courses, at MSc and PhD levels, were held at the host institutions during the summer months of 2017, end of May (Colorado) to first week of July (Svalbard).

Topics of the courses are a general introduction to CCS (Colorado), a basic knowledge to estimate CO2 storage capability (UiO), and geological constraints seen from field sites at Svalbard (UNIS).

Students from eight nations (Indonesia, China, Russia, Germany, Canada, Norway, Netherland, and Pakistan) participated, making this an unforgettable experience for both students and staff.

The course will be held again summer 2018, and we welcome CCS-interested applicants, especially from the High North countries, to apply. PS! **Deadline** for hospitants to University of Oslo is **January 3rd**, so if you are interested, please contact us for more information soon.

Please contact Helge Hellevang (*helge.hellevang@geo.uio.no*),

From the 2017 summer course at UNIS. Svalbard offers fantastic insight into the geological framework of CO2 storage sites, reservoir and seal.

Master project

Field work in Californian hills

Read more details on www.fme-success.no

Iselin Tjensvold is currently a Master student – supervised by Christian Hermanrud (Prof II position financed by FME SUCCESS at UiB). In her Master thesis she is exploring the possibility of categorizing sand injectites based on the basin setting they occur.

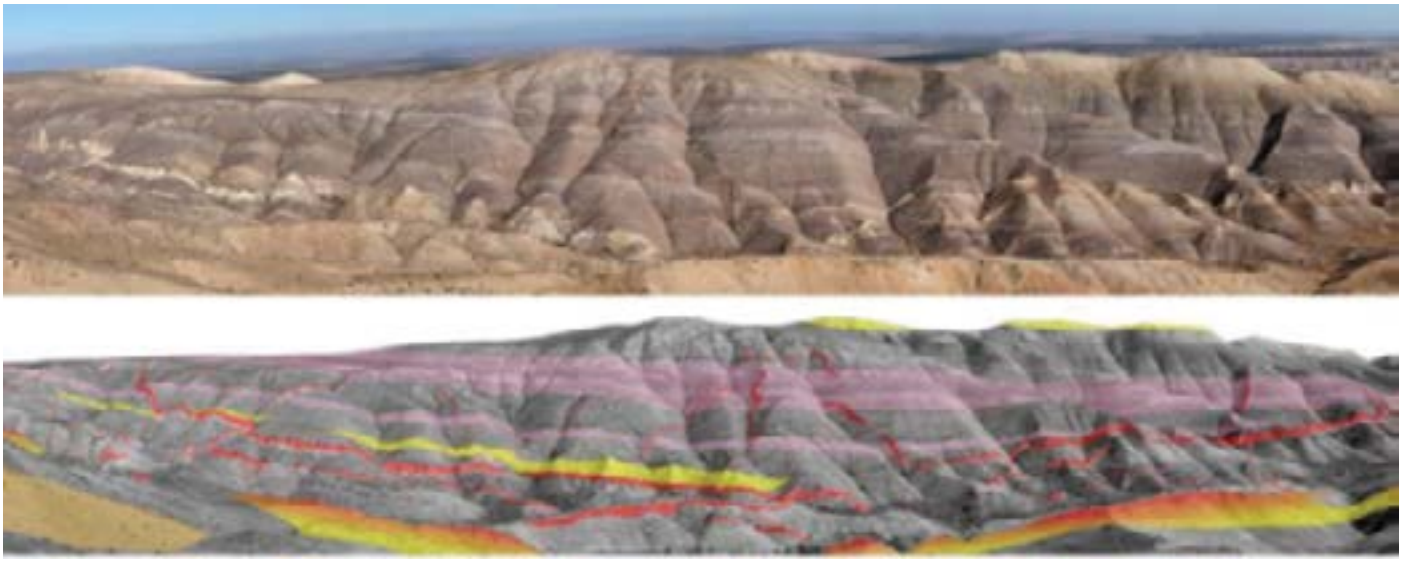
At the University of Bergen, she has access to regional 3D broadband seismic data available (acquired by CGG) from the Northern North Sea. In this dataset she will study sand injectites formed at inverted passive margins.

Iselin was invited as a field assistant for Antonio Grippa (research fellow at The University of Aberdeen, UK) in the Panoche and Tumey Hills september this year. These hills represent one of the best exposed sandstone intrusion networks in the world. Deep water depositional sands were remobilized at a convergent basin setting and hence the observations from this fieldtrip are most relevant and valuable in the context of the link between outcrop and seismic interpretation.

Iselins conclusions from her field trip are:

- Sandstone intrusions create large networks, establishing pressure communication between sand bodies that were not connected originally, and hence new migration routes for gas or fluids are constructed.
- It is important to keep in mind that sandstone intrusions may not only be interconnected to each other, but also other sand bodies which they cross-cut.
- Sandstone intrusions in the Panoche and Tumey Hills formed at the continental margin, and not within the accretionary prism. However, based on observations from Winslow (1983) in Chile, injectites occurring in relation to the compression within the accretionary prism should not be excluded from possible geological settings where sand injectites occur.

Sand injectites in the Right Angle Canyon, California (modified after Hurst and Vigorito (2017).



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*.

To subscribe to this newsletter, please mail *Charlotte.Krafft@cmr.no*.