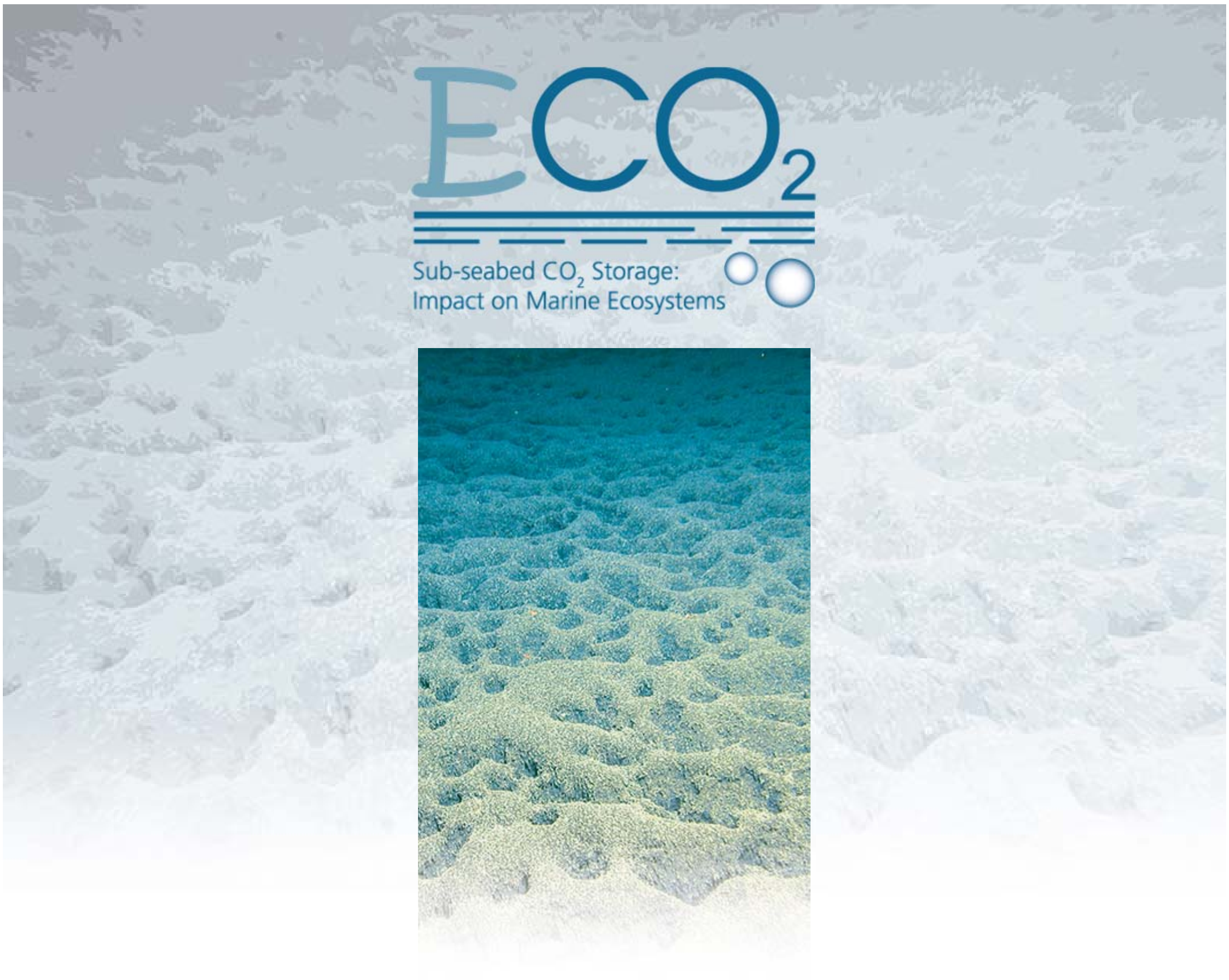

ECO_2 Briefing Paper No. 1

The Scientific Basis for Offshore CCS

April 2012

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Introduction

by Klaus Wallmann and Anja Reitz, GEOMAR, Germany

Seeing that we are concluding the first year of ECO_2 activities, we would like to present you this first briefing paper focusing on fieldwork activities carried out. ECO_2 – *Sub-seabed CO_2 storage: Impact on Marine Ecosystems* is one of three closely linked large scale integrating collaborative research projects within the FP7 work program 'The Ocean of Tomorrow'. The aim of the ECO_2 project is to establish a framework of best environmental practices to guide the management of offshore CO_2 injection and storage. The project thus actively contributes to the implementation of the EU directive on "Geological Storage of CO_2" for the marine realm. ECO_2 focuses on the quantitative assessment of potential and actual impacts on marine ecosystems at CO_2 injection facilities and the entire storage site. A comprehensive monitoring concept for storage sites will be developed comprising innovative techniques that are apt to detect different modes and levels of leakage including that of pre-cursors. Field studies at operated and prospective sites (Sleipner, Snøhvit, B3 field) will be supported and complemented by laboratory experiments and numerical simulations on different scales at natural CO_2 seeps (North Sea, Mediterranean Sea). An integral part of the project is to transfer this knowledge into an environmental risk management concept and an economic evaluation of the costs of leakage, monitoring, mitigation measures, and a clear communication framework. An understanding of the precautionary principle as a primary tool for balancing the environmental risks will be developed.

The results of the ECO_2 project will flow into a policy stakeholder dialogue process, with the aim of providing key stakeholders with the sound scientific knowledge necessary to facilitate decision-making for offshore CCS. This process will involve a number of meetings with an appointed Stakeholder Dialogue Board as well as the publication of scientific briefing papers which will be presented to policymaking communities at the EU and other relevant levels during workshops held in Brussels.

This ECO_2 briefing paper summarizes the key research work completed in the first year of the project, focusing on the results of first research cruises.

Sleipner – CCS Storage below the North Sea

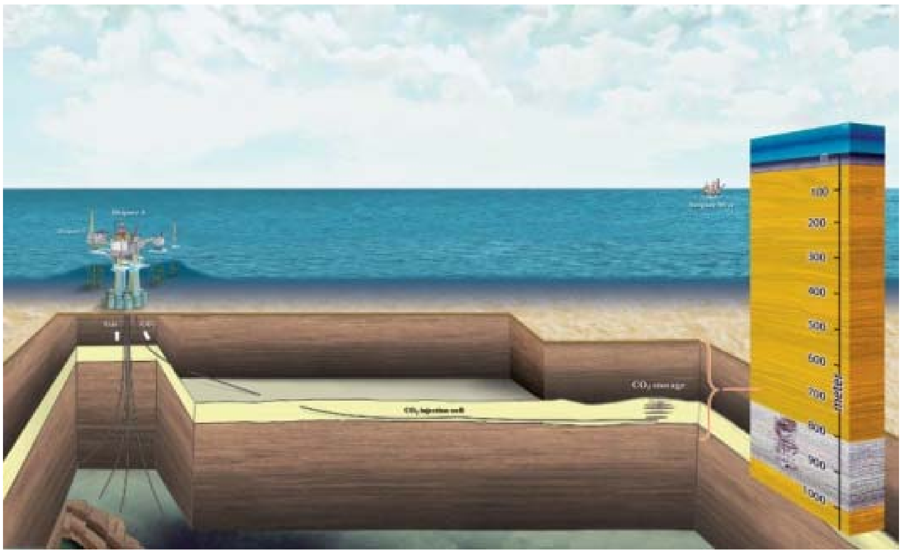

Figure 1: A schematic overview of the Sleipner area (© Statoil)

The Statoil-operated Sleipner Vest gas and condensate field contains around 9% CO_2, which exceeds customer requirements. An offshore CO_2 tax was introduced by the Norwegian government in 1991, and is currently around USD 60 per ton. As a response to this, Statoil and partners decided on removing the CO_2 and injecting it into a deep geological layer beneath the Sleipner A platform. CO_2 capture on Sleipner uses a conventional amine process, made compact for installation on a platform. Sleipner brought the world's first offshore CO_2 capture plant into operation in October 1996. This solution has cut CO_2 emissions by almost a million tons per year. That corresponds to roughly 3% of Norway's CO_2 emissions.

The Utsira formation, which consists of brine-filled sandstones 800 - 1100 metres beneath the sea surface, was selected as the storage reservoir. The unconsolidated sand succession in the Utsira formation is interbedded in the Sleipner area with thin (<1 m) shale stringers and has a net-to-gross ratio of 95%. The sand is highly porous (35-40%) and permeable (above 1 Darcy). An overlying gas-tight cap rock, consisting mainly of shale up to the seafloor at 82 m depth, prevents the CO_2 from leaking.

A deviated injection well has been drilled about 2.4 km east of the platform, under a local gentle dome. CO_2 is at the phase boundary between gas and liquid at the well head, and is pressurized into supercritical conditions at the well bottom perforation and in the reservoir. Injection has occurred with high regularity, with major interruptions only during the typically ≈4-week work-over periods of the platform every second year. By March 2012, 13.3 million tons of CO_2 had been injected.

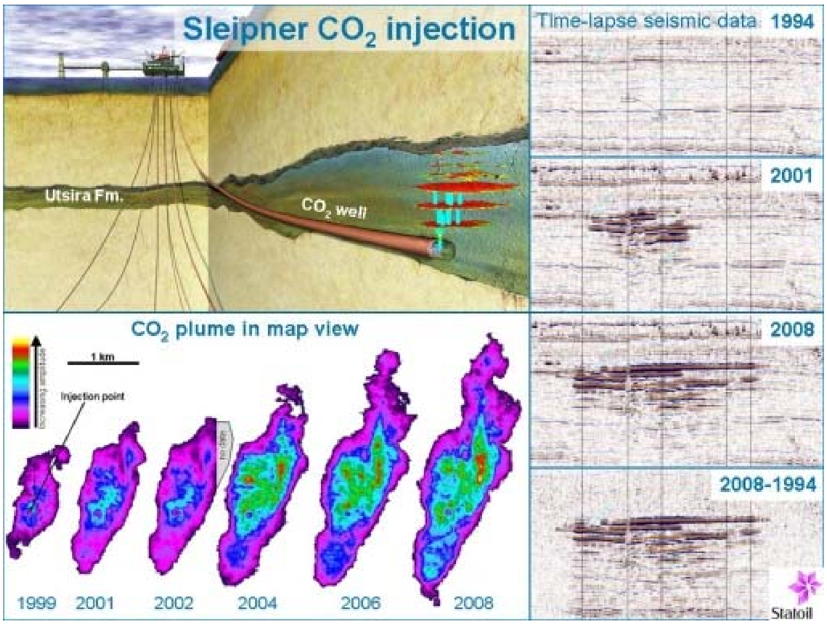

Figure 2: Schematic view of Sleipner inject site and CO2 plume development (© Statoil)

Seven repeat 3D seismic surveys have been acquired, giving a unique set of monitoring data. The CO_2 plume yields highly reflective layers, with an area that had grown to 3.6 km^2 by 2010. No leakage to levels above the Utsira formation has been observed by inspection of time-lapse difference seismic sections. High data repeatability gives a leakage detection threshold as low as a few Kt of CO_2.

High-precision seafloor gravity measurements show a decrease due to CO_2 pushing away denser water. When combining this with recent temperature measurements, one has calculated the maximum amount of CO_2 that has been absorbed in the formation water has been calculated to be 1.8 % per year.

Detailed interpretation and flow modelling for matching and prediction purposes has been a challenge on Sleipner. Strong gravitational segregation causes CO_2 to flow upward in the reservoir with the plume shape resembling the top reservoir topography. 4D seismic images suggest pressures are only marginally above hydrostatic. The injected CO_2 flows in nine distinct high-saturation layers not more than a few meters thick, capped by thin intra-sand shales above.

The seafloor has been mapped with multibeam echo sounding and side-scan sonar. Videos have been taken by ROV, as a routine precaution, and as expected no seafloor changes (pockmarks, bubbles) have been observed.

ALKOR 374 – The First ECO2 Cruise

by Peter Linke, GEOMAR, Germany

ALKOR cruise 374 was the first cruise conducted in the framework of the EU project ECO_2, which sets out to assess the risks and long-term impacts associated with the storage of CO_2 below the seabed. The major working area during this cruise was the industrial CO_2 storage site Sleipner in the Norwegian sector of the North Sea. The objectives of the cruise were to conduct a first survey, validate novel gas monitoring techniques and establish a baseline for upcoming ECO_2 expeditions and experiments.

At Sleipner, abandoned well sites close to the CO_2 injection point in approx. 1000 m sediment depth and the area above the suspected subsurface CO_2 plume were surveyed for any signs of gas seepage. Video-guided sensors to detect methane, carbon dioxide, and pH were deployed and bottom water was pumped directly into a mass spectrometer on board the ship for analysis (Figure 3). Additionally, sediment samples were taken at Sleipner for geochemical analysis and physiological experiments on selected macrofauna back onshore. Finally, benthic landers were placed on the seabed above the central injection point to record the current regime and to investigate the natural oxygen consumption and carbon dioxide production by the shallow sub-seabed ecosystem (Figure 4). So far, no sign of CO_2 emission was found in the surveyed area and the measured CO_2 concentration are in the range of the natural variability of CO_2 in the bottom water of the North Sea.

In a following cruise with the Irish RV CELTIC EXPLORER in July/August 2012 the survey area will be extended to include areas where factures and acoustic chimneys have been detected in the 3D-seismic records. In these areas, detailed sampling of pore waters in the overburden of the Utsira formation and experiments on the near field dispersion of a gas plume will be conducted combined with a model approach.

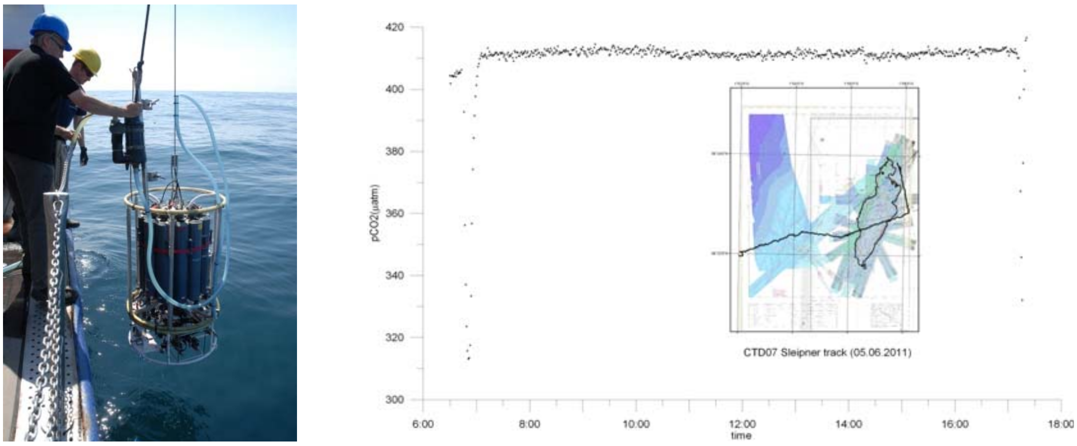

Figure 3: Video-guided pump CTD track over the Sleipner CO_2 storage complex with the record of the CO_2 sensor. The bottom track crosses abandoned wells and the suspected subsurface CO_2 plume with no sign of CO_2 emission (© photo and image: GEOMAR, small map: Statoil).

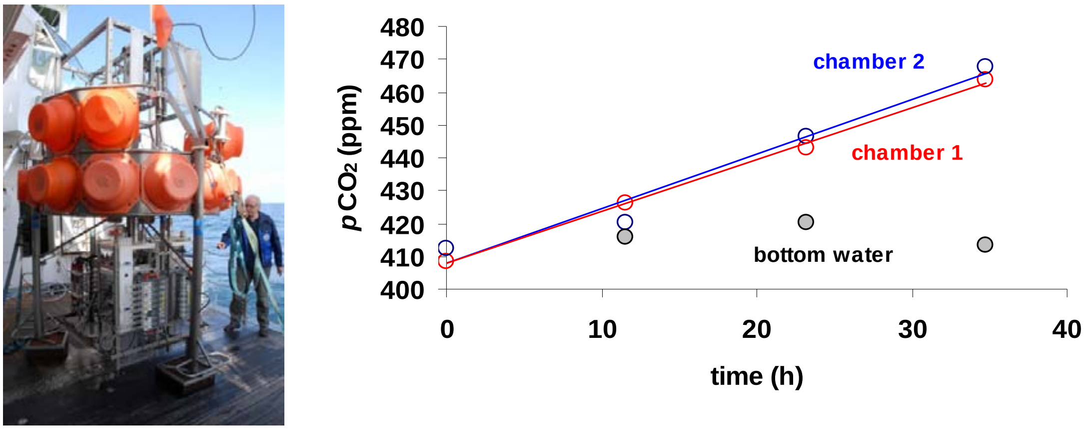

Figure 4: Video-guided deployment of a benthic chamber lander. The pCO_2 increase inside the two benthic chambers in comparison to bottom water pCO_2 reflects the background CO_2 production due to benthic respiration (© photo and image: GEOMAR)

Mapping the Sleipner Area – Cruise CGB-ECO2-2011B

by Tamara Baumberger and Rolf-Birger Pedersen, University of Bergen, Norway

On the nine-day long CGB/UiB (Center for Geobiology/University of Bergen) cruise to the Sleipner area in the North Sea in June 2011, the research vessel R/V G.O. Sars was equipped with an autonomous underwater vehicle (AUV) and a remotely operated vehicle (ROV) as well as equipment for sediment sampling. The main objectives for this cruise was to collect information about the cap rock integrity above the sub-seafloor CO_2 plume as well as to search for seabed fluid flow features. A further task was to image the water column above the three abandoned wells and the CO_2 plume as well as sampling gas, sediments and bacterial mats in the area of the abandoned wells.

Multibeam, single beam and synthetic aperture sonar (SAS) as well as a photo camera were used for detailed mapping and imaging of the seafloor above the sub-seafloor CO_2 plume and transects out from the plume area. Images obtained by the SAS system attached to the AUV showed several shell-rich areas in the seabed above the CO_2 plume. Pipelines and other anthropogenic features were easily recognized (see Figure 5). No indications for seabed gas escapes above the sub-seafloor CO_2 plume area were found.

Additionally, the extended area around the abandoned wells was investigated using different mapping, imaging and sampling techniques. Along all three abandoned wells gas was seeping up to the seafloor. Extensive formation of microbial mats was visible in a very short distance from these wells. Gas was sampled from all three locations. Shipboard gas analyses showed that methane is the major component of the seeping gas. A digital camera mounted under the ROV was used to picture microbial mat formations of one of the abandoned wells in detail. Individual photographs were put together resulting in a detailed high-resolution photo mosaic that describes size, shape and gas leakage spots of the microbial mats. This survey technique can be used to register whether gas leakages and microbial mat structures or sizes are changing over time.

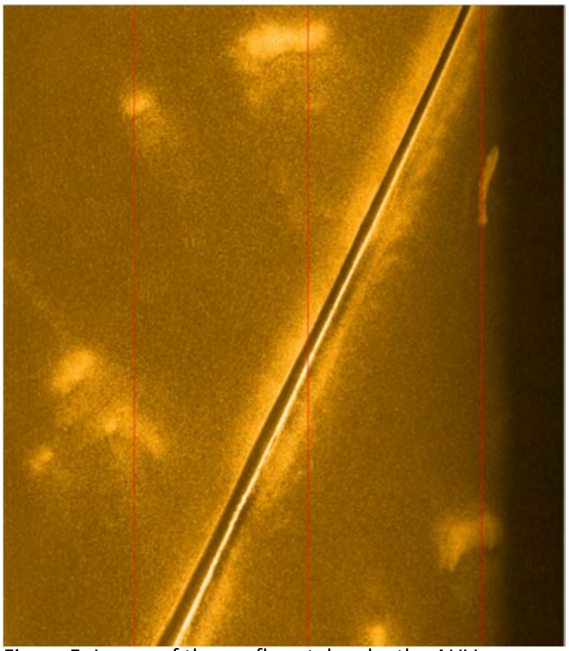

Figure 5: Image of the seafloor taken by the AUV sonar showing a pipeline in the Sleipner area (© University of Bergen)

One of the abandoned wells located close to the rim of the sub-seafloor CO_2 plume was sampled in more detail for a variety of analyses on fluids, microbial mats, microbial rate measurements and sediments within geochemistry, macrobiology and microbiology. The analyses are currently ongoing in the shore-based laboratories at CGB and the Department of Earth Science at the University of Bergen.

Future work of the CGB/UiB will concentrate on finalizing the shore-based analysis of the obtained geochemical, geobiological and biological samples from the Sleipner area and the subsequent interpretation of this compelling data set. Furthermore, focus will be laid on the description of AUV-related survey techniques as an instrumental tool for long-term surveys of seabed evolutions. A UiB-funded follow-up cruise will revisit the Sleipner area in summer 2012 and concentrate on seafloor mapping and visual and geochemical imaging using sophisticated oceanographic tools.

Snøhvit – The world's first gas liquefaction plant with CCS

The Snøhvit gas field in the Barents Sea is the world's first gas liquefaction plant with CCS. Statoil is the operator and CO_2 injection started 2008. The hydrocarbon gas contains 5-8 % CO_2. This development combines subsea wellheads and templates at 320 m water depth with a 145-kilometre multiphase-flow pipeline running to an onshore gas liquefaction plant. A conventional amine process is used for CO_2 capture, after which a second 145-kilometre pipeline returns the CO_2 to Snøhvit, via a seafloor template and a near-vertical well.

The CO_2 is injected into Tubåen formation, which lies about 2650 m beneath the sea surface, below

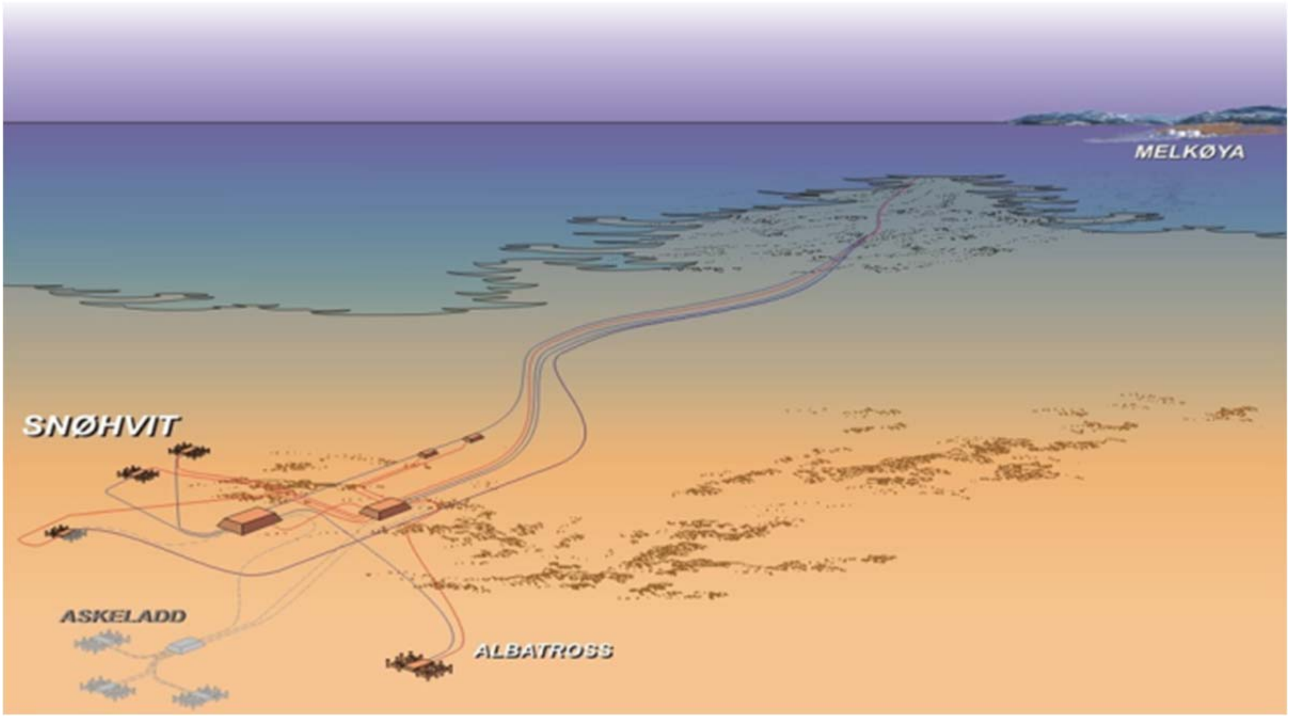

Figure 6: Snøhvit field overview (© Statoil)

brine-filled fluvial sandstones with typically 12-15 % porosity. The permeability is > 500 milliDarcy, but the lateral extent of such good sands is uncertain. The formation is up to 110 m thick and contains several shale intervals; vertical communication throughout the reservoir is limited. The injection well is situated in a faulted block which is open in one end. The cap rock succession above the Snøhvit reservoir is thicker and more consolidated than at Sleipner, with alternating shale and sandstones.

The Tubåen formation within the fault blocks comprising the Snøhvit field is estimated to contain a pore volume of about 1 billion m^3 with further possible communication to neighbouring down-faulted blocks (see Figure 7). Up to April 2011 more than 1 Mt of CO_2 have been stored in the Tubåen formation. Performance has been continuously monitored by on-line down-hole pressures and temperatures measurements 800 m above the reservoir in the injection well, and by two repeat 4D seismic surveys.

There was a clear trend of pressure increase over the 3 years of injection history in the Tubåen formation. This indicates moderate effective permeability, which could be caused by either sedimentary, tectonic or diagenetic features. The spatial variability of the 4D seismic amplitude pattern suggests that lateral heterogeneities play an important role for the lateral outflow of CO_2 from the injection well.

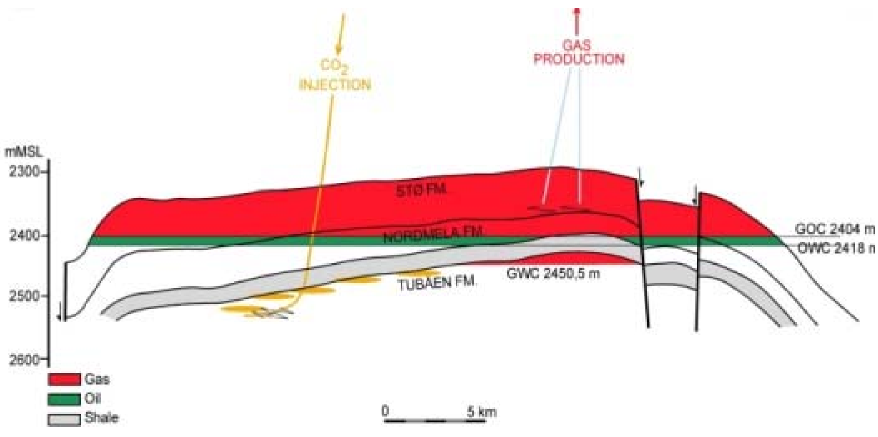

Figure 7: Snøhvit field cross section (© Statoil)

Estimated fracture pressure has not been exceeded – with a safe margin. It was decided to stop injection into the Tubåen Fm. in April 2011, and injection commenced in the overlying Stø formation, in the downflank water zone of the gas reservoir, and at significantly lower pressures. The 4D seismic data is of sufficient quality to assess with high confidence that there is no leakage into the overburden.

R/V Helmer Hanssen cruise to Snøhvit field

by Stefan Bünz, University of Tromsø, Norway

In July 2011, the University of Tromsø conducted a one-week research cruise to the Snøhvit reservoir and CO_2 storage area using their research vessel R/V Helmer Hanssen. The main objectives of the cruise were to acquire novel high-resolution seismic data in order to:

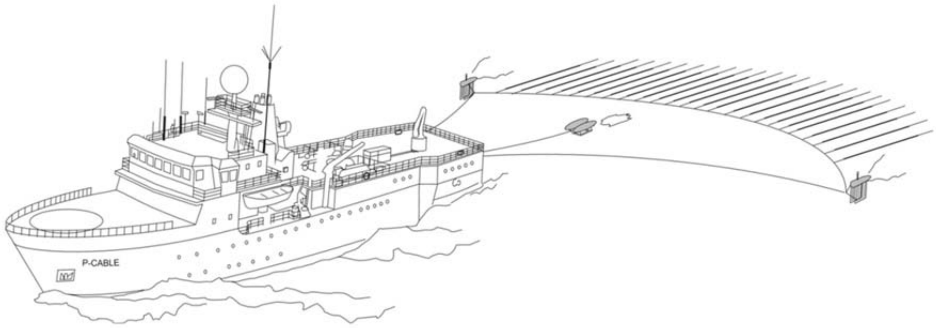

Figure 8: Schematic diagram of P-Cable 3D seismic system (© University of Tromsø)

- characterize sub-seafloor architecture and identify potential seafloor and sub-seafloor leakage systems and fluid accumulations;
- better understand potential leakage mechanisms in the Snøhvit area;
- establish new high-resolution 3D seismic technology as a major tool for leakage detection and monitoring.

The newly developed P-Cable high-resolution 3D seismic technology was employed for the first time in CO_2 storage baseline and monitoring efforts. The P-Cable system represents a high-resolution 3D seismic imaging tool, which consists of a cable towed perpendicularly to the ship's steaming direction, a so-called cross-cable that is spread behind the vessel by two large trawl doors (Figure 8). Up to 24 multi-channel streamers with a length of 25 m are attached to the cross cable. The array of single-channel streamers acquire 24 seismic lines simultaneously, thus covering an approx. 240 m wide swath with close in-line spacing in a cost efficient way. GPS antennas are mounted on both the gun float and the trawl doors to ensure accurate navigation with uncertainties of less than a meter. The spatial resolution of such a system is at least one order of magnitude higher than conventional 3D seismic, whereas the temporal resolution is improved 3-5 times. The increases in resolution facilitate a much better target identification and achieve a much more accurate imaging of, for example, shallow subsurface structures and fluid flow systems. In addition to the 3D seismic imaging, we used ocean-bottom seismometers (OBS) to acquire information of the full

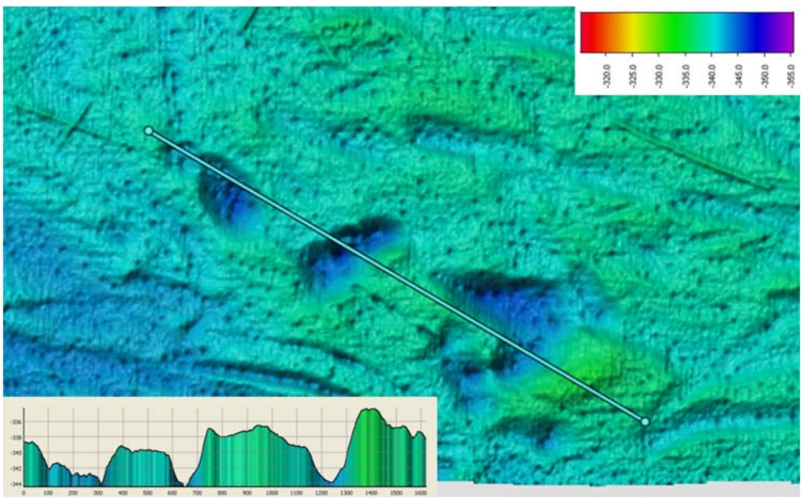

Figure 9: Two classes of pockmarks occur over parts of the Snøhvit field and are indicators of former fluid expulsion at the seafloor. Few large pockmarks have diameters of several hundreds of meters and are up to 10 m deep. Whereas several thousands of smaller pockmarks are up to 20 m wide and up to 1 m deep (© University of Tromsø).

wave field that will enable a better characterization of sub-seafloor sediments, better imaging through gas-charged strata or targets of poor p-wave reflectivity, better discrimination of pore fluids, and an enhanced ability to estimate fluid and gas-hydrate concentrations. The OBS data will be important for distinguishing fluid content and calibration of the high-resolution 3D seismic data. High-resolution seafloor maps were generated from multibeam data acquired during the 3D seismic survey.

Two small-sized 3D seismic cubes of 16 km^2 were acquired over two areas covering the Snøhvit reservoir. These areas show indications of leakage from deeper strata on conventional 3D seismic data. The P-Cable 3D seismic data allows building a link to shallow fluid migration processes and potential expulsion at the seafloor. The seafloor in one of the areas is characterized by pockmarks indicative of recent or former expulsion of fluids (Figure 9). Two pockmark classes can be identified: large ones that are several hundreds of meters in diameter, and small ones that are less than 20 m in diameter. The origin of these two pockmark classes does not seem to be related as small pockmarks commonly occur within large pockmarks, thus they are younger than their large counterparts. Water-column hydro-acoustic systems were active during the whole survey but did not show any signs of active leakage of gas from seafloor sediments over these pockmark areas. The interpretation of the new high-resolution 3D seismic data and the OBS data is underway and will help to better understand the origin of these pockmarks and their link to sub-surface fluid flow. Also, a repeat seismic survey in 2013 will help document any changes to these pockmarks systems, and hence, their role for recent and future fluid expulsion. Thus, P-Cable 3D seismics and high-resolution bathymetric systems could represent important and novel monitoring techniques for shallow leakage systems at CO_2 storage sites.

Natural Analogues – Examples in Nature

The fieldwork conducted at storage sites as described above will be supported by modelling and experiments conducted at natural CO_2 seep sites.

These “natural analogues” are useful as study sites to better understand CO_2 seepage and its impacts as well as to test new procedures and technologies.

Throughout the duration of the ECO_2 project, four sites will be investigated, of which two are presented in this briefing paper:

- **Panarea area** (Southern Tyrrhenian Sea) - is part of the Aeolian Arc north of Sicily; it is a submarine exhalative field located east of Panarea Island. The gas vents are aligned along tectonic features and emit CO_2 originating from degassing magma.
- **Southern Okinawa Trough** (NE off Taiwan) - is a back arc basin hosting several hydrothermal fields. Three of these seeps emanate liquid CO_2 droplets at a water depth of 1300 m and CO_2-hydrates form in the surface sediments.
- **Jan Mayen Vent Field** (North Atlantic) - is situated on the Western Jan Mayen Fracture Zone in ≈700 m water depth; its hydrothermal fluids are characterized by high carbon dioxide but low methane and hydrogen concentrations.
- **Salt Dome Juist** (Southern North Sea) - is located in the southern German North Sea in 30 m water depth above the Salt Dome Juist; it is a sedimentary seep where CO_2 levels are ≈10-20 times above background values.

PANAREA – The ECO2-2 Cruise

by Stefanie Grünke, Max Planck Institute for Marine Microbiology, Germany

Panarea Island is located north of Sicily in the Southern Tyrrhenian Sea. It is part of the Aeolian Archipelago, which is influenced by the active volcano Stromboli. Fumarolic activities and submarine gas seeps are common features around Panarea and have been known to occur in this area since ancient times (Aliani *et al.*, 2010; Caramanna *et al.*, 2011). The released gas is mainly composed of carbon dioxide (CO_2), but may also contain traces of hydrogen sulphide and methane. Based on the long-term seepage activity around the island, the high CO_2 content of the released gases and the shallow water depth, Panarea Island represents an excellent natural laboratory for investigating the effects of CO_2 leakage and ocean acidification on benthic organisms and marine ecosystems (Caramanna *et al.*, 2011).

In summer 2011, scientists of the Max-Planck-Institute for Marine Microbiology's HGF-MPG Joint Research Group (Germany) and the HYDRA Institute for Marine Sciences (Elba, Italy) conducted a first survey on submarine gas seeps around Panarea. The aim was to identify suitable sampling sites with respect to investigating the effects of long-term CO_2 leakage on benthic bacterial and meiofaunal communities (cooperation with University of Ghent, Belgium) as well as measuring gas fluxes at the seafloor. Out of 11 initially sites visited, only three sites located between 15-20 m water depths were selected for further investigations (Figure 10). Two of the sites represented cold CO_2 seeps, where the released gas was composed of more than 90% CO_2 and was free of sulphide and methane. A reduction in pH levels was measured both in the water column (0.1-0.3 pH units) as well as within the upper 5 cm of sediment (1.2-1.3 pH units) as compared to the reference site, which was not impacted by CO_2 leakage (seawater pH 8.1; sediment pH 7.8). High-resolution fingerprinting with ARISA (Automated Ribosomal Intergenic Spacer Analysis) revealed that the benthic bacterial communities at the two CO_2-vented sites were distinctly different from those at the reference site, indicating the presence of microbes specifically adapted to this high CO_2-low pH environment. Similar results were obtained for meiofaunal communities. While the reference site comprised a typical sandy sediment nematode community, the two gas sites were distinctly different and showed an unusually high dominance of organisms belonging to the genus *Microlaimus,* an early colonizer of disturbed sediments.

a) 

b) 

c) 

Figure 10: Sampling sites off Panarea Island: a,b) gas-impacted sites, c) reference site without CO_2 leakage (© HYDRA).

Future analyses will now focus on the identification of specific organisms adapted to this high CO_2-low pH environment. Furthermore, transplantation experiments with sandy sediment and hard substrates will contribute to identifying short- and mid-term effects of CO_2 leakage on benthic organisms and their function. Gas flux analyses will be carried out in more detail to specify the CO_2 levels causing a shift in benthic community structure, and scientists will compare different sensors for pCO_2 and pH to set up a strategy for efficient environmental monitoring.

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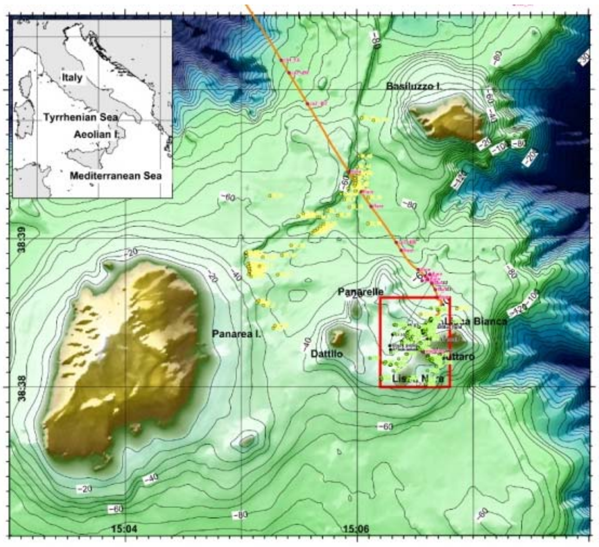
PANAREA – The PaCO2 Cruise

by Daniel McGinnis, University of Southern Denmark



discovered flare fields – shown as pink and yellow dots (© PaCO2 cruise).

The natural CO_2 gas seeps that occur in the shallow waters near Panarea Island (Aeolian Islands, Italy) were studied as a large-scale, real-world analogue of ocean floor CO_2 seepage. The oceanographic survey was performed aboard RV Urania U10/2011 from 27 July – 01 August 2011 (Naples – Naples) whose mission was to investigate the seepage sites and explore the effectiveness of various and novel technologies for the detection and quantification of CO_2 seepage. The project's ship time was funded by Eurofleets (PaCO_2), with work being performed within the scope and with joint funding provided by the EU project ECO_2.

During the mission, RV Urania explored previously mapped seeps at Panarea and searched for new seepage areas in deeper waters off the Panarea Plateau. Seeps were detected using a combination of seismic and acoustic data acquisition, as well as online and continuous dissolved and atmospheric methane and CO_2 measurements. Focus was placed on evaluating hydro-acoustic techniques for CO_2 seepage location, for example the novel R2Sonic multibeam for water column flare (gas bubble) imaging. The R2Sonic allowed to obtain spectacular acoustic images of bubble-plumes rising in the water column (Figure 12). The combination of these techniques led to the important discovery and subsequent mapping of extensive and previously unpublished gas seepage fields surrounding the Panarea Plateau (Figure 11).

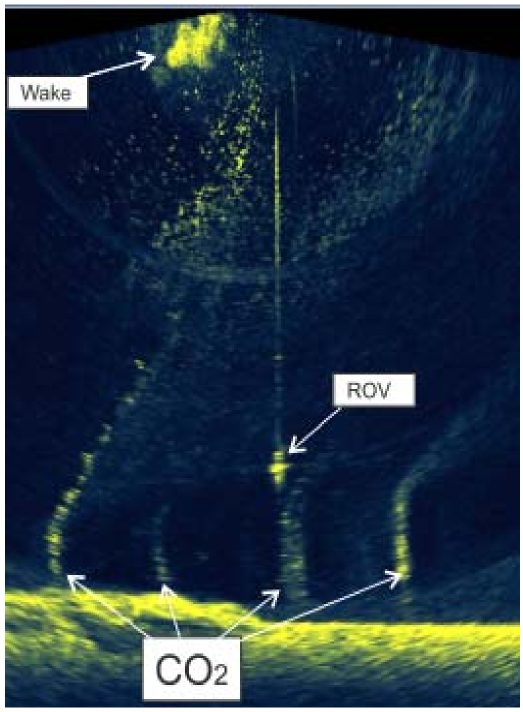


Figure 12: Water column imaging data recorded at Panarea (Italy) showing four natural CO2 bubble streams released at 24 m depth. The ROV appears in the center beam together with its connecting umbilical, and the vessel induced bubble wake plots close to the sea surface. Currents deflect the bubbles to the right (© PaCO2 cruise).

Besides remote detection, experimental in situ work was conducted to test the novel Eddy Correlation (EC) method to quantify the gas and fluid flux rates from bubbling seepage sites. The

EC lander was deployed at the bubble-seep location Bottaro (Figure 13) and consisted of an Acoustic Doppler Velocity (ADV) meter and fast-responding oxygen and temperature sensors. The processed data will allow us to determine the turbulence and 3-dimensional velocity within the seepage area, as well as nearly real-time heat and dissolved oxygen fluxes at the sediment-water interface. Surprisingly, preliminary results indicate dissolved oxygen fluxes approaching -150 mmol/m^2/day, despite being located on a rocky seafloor. Measured heat fluxes in most cases mirrored oxygen fluxes at the Bottaro site, suggesting that heated fluid containing reduced substances was seeping from the sea floor along with the bubbles.

In addition to the remote surveying approach and in situ technologies described here, many additional interdisciplinary measurements were performed at the Panarea seepage site. These combined results will further investigate the biological impact of CO_2 seepage. Furthermore, the data collected will be used to calibrate and validate several plume and bubble models, which will be used to predict the transport and fate of released CO_2 and associated constituents.

The international team of scientists onboard R/V Urania performed complementary sampling and measurements for biological, chemical and physical parameters throughout the area to quantify the spread and impact of the released CO_2.

Figure 13: Aquatic Eddy Correlation lander deployed at Bottaro site (© PaCO2 cruise).

Jan Mayen Vent Fields – Cruise CGB-ECO2-2011A

by Tamara Baumberger and Rolf-Birger Pedersen, University of Bergen, Norway

The Jan Mayen vent fields are located at the southern end of the Mohns Ridge, close to the Jan Mayen Fracture Zone. These vent fields host two major venting areas: Soria Moria at 700 m water depth and Trollveggen at 550 m water depth. The venting chimneys release hydrothermal fluids of up to 270°C. These fluids emitted at the seafloor are characterized by high CO_2, but low CH_4 and H_2 contents and are thus providing information on CO_2 seepage at a natural analogue.

In June 2011, a two week long oceanographic expedition to the Jan Mayen vent fields was conducted by the CGB/UiB (Center for Geobiology/University of Bergen) on the research vessel R/V G.O. Sars.

The main objectives of this expedition were to:

1. test and improve procedures and techniques for seabed mapping and imaging;
2. test and improve bubble plume detection and imaging techniques;
3. constrain the CO_2 content of the gas emitted, to study both potential hydrate formation and CO_2 dispersion in the water column and its effect on the environment.

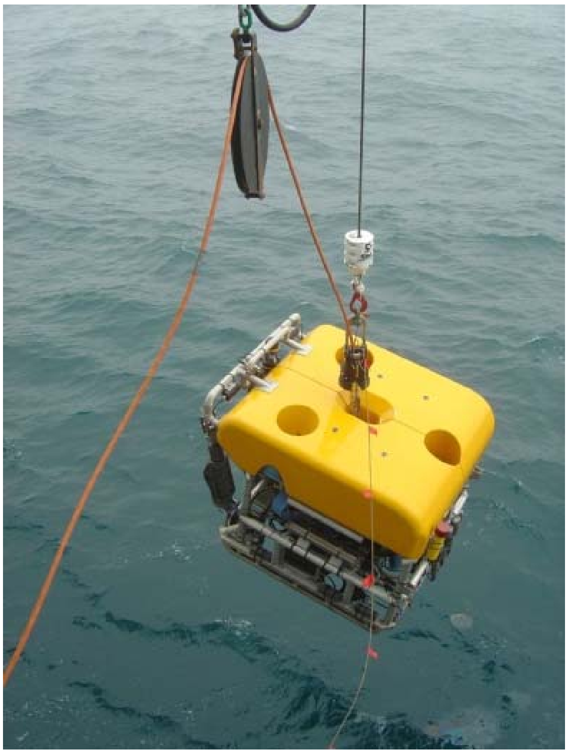


Figure 14: Launching the ROV to dive at the Jan Mayen vent fields (© University of Bergen)

Different approaches were chosen to test and improve seabed mapping and imaging. Bathymetric data was obtained by using the hull-mounted multibeam echo sounder. Thereby, it was possible to efficiently detect bubble plumes in the water column. Subsequently, an autonomous underwater vehicle (AUV) equipped with a synthetic aperture sonar (SAS) system and a photo camera was used to map and image the hydrothermal venting area in detail. The detected bubbles were further characterized by a single beam echo sounder system. At several sites within the venting areas, gas, fluid and sediment samples for further analysis of element and isotope compositions in shore-based laboratories were harvested using a remotely operated vehicle (ROV) (see Figures 14 and 15). In addition, the ROV obtained samples for benthic fauna analyses. Several CTD deployments were performed within the hydrothermal plume area as well as in background seawater. These water samples were analysed shipboard for dissolved gases, nutrients, pH and alkalinity.

Figure 15: Collecting CO_2 bubbles from one of the Jan Mayen vent fields (© University of Bergen)

To date, shore-based analyses of the obtained material are ongoing. A follow-up cruise to the Jan Mayen vent fields is going to happen in summer 2012. This expedition will concentrate on obtaining further data of the CO_2-dispersion in the water column, as well as on further development of techniques to quantify the CO_2 release from the seafloor. Special attention will also be paid to environmental effects of seeping CO_2 at natural analogues.

Monitoring Strategies and Technologies

by Dominique Durand, NIVA, Norway

One of the key tasks of the ECO_2 Project will be to develop guidelines for innovative and cost-effective monitoring strategies to detect and quantify potential leakage of CO_2 from storage sites and its effects on the marine ecosystems. Soon after the project kick-off, a workshop was held in Kiel on May 19, 2011 to provide ECO_2 internal recommendations on the technologies and monitoring strategies to be implemented and tested as part of the project. Specific contributions that ECO_2 will implement, include:

- Geophysical and hydro-acoustic monitoring techniques;
- Geochemical monitoring techniques;
- Hydrochemical techniques;
- Novel high-end biology-based technologies; and

- Novel concepts for the monitoring of methane and toxic trace elements.

At the Kiel workshop, the consortium agreed on a number of areas of focus for the project:

1. Monitoring has a key role in the implementation of CCS and especially CO_2 storage, as it would aim at detecting and quantifying potential leakage and/or seepage of CO_2. Monitoring should also provide the necessary background data for assessing the impact of seepage at the seafloor on both benthic and pelagic marine environments. Through monitoring, one must also ensure that the environmental data required for simulating CO_2 chemical behaviour, migration and impact would be gathered in a way (sampling) that fulfils the needs of the various modelling tools to be integrated in ECO_2.
2. The monitoring effort related to CO_2 storage is essentially multi-disciplinary, with relevant contributions from, among others, geomechanics, fluid migration in porous media, geochemistry, biogeochemistry, ecotoxicology, modelling, and covering many potentially relevant technologies ranging from large-scale acoustic survey by seismic techniques to gene expression of biological markers.
3. Within ECO_2, a significant challenge lies in our capacity to digest the many scientific results from cruises and in-situ experiments, mostly dedicated to process studies, into guidelines to operators and authorities for long-term monitoring of storage sites.

In addition, a basic set of parameters to be measured by all ECO_2 cruises have been defined and agreed upon. Specifically, two forms have been elaborated jointly as tools to plan cruises and to gather relevant feedbacks after cruises. The information collected through these forms and stored in the central ECO_2 database will be the basis for further definition of monitoring strategies during the course of the project. Finally, a series of recommendations has been proposed in order to help the science leaders in ECO_2 to coordinate their research activities towards the common project goal, which is to produce best practices.

International Collaboration

by Ian Wright, National Oceanography Centre, United Kingdom

In December 2011, visits were organized on behalf of ECO_2 with several Australian CCS research groups (CSIRO in Hobart and Perth, Global CCS Institute in Canberra, and CO_2 Cooperative Research Centre in Canberra) to discuss synergies and collaborations with respect to sub-seabed CO_2 storage impact investigations.

Australian groups are aware of the need to develop an understanding of sub-seafloor storage and the potential associated environmental risk and impact of leakage, and sensors and seafloor and water column deployments. There are opportunities to collaborate with CO_2CRC (especially their university and industry partners) and CSIRO, to progress work around deployments of marine monitoring systems (and even technology demonstration projects) as ECO_2 science progresses its understanding of the crucial physical, chemical and biological processes that are the critical signals of leakage. Sensor developments at CSIRO Perth offer possibilities for collaboration with ECO_2 partners involved in cross cutting theme 2 (CCT2) *Monitoring Technologies and Strategies*. The Global CCS Institute is interested in collaborative hosting of a workshop or conference in legal and economic studies in 2013 in partnership with ECO_2 work package 5 *Risk Assessment, Economic, Legal Studies and Policy Stakeholder Dialogue*. Regarding the Australian CCS demonstration projects that will store CO_2 onshore, there are some generic issues of cap rock integrity, and fluid escape and ascent pathways that would overlap with ECO_2 work package 1 *Architecture and Integrity of the Sedimentary Cover at Storage*

Sites that offers opportunities for ECO_2 engagement. ECO_2 offers have been made to Australian research groups around participation in ECO_2 cruises.

In January 2012, a further trip was organized, this time to a series Japanese CCS research groups (Kyushu University, RITE in Kyoto, University of Tokyo, Multi-partner collaborative CCS research consortium, and Global CCS Institute in Tokyo) to discuss synergies and collaborations with respect to sub-seabed CO_2 storage impact investigations. The monitoring program of the forthcoming Tomakomai CCS demonstration project site will focus largely around sub-surface geophysical well monitoring, with minimal research program of seafloor and water column monitoring. The Tomakomai project offers opportunities for ECO_2 to better understand sub-surface geophysical well monitoring, and conversely for the emerging Japanese consortium to better understand seafloor and water column monitoring. The sensor developments being made with Prof. Shitashima in new pH and CO_2 sensors offer significant opportunities for collaboration particularly for ECO_2 partners involved in CCT2. ECO_2 offers have been made to the new Japanese research consortium to participate on all ECO_2 cruises. Due to immediate Japanese research collaboration interests in pH and CO_2 sensors and particularly timing of cruises (that clashed with the Japanese field-work program), the Kyushu group have accepted the offer to participate on the NOC cruise to Sleipner in September 2012 where Japanese developed sensors will be deployed in the Autosub6000 AUV. The lead point of contact for the new Japanese research partnership is Mr. Ryozo Tanaka (RITE).

ECO_2 Notes …

… upcoming cruises

For the second year of the project, 8 research cruises are scheduled and one additional one is planned. Four of these research cruises focus on the Sleipner area to continue and enlarge the knowledge gained at this site. The B3 field site in the Polish part of the Baltic Sea, which is a potential storage site past 2016 when exploitations of oil by Grupa Lotos and Petrobaltics will be closed, will be the focus of three research cruises in 2012. This site has not been investigated in 2011.

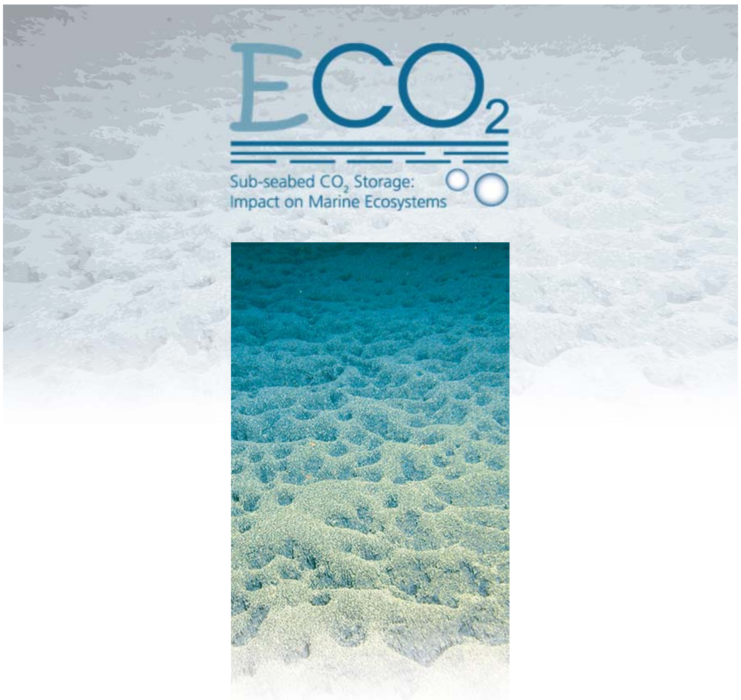
Time	Cruise Name	Site
16 – 24 April 2012	R/V Heinke	Salt Dome Juist & Sleipner
03 – 21 June 2012	Small boat	Panarea
22 – 30 June 2012	R/V G.O.Sars	Sleipner
20 July – 06 August 2012	R/V Celtic Explorer	Salt Dome Juist & Sleipner
23 July – 04 August 2012	R/V G.O.Sars	Jan Mayen
02 – 28 Sept 2012	R/V James Cook	Sleipner
04 – 11 Nov 2012	R/V Alkor	B3 field
April/May 2012	R/V St. Barbara	B3 field
not yet scheduled	R/V IMOR	B3 field

Laboratory experiments conducted in shore based facilities, on board of research vessels or at other easy accessible marine facilities will be the core topic of the next ECO_2 briefing paper.

… 2nd ECO_2 Annual Meeting

The second ECO_2 annual meeting will take place from 22 – 25 May 2012 in Southampton, U.K. at the National Oceanography Centre. The meeting will bring all 27 partners and the members of the Scientific and Stakeholder Advisory Boards together.

For more information please contact Anja Reitz.



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