Cruise Report GS12A

Scientific cruise to the Sleipner area in the North Sea.

R/V G.O. Sars, **Expedition No. 2012108**/CGB2012

June 22th– 30th 2012

Bergen, Norway – Bergen, Norway

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1.0 Introduction

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1.2 Objectives

The 2012 cruise to the area overlying the subsurface CO2 storage site of the Utsira Formation around the Sleipner platforms in the North Sea, was part of the activities at the Centre for Geobiology and the research project ECO2 funded by the European Union/European Atomic Energy Community Seventh Framework Programme ([*FP7/2007-2-13*] [*FP7/2007-2011*]) under grant agreement n° [*265847*]. The main objectives of this expedition were 1) revisit the fracture discovered during the June 2011 cruise and to expand the geomicrobial analysis, 2) to test and improve procedures and techniques for high resolution mapping and imaging of the seafloor, 3) perform shallow 3D seismic in the fracture area, 4) to test techniques for high resolution digital photoing of seafloor for creating photo mosaic spanning several km2, 5) measure concentrations of inorganic carbon in the seawater above the CO2 storage area, , 6) test new sensors for autonomous, *in situ* determination of CO2 system parameters, 7) harvest sediment cores for macrofaunal baseline descriptions.

1.3 Background

1.3.1 Storage of CO2 gas in the Utsira Formation of the North Sea.

Since 1996, Statoil has injected CO2 gas from the Sleipner West field and into the Utsira Formation. At the Sleipner West platforms in the northern part of the North Sea, Statoil pumps up natural gas from approximately 3000 m depth below the seafloor. The natural gas has a too high content of CO2 gas, and the CO2 is extracted on the platforms by the amide technology. The extracted CO2 gas is continously reinjected into the saline aquifer of the Utsira Formation at approximately 1200 m depth below the seafloor. By 2012 about 14 million tons of CO2 had been injected. The subseafloor CO2 plume covers today an area of approximately 4 km in length and about 1-2 km wide.

The storage of CO_2 in the Utsira Formation is the largest industrial scale storage site worldwide (except for American sites of enhanced oil recovery), and is used as study site for several national and European projects on Carbon Capture and Storage (CCS). The CCS is regarded as a key technology for the reduction of CO_2 emissions from power plants and other industrial sources at the European and international level.

1.3.2 Scientific studies of sub-seabed CO2 storage sites.

Center for Geobiology is a partner of three large CCS project; the national FME-SUCCESS project, the European ECO2 project and the European CO2BASE project (kick-off in autumn 2012). All three projects have focus on the Sleipner area of sub-seafloor CO_2 injection and storage.

The ECO2 (Sub-seabed Carbon Dioxide Storage: Impact on Marine Ecosystems) project sets out to assess the risks associated with storage of CO_2 below the seabed. Little is known about the short-term and long-term impacts of CO_2 storage on marine ecosystems even though CO_2 has been stored sub-seabed at Sleipner for over 16 years and for over four years 2400 m below the seafloor in the Barents Sea (Snøhvit). Against this background, the ECO2 project will assess the likelihood of leakage and impact of leakage on marine ecosystems. Novel monitoring techniques will be applied to detect and quantify the fluxes of formation fluids, natural gas, and CO_2 from storage sites. A best practice guide will be developed for the management of sub-seabed CO_2 storage sites considering the precautionary principal and costs of monitoring and remediation. The ECO2 project has 27 partners, including Statoil and Det Norske Veritas, and the scientific core of ECO2 is formed by work packages WP1 – WP4. Centre for Geobiology is directly involved in WP 1, 2 and 3, dealing with application of natural science approaches to constrain the potential pathways and the likelihood of leakage from storage sites through the sedimentary overburden (WP1), to quantify emission rates at the seabed (WP2), and to investigate the fate of the emitted CO_2 (WP3).

The Norwegian FME-SUCCESS project (Subsurface CO_2 storage, critical elements and superior strategy) addresses several important areas for CO_2 storage in the subsurface: storage performance, sealing properties, injection, monitoring and consequences for the marine environment. Centre for Geobiology is here a member of Activity 5: The marine component. The main goal of Activity 5 is to improve the understanding of shallow marine processes and the ecological impact of CO2 exposure, and develop marine monitoring methods. The activity addresses CO2 seeps through the seabed in terms of (i) knowledge gaps on processes in the upper sediment/benthic boundary layer; (ii) ecological impact from CO2 exposure; (iii) monitoring technologies.

The CO2BASE project ("Preparing for sub-sea storage of CO2: Baseline gathering and monitoring for the North Sea") is funded by CLIMIT (Norwegian Research Council programme), Statoil and Shell and had the kick-off meeting in Bergen autumn 2012. The EC directive (2009/31/EC) on geological storage of CO2, as well as recommendations from OSPAR and London Conventions, require a risk and environmental status assessments for "detection of leakage" and "detection of significant adverse effects for the surrounding environment, human health, or users of the surrounding biosphere". In the case of sub-seabed storage in geological formations, these assessments will have to include potential impact on the marine environment, and will have to outline a subsequent monitoring program. To be able to detect changes it is essential to have proper baseline at hand, and to be able to exclude natural trends. Hence, it is important to establish routines and procedures for baseline gathering as a first step toward marine monitoring of offshore storage sites. The aim of this project is to perform a pilot baseline study on two sites. The areas above the Sleipner CO2 plume and the potential future CO2 storage site in the Johansen formation are chosen, in order to determine best practices for baseline data acquisition. The project will demonstrate procedures for gathering, evaluating and utilization of existing data, and how to plan and execute measurement programs to supplement these. In addition it is the aim to demonstrate how the interaction between numerical models and measurements can improve both the models and design of measurements and monitoring programs. The main objective is to perform a pilot baseline study to determine best practices for a baseline acquisition and monitoring programs at subsea CO2 storage sites.

While the he cruise to the Sleipner area in June 2011 was the start-up of Centre for Geobiology´s scientific inputs to ECO2, FME-SUCCESS and CO2BASE, this cruise in 2012 was to revisit the seafloor fracture (Fig. 1) discovered by us in 2011 to continue the multidisciplinary analysis.

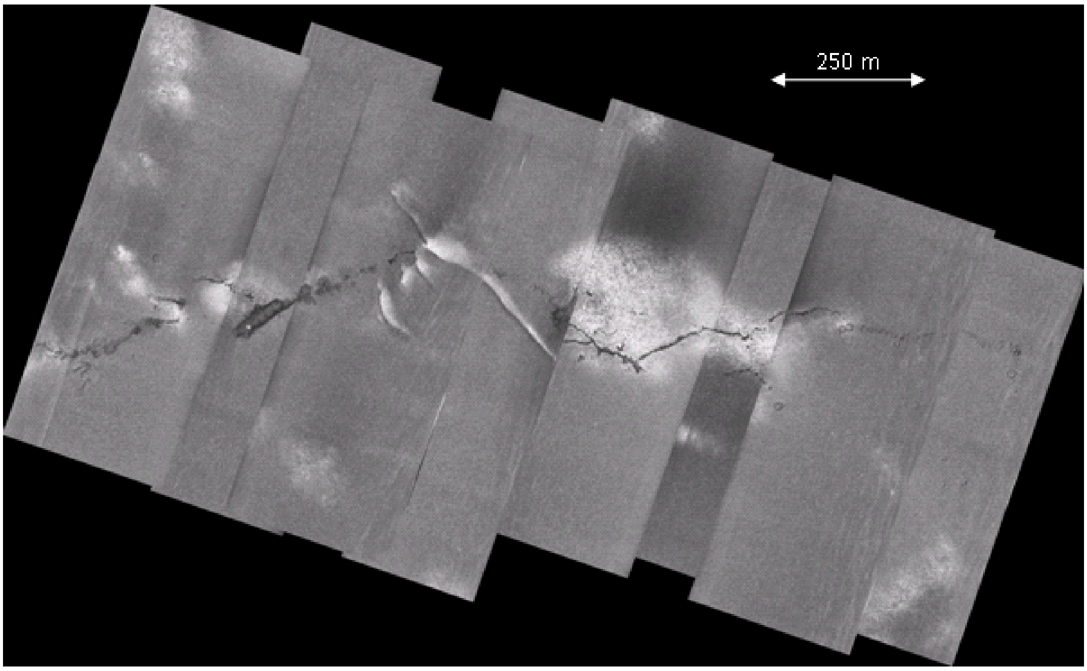

Figure 1: Combined HISAS images showing the seafloor fracture discovered by us in June 2011.

2.0 EQUIPMENT

2.1 Operational equipment

2.1.1 Multibeam echo sounder EM302

Bathymetric mapping was performed with an EM 302 multibeam echo sounder. The EM 302 uses a nominal sonar frequency of 30 kHz and is designed to do mapping from 10 m depths up to 7000 m. A transmit fan is split into individual sectors, each with active steering according to the vessel roll, pitch and heave, and each sounding is placed on a best fit on a line perpendicular to the survey line.

2.1.2 Singlebeam echo sounder EK60

The Simrad EK60 installed onboard the G.O. Sars is an echo sounder that can operate several echo sounder frequencies simultaneously ranging from 18 to 710 kHz.

2.1.3 Parametric Sub Bottom Profiler Topas PS 018

The G.O. Sars is equipped with a parametric sub bottom profiler Topas PS 018 operating at a primary frequency of 15 kHz (secondary 0.5 - 5 kHz) and a primary beam with of 3.5 degrees (secondary 5 degrees). It has a depth range of 30 to 10000 meters, a range resolution of less than 0.3 meters and a penetration capacity of over 150 meters.

2.1.4 Seismic mini streamer

We used a single 90 $inch^3$ airgun from Bolt, model 1900, with an operating pressure of 138 bar and towed it at approx. 4 m depth. Shot interval was 12 s at 5 knots ship speed, which corresponds to approximately 25 m distance between each shot. The receiver unit was a 200 m long mini-streamer with 8 hydrophone groups with 6.25 m spacing on the 43.75 m long active part of the streamer.

2.1.5 ROV

During the cruise the ship was equipped with the ROV Bathysaurus II, which has a depth range of 4000 meters. The Bathysaurus II was equipped with the best manipulator arms available, state-of the-art positioning systems, and high-resolution digital camera for stills, and advanced digital video cameras.

ROV equipment

Temperature-probe: A temperature probe for the range of 0-150 °C was used for measurements of seabed sediment (down to 25 cm depth).

Water samplers: The water sampling system consists of two 1 l titanium fluid samplers attached to a snorkel inlet.

Sampling box (L:60cm, W:60cm, H:30cm)**:** An aluminum scuffle box was fixed to the frame of the ROV for bulk collection of seafloor sediment.

Push cores: Three holders for push cores were placed on the ROV for seabed sampling of sediment with fragile bacterial mats on top. The harvested sediment cores were 10-20 cm long.

2.1.6 AUV

The HUGIN AUV is an autonomous underwater vehicle developed by Kongsberg Maritime and FFI. It is equipped with a range of acoustical, optical and chemical sensors.

The HISAS 1030 sonar mounted on the HUGIN AUV is an advanced interferometric sidescan sonar developed by Kongsberg Maritime and FFI. It consists of a transmitter and two vertically displaced receiver arrays configured as an interferometer. The HISAS is capable of synthetic aperture sonar (SAS) imaging, resulting in an obtainable image resolution down to 2x2 cm (depending on the conditions). High-resolution bathymetric maps are obtained by comparing the sidescan images formed at the two receiver arrays. The HISAS frequency range is approximately 60 to 120 kHz, with a bandwidth of 30-50 kHz.

In addition to the HISAS 1030 SAS, the HUGIN AUV is equipped with an optical black&white camera and a chemical sniffer for methane detection, as well as a multibeam echosounder.

2.1.7 CTD

For measurements of conductivity, temperature and depth of the water column a Seabird 911plus CTD rosette with 12 Niskin water samplers. Standard setup is with SBE 4C conductivity sensor and SBE3plus temperature sensor.

2.1.8 Benthic Lander and ROV-mounted benthicLander

The benthic lander allows *in-situ* and at-depth studies of benthic ecosystems and flux rates of diverse fluid constituents. The benthic lander consists of two chambers. To both chambers a series of seven 60 ml syringes is attached for fluid sampling during the incubation period. Sensors for O_2, pH and temperature are mounted inside the chambers for continuous measurements. Syringes and chambers are controlled over a preprogramed sequence.

The second lander system was constructed to be placed on the seafloor by the ROV. It consisted of a single benthic chamber with seven attached syringes for fluid sampling (60 ml). Syringes and the chamber were controlled over a preprogramed sequence. Sensors for O_2, pH and temperature are mounted inside the chambers for continuous measurements.

3.0 METHODS

3.1 Shipboard geochemical analysis and sample preparation

Dissolved gases and several redox sensitive parameters and nutrients in fluids, water column and sediment porewater (e.g. H_2, CH_4, O_2, sulphide, alkalinity, pH, ammonium, NO_{tot}, PO_4, DIC) were measured onboard. In addition, samples for onshore analyses of other essential parameters (total gas content, major and trace elements, stable isotopes, organic acids, nutrients) in fluids and solids (TIC, TOC, stable isotopes) were collected and preserved onboard.

3.2 Shipboard: Collection of pore water from sediment push cores

Pore water sampling was carried out immediately after obtaining the push cores on deck by using Rhizon samplers at intervals in the range of 3 cm. Rhizon samplers use the vacuum produced by syringes to extract the pore water.

3.3 Shipboard: pH, alkalinity and nutrients analyses

Aliquots of pore water (2 ml) and CTD water samples (60-100 ml) was analysed onboard for pH and alkalinity. pH was measured using a mobile pH meter (Metrohm), alkalinity was measured by the use of a Titrino autotitrator (Metrohm).

Concentrations of dissolved sulphide, ammonium, nitrate/nitrite and phosphate in seawater and pore water were analysed onboard by photometric methods using a 4-channels Quaatro Continuous Flow Analyzer (Seal Analytical). For sulphide and ammonium the methylene blue and indophenol methods were used, respectively. Nitrate was reduced to nitrite by a Cu-Cd reduction coil, and nitrite was then detected as a red complex. For phosphate the blue phosphor-molybdenium method was applied.

3.4 Shipboard: Collection of dissolved gases in water column and sediments

The dissolved gases collected on the cruise included: O_2, H_2, CH_4, higher hydrocarbons, He and H_2S. The dissolved gases were collected from 4 different sample types: 1) from the water column taken by CTD, 2) from the water column obtained by Titanium-major samplers, 3) from the Benthic Lander samples and 4) from pore water extracted from push cores.

Dissolved gasses from water column samples

To determine dissolved H_2 and CH_4 concentrations in the water column, 100 ml (50 ml for benthic lander samples) of bubble free fluid was drawn into a 140 ml (60 ml) syringe followed by the addition of 40 ml (12 ml) headspace gas of ultra-pure helium. The sample was shaken and let warm to room temperature to reach equilibrium for H_2 and CH_4 between the water and the gas phase. After equilibration, the headspace gas was injected into a TOGA SRI 8610C gas chromatograph equipped with a highly sensitive He-pulsed discharge detector (PDD) for H_2 analyses and with a flame ionization detector (FID) for CH_4 analyses. Gas cylinders with 5.0 He (carrier gas, 2 x 50 l), 5.0 H_2 (1 x 50 l) and synthetic air (2 x 50 l) were connected to the gas pipeline system in the gas central room on the vessel (regulators onboard the ship).

Immediately upon recovery of the CTD sampling package, air-free water samples were flushed through 24-inch-long sections of refrigeration grade Cu tubing with duplicate half-sections cold-weld sealed for later laboratory determinations of water column He concentrations at NOAA/PMEL Helium Isotope Laboratory in Newport, OR, USA (Young and Lupton, 1983).

Dissolved O_2 concentrations were measured *in-situ* using a needle-type fiber-optic microsensor (PreSens, Germany) directly put into subsamples of the water in the Niskin bottles on the CTDs. For all samples the O_2 measurements were done over 1 minute, in triplicate immediately after CTDs were on deck.

Dissolved gasses from sediment samples

For H_2 and CH_4 concentration determination in sediments obtained by push cores, 5 ml of sediment was collected with a 10 ml tip cut plastic syringe in the middle to bottom part of the 10 cm long core. The sediment was then placed into a 140 ml syringe and 100 ml of 1.2 M NaCl solution with sodium azide (0.1%) were added. This was followed by the addition of 40 ml headspace gas of ultra-pure helium. The content was mixed by shaking and left for at least half an hour at room temperature before the headspace gas was analysed by using a GC as described above.

Dissolved O_2 concentrations were measured in extracted pore water and directly into the sediment using needle-type fiber-optic microsensors (PreSens, Germany). For each sample all O_2 measurements were done over 1 minute, in triplicate.

3.5 Shipboard: Preparation of samples for onshore analyses

For onshore ion chromatography (IC) analyses at UoB of Cl, SO_4^{2-}, and Br^- aliquots of CTD and pore water samples were filtered (0.2 µm) and collected in 10 or 30 ml sized plastic bottles and stored in the fridge at ~ 4°C.

For onshore inductively coupled plasma optical emission spectrometry (ICP-OES) analyses at UoB of alkali elements (Li, Na, K), alkali earth elements (Mg, Ca, Sr, Ba), and other elements (e.g. Mn, Fe, Si, Al, B, Ti, heavy metals) aliquots of CTD and pore-water samples were filtered (0.2 µm) and collected on 10-100 ml sized acid clean plastic bottles, acidified by adding ultra pure nitric acid to a final concentration of 3%, and stored in the fridge at ~ 4°C.

For onshore analyses of nitrate, nitrite and phosphor by using a continuous flow analyzer at UoB, aliquots of CTD and pore water samples were filtered (0.2 µm) and collected on 10 or 30 ml sized amber plastic bottles and stored in the freezer at ~ 20°C.

For DIC stable isotopes analyses, 0.2 to 1 ml filtered (0.2 µm) sample was injected into prepared (8 drops of melted phosphoric acid, flushed with He) vacutainers without having air contact.

3.6 Shipboard microbial analysis and sample preparations for onshore analysis

All microbiology analysis of sediments and microbial mats were done in the frame of the FME-SUCCESS project (www.fme-success.no).

3.7 Shipboard sample preparations for onshore macro fauna analysis

Sediment samples were collected in the Benthic Lander chambers (22 cm width, 1cm height) to determine macrofauna diversity and density. Samples were sieved over a 0.5 mm mesh. Each sample was transferred to a 500 ml container and preserved with 10% formalin.

4.0 CRUISE ACTIVITIES AND INITIAL RESULTS

Table I: Sleipner 2012 Cruise log.

Activity	Description	Date Time	Latitude	Longitude	Water depth (m)
12A-Topas-01	Start of line	2012/06/23 04:29	59°56.454`N	05°06.930`E	
	End of line	2012/06/23 09:55	59°17.00`N	04°02.000`E	284
12A-CTD-01	Deployed	2012/06/23 09:55	59°17.00`N	04°02.000`E	284
	Recovered	2012/06/23 10:23	59°17.00`N	04°02.000`E	284
12A-Topas-02	Start of line	2012/06/23 10:58	59°17.01`N	04°05.000`E	
	End of line	2012/06/23 14:00	59°16.979`N	03°01.866`E	124
12A-CTD-02	Deployed	2012/06/23 14:05	59°16.979`N	03°01.860`E	124
	Recovered	2012/06/23 14:13	59°16.979`N	03°01.860`E	124
12A-Topas-03	Start of line	2012/06/23 14:16	59°16.979`N	03°01.860`E	124
	End of line	2012/06/23 14:28	59°16.943`N	02°59.755`E	
12A-Topas-04	Start of line	2012/06/23 14:47	59°16.925`N	02°59.236`E	117
	End of line	2012/06/23 15:55	59°17.028`N	02°41.932`E	119
12A-CTD-03	Deployed	2012/06/23 15:58	59°17.031`N	02°41.934`E	119
	Recovered	2012/06/23 16:08	59°17.031`N	02°41.934`E	119
12A-Topas-05	Start of line	2012/06/23 16:10	59°17.031`N	02°41.934`E	119
	End of line	2012/06/23 21:22	58°35.768`N	02°04.978`E	86
12A-CTD-04	Deployed	2012/06/23 21:25	58°35.768`N	02°04.978`E	86
	Recovered	2012/06/23 21:30	58°35.768`N	02°04.978`E	86
12A-ROV-01	Deployed	2012/06/23 21:46	58°35.778`N	02°04.980`E	86
	Recovered	2012/06/23 21:49	58°35.778`N	02°04.980`E	86
12A-ROV-02	Deployed	2012/06/23 21:53	58°35.766`N	02°04.978`E	86
	Recovered	2012/06/23 22:41	58°35.766`N	02°04.978`E	86
12A-AUV-01	Deployed	2012/06/23 23:58	58°35.129`N	02°05.572`E	89
	Recovered	2012/06/24 11:02	58°35.129`N	02°05.572`E	89
12A-CTD-05	Deployed	2012/06/24 12:04	58°35.759`N	02°04.977`E	89
	Recovered	2012/06/24 12:11	58°35.759`N	02°04.977`E	89
12A-ROV-03	Deployed	2012/06/24 12:34	58°35.759`N	02°04.977`E	89
	Recovered	2012/06/24 16:28	58°35.757`N	02°05.294`E	89
12A-GCV-01	Deployed	2012/06/24 13:55	58°35.756`N	02°04.984`E	89
	Recovered	2012/06/24 14:36	58°35.756`N	02°04.984`E	89
12A-ROV-04	Deployed	2012/06/24 18:33	58°35.758`N	02°05.294`E	89
	Recovered	2012/06/24 18:53	58°35.758`N	02°05.294`E	89
12A-ROV-05	Deployed	2012/06/24 19:17	58°35.758`N	02°05.294`E	89
	Recovered	2012/06/24 19:24	58°35.758`N	02°05.294`E	89
12A-CTD-06	Deployed	2012/06/24 20:21	58°35.624`N	02°04.070`E	89
	Recovered	2012/06/24 20:27	58°35.624`N	02°04.070`E	89

12A-ROV-06	Deployed	2012/06/24 20:33	58°36.624`N	02°04.080`E	89
	Recovered	2012/06/24 20:43	58°36.624`N	02°04.080`E	89
12A-Topas-06	Start of line	2012/06/24 21:02	59°34.500`N	02°01.500`E	89
	End of line	2012/06/24 21:10	59°34.500`N	02°03.500`E	89
12A-Topas-07	Start of line	2012/06/24 21:14	59°35.000`N	02°04.600`E	89
	End of line	2012/06/24 21:26	59°36.500`N	02°04.600`E	89
12A-Topas-08	Start of line	2012/06/24 21:29	59°35.000`N	02°04.100`E	89
	End of line	2012/06/24 21:41	59°36.500`N	02°04.100`E	89
12A-Topas-09	Start of line	2012/06/24 21:49	59°35.036`N	02°04.327`E	89
	End of line	2012/06/24 22:39	59°41.323`N	02°04.370`E	89
12A-AUV-02	Deployed	2012/06/24 23:30	58°36.121`N	02°07.375`E	
	Recovered	2012/06/25 09:29	58°36.121`N	02°07.375`E	
12A-ROV-07	Deployed	2012/06/25 09:37	58°36.012`N	02°07.451`E	
	Recovered	2012/06/25 10:13	58°36.012`N	02°07.451`E	
12A-CTD-07	Deployed	2012/06/25 13:47	58°23.470`N	01°58.010`E	79
	Recovered	2012/06/25 13:56	58°23.470`N	01°58.010`E	79
12A-CTD-08	Deployed	2012/06/25 13:36	58°23.504`N	01°56.002`E	80
	Recovered	2012/06/25 13:44	58°23.504`N	01°56.002`E	80
12A-CTD-09	Deployed	2012/06/25 15:19	58°22.998`N	01°56.997`E	79
	Recovered	2012/06/25 15:24	58°22.998`N	01°56.997`E	79
12A-CTD-10	Deployed	2012/06/25 15:56	58°22.504`N	01°57.004`E	79
	Recovered	2012/06/25 16:04	58°22.504`N	01°57.004`E	79
12A-CTD-11	Deployed	2012/06/25 16:33	58°22.000`N	01°58.002`E	79
	Recovered	2012/06/25 16:39	58°22.000`N	01°58.002`E	79
12A-CTD-12	Deployed	2012/06/25 17:12	58°23.506`N	01°57.008`E	79
	Recovered	2012/06/25 17:18	58°23.506`N	01°57.008`E	79
12A-ROV-08	Deployed	2012/06/25 19:40	58°35.751`N	02°05.304`E	93
	Recovered	2012/06/25 20:40	58°35.751`N	02°05.304`E	93
12A-AUV-03	Dep/Rec	2012/06/25 23:15	58°36.697`N	02°02.374`E	
12A-Seismo-01	Start of line	2012/06/26 00:56	58°36.313 N	02°05.546E	
	End of line	2012/06/26 08:58	58°34.983`N	02°03.558`E	
12A-Topas-12	Start of line	2012/06/26 00:33	58°33.59`N	02°05.55`E	
	End of line	2012/06/26 08:58	58°34.983`N	02°03.558`E	
12A-AUV-04	Deployed	2012/06/26 09:31	58°34.897`N	02°02.374`E	
	Recovered	2012/06/26 20:45	58°34.897`N	02°02.374`E	
12A-ROV-09	Deployed	2012/06/26 10:38	58°35.766`N	02°04.982`E	
	Recovered	2012/06/26 11:16	58°35.766`N	02°04.982`E	
12A-ROV-10	Deployed	2012/06/26 12:45	58°35.762`N	02°04.964`E	91
	Recovered	2012/06/26 15:09	58°35.762`N	02°04.964`E	91
12A-ROV-10 cham1	Deployed	2012/06/26 14:00	58°35.776`N	02°04.948`E	89
12A-ROV-12 cham1	Recovered	2012/06/27 00:15	58°35.778`N	02°04.982`E	89

12A-ROV-11	Deployed	2012/06/26 16:38	58°35.771`N	02°04.949`E	89
	Recovered	2012/06/26 17:44	58°35.771`N	02°04.949`E	89
12A-MC-01	Deployed	2012/06/26 19:07	58°35.734`N	02°05.056`E	
	Recovered	2012/06/26 19:20	58°35.734`N	02°05.056`E	
12A-Seismo-02	Start of line	2012/06/27 01:25	58° 36.313N	02° 03.891E	
	End of line	2012/06/27 08:03	58° 35.608N	02° 00.832E	
12A-Topas-12A	Start of line	2012/06/27 01:21	58° 36.313N	02° 03.891E	
	End of line	2012/06/27 08:03	58° 35.608N	02° 00.832E	
12A-AUV-05	First	2012/06/27 10:00	58°35.575`N	02°10.281`E	
	Second	2012/06/27 10:11	58°35.574`N	02°10.284`E	
12A-CTD-13	Deployed	2012/06/27 10:22	58°35.558`N	02°10.324`E	91
	Recovered	2012/06/27 10:22	58°35.558`N	02°10.324`E	91
12A-AUV-06	Deployed	2012/06/27 10:46	58°35.969`N	02°10.354`E	
	Recovered	2012/06/27 11:11	58°35.969`N	02°10.354`E	
12A-AUV-07	Deployed	2012/06/27 12:30	58°34.544`N	02°07.455`E	
	Recovered	2012/06/27 21:58	58°34.544`N	02°07.455`E	
12A-Lander-01	Deployed	2012/06/27 14:35	58°35.7678`N	02°04.9596`E	89
	Recovered	2012/06/27 18:08	58°35.7678`N	02°04.9596`E	89
12A-EM302-1	Start of line	2012/06/27 11:18	58°35.009`N	02°08.789`E	94
	End of line	2012/06/27 19:48	58°36.10`N	02°02.78`E	94
12A-Topas-13	Start of line	2012/06/27 20:08	58°35.892`N	02°04.761`E	
	End of line	2012/06/27 20:31	58°35.751`N	02°05.160`E	
12A-Lander-02	Deployed	2012/06/27 21:00	58°37.165`N	02°04.962`E	
	Recovered	2012/06/28 10:30	58°37.165`N	02°04.962`E	
12A-Seismo-3	Start of line	2012/06/28 01:42	58° 36.313N	02°04.100E	
	End of line	2012/06/28 08:22	58° 35.26N	02°04.98E	
12A-Topas-14	Start of line	2012/06/28 01:39	58° 36.313N	02°04.100E	
	End of line	2012/06/28 08:22	58° 35.26N	02°04.98E	
12A-CTD-14	Deployed	2012/06/28 09:12	58°37.309`N	02°04.911`E	85
	Recovered	2012/06/28 09:18	58°37.309`N	02°04.911`E	85
12A-AUV-08	Deployed	2012/06/28 12:36	58°36.830`N	02°04.987`E	
	Recovered	2012/06/28	58°36.830`N	02°04.987`E	
12A-CTD-15	Deployed	2012/06/28 11:13	58°37.717`N	02°04.492`E	89
	Recovered	2012/06/28 11:20	58°37.717`N	02°04.492`E	89
12A-CTD-16	Deployed	2012/06/28 11:28	58°35.717`N	02°04.492`E	89
	Recovered	2012/06/28 11:34	58°35.717`N	02°04.492`E	89
12A-ROV-13	Deployed	2012/06/28 13:46	58°35.757`N	02°05.242`E	93
	Recovered	2012/06/28 14:45	58°35.757`N	02°05.242`E	93
12A-Lander-03	Deployed	2012/06/28 15:24	58°35.077'N	02°04.472'E	92
	Recovered	2012/06/28 19:45	58°35.077'N	02°04.472'E	92
12A-ROV-14	Deployed	2012/06/28 16:09	58°35.758'N	02°05.288'E	92
	Recovered	2012/06/28 16:58	58°35.758'N	02°05.288'E	92

12A-ROV-15	Deployed	2012/06/28 18:14	58°35.776'N	02°05.013'E	93
	Recovered	2012/06/28 19:11	58°35.776'N	02°05.013'E	93
12A-ROV-16	Deployed	2012/06/28 22:03	58°35.771'N	02°05.008'E	93
	Recovered	2012/06/28 22:41	58°35.771'N	02°05.008'E	93
12A-MC-02	Deployed	2012/06/29 03:27	58°33.152`N	01°40.758`E	
	Recovered	2012/06/29 03:45	58°33.152`N	01°40.758`E	
12A-MC-03	Deployed	2012/06/29 03:55	58°33.152`N	01°40.758`E	
	Recovered	2012/06/29 04:10	58°33.152`N	01°40.758`E	
12A-MC-04	Deployed	2012/06/29 04:20	58°33.152`N	01°40.758`E	
	Recovered	2012/06/29 04:36	58°33.152`N	01°40.758`E	
12A-MC-05	Deployed	2012/06/29 04:45	58°30.764`N	01°56.098`E	
	Recovered	2012/06/29 04:55	58°30.764`N	01°56.098`E	
12A-MC-06	Deployed	2012/06/29 05:05	58°30.764`N	01°56.098`E	
	Recovered	2012/06/29 05:15	58°30.764`N	01°56.098`E	
12A-MC-07	Deployed	2012/06/29 05:25	58°30.764`N	01°56.098`E	
	Recovered	2012/06/29 05:30	58°30.764`N	01°56.098`E	
12A-CTD-17	Deployed	2012/06/29 05:19	58°24.00`N	01°56.50`E	82
	Recovered	2012/06/29 05:22	58°24.00`N	01°56.50`E	82
12A-CTD-18	Deployed	2012/06/29 06:04	58°24.00`N	01°57.00`E	82
	Recovered	2012/06/29 06:05	58°24.00`N	01°57.00`E	82
12A-CTD-19	Deployed	2012/06/29 08:42	58°22.998`N	01°56.002`E	82
	Recovered	2012/06/29 08:49	58°22.998`N	01°56.002`E	82
12A-CTD-20	Deployed	2012/06/29 09:20	58°23.00`N	01°56.50`E	82
	Recovered	2012/06/29 09:25	58°23.00`N	01°56.50`E	82
12A-CTD-21	Deployed	2012/06/29 09:49	58°23.00`N	01°58.997`E	82
	Recovered	2012/06/29 09:55	58°23.00`N	01°58.997`E	82
12A-CTD-22	Deployed	2012/06/29 10:50	58°24.011`N	01°53.609`E	82
	Recovered	2012/06/29 10:56	58°24.011`N	01°53.609`E	82
12A-ROV-17	Deployed	2012/06/29 13:39	58°35.776`N	02°05.000`E	92
	Recovered	2012/06/29 14:57	58°35.776`N	02°05.000`E	92
12A-ROV-18	Deployed	2012/06/29 16:06	58°35.707`N	02°04.546`E	92
	Recovered	2012/06/29 16:46	58°35.707`N	02°04.546`E	92
12A-ROV-19	Deployed	2012/06/29 17:14	58°35.914`N	02°03.919`E	92
	Recovered	2012/06/29 18:00	58°35.914`N	02°03.919`E	92
12A-CTD-23	Deployed	2012/06/29 21:02	59°01.97`N	02°51.27E	135
	Recovered	2012/06/29 21:10	59°01.97`N	02°51.27E	135

4.1 Hugin mapping and seismics

by Ann E. A. Blomberg and Karin Landschulze, CGB/UoB

4.1.1 Hugin mapping

During the Sleipner 2012 cruise, the HUGIN AUV was used for detailed acoustical and optical mapping of the seafloor fracture structure discovered in 2011. A region to the west and southwest of the known fracture was imaged with the HISAS. The optical camera was used to acquire detailed images of the bacterial mats present along the fracture. Chemical sniffers were used to map the amount of methane in the water column. The HUGIN AUV was also used to obtain optical images of selected regions along this structure

4.1.2 Seismics

The aim with seismic data acquisition during the 2012 cruise was to get high resolution shallow seismic data from the top 100-200 m below the sea bottom. This, combined with sub bottom profiler data, will help to link the discovered fracture to deeper structures. Seismic data acquisition was accomplished on a total of 28 lines covering the extent of the fracture visible on the sonar data, and extending further to the West.

4.2 Sediments and fluid and gas fluxes across the seabed

4.2.1 Sediments from push cores (ROV)

Geochemical, microbiological and macrobiological investigations were performed on the sediment push cores obtained by the ROV.

Geochemical studies

Geochemical studies were conducted on eight push cores in total. On six cores pore water and dissolved gas studies were performed, one core was investigated for pore water compositions only and one core was fully sampled for onshore total gas and isotopic composition determinations (Table 2).

Table 2: Performed geochemical analyses on the sediments obtained from push cores.

Push core	Site	pH	alkalinity	H_2S/NH_4^+	nutrients	CH_4/H_2	O_2	DIC	total gas
GS12A-ROV09-PC	Frac A			x	x		x		
GS12A-ROV13-PC	Frac B	x	x	x	x	x		x	
GS12A-ROV14-PC3	Frac B	x	x	x	x	x	x	x	
GS12A-ROV15-PC1	Frac A	x	x	x	x	x	x		
GS12A-ROV15-PC2	Frac A	x	x	x	x	x	x		
GS12A-ROV15-PC3	background	x	x	x	x	x		x	
GS12A-ROV18-PC2	new western part	x	x	x	x	x			
GS12A-ROV18-PC3	new western part								x

Preliminary results from dissolved H_2S and CH_4 concentrations measurements in sediments at the fracture suggest local differences in the prevailing distribution pattern. Some areas at the fracture are characterized by high H_2S and high CH_4 concentrations and at other areas CH_4 concentrations above background combined with low contents of H_2S are prevailing. Oxygen measurements in the sediment suggest anaerobic conditions at maximal 1 cm depth.

4.2.2 Benthic Lander operations

By Teresa Amaro, Uta Brandt, Andrew Sweetman, NIVA Oslo/Bergen

By Tamara Baumberger, Pål Tore Mørkved, Anne Stensland, Ingunn H. Thorseth, CGB/UiB

To quantify the short and medium term impact of CO2 leakage on the structure, diversity and functioning of benthic communities, mesocosm experiments are being conducted at the NIVA marine research station Solbergstrand, Oslofjord, Norway. For that, a high CO_2 exposure system has been built to perform an experiment where 5 treatment levels (ambient control (400 ppm), 1000, 2000, 5000 and 20000 ppm CO_2) are being run. Each experiment will run for 140 days and sampled at regular time points.

During the last week of June, NIVA has participated on a cruise to Sleipner with the objective to validate the results from the mesocosm experiments described above. To estimate the severity and speed of impact on ecosystem function, measures on changes on community respiration and sediment environment (profiles for O2, pH and alkalinity) were performed. For this, three deployments of a benthic chamber lander were done at the Sleipner storage site (Table 3).

Table 3: Resume of the 3 lander deployments at Sleipner cruise**.**

Activity	Date	Time Deployment (Norw)	Time Recovery (Norw)	Coordinates (Lat.)	Coordinates (Long.)	Depth (m)	Location Name
12A-49-Lander-1	27.06.2012	14:35	18:05	58°35.7678`N	02°04.9596`E	89,15m	FRAC-A
12A-53-Lander-2	27.06.2012	21:00	10:30	58°37.165`N	02°04.962`E		Ref
12A-63-Lander-3	28.06.2012	15:24	19:45	58°35.077'N	02°04.472'E	92m	

Moreover, flux rates of pore fluids and dissolved gases at the sediment-seawater boundary were estimated in two different areas (fraction, background area). For this, water samples were collected in 60 ml syringes, which were attached to the chambers of the benthic lander system and released by following a pre-programmed time sequence. The fluids sampled with syringes were either fully used for dissolved gas (H_2 and CH_4) analyses or subsampled for pH, alkalinity, sulfide, ammonium, nutrients and DIC analyses.

Together with these measurements, sediment samples were collected in these chambers (22 cm width, 1 cm height) to determine macrofauna diversity and density. Furthermore, to compare the macrofauna community from Sleipner area with the one collected for the mesocosms experiment, three multicorer deployments (with 4 cores of 10 cm diameter) were collected next to Sleipner area (Table 4).

Table 4: Resume of the 3 multicorer deployments next to Sleipner area.

Activity	Date	Time Deployment (Norw)	Time Recovery (Norw)	Coordinates		Depth (m)
12A-66-MC-2	29.06.2012	03:27	03:45	58°33,152`N	01°40.758`E	
12A-67-MC-3	29.06.2012	04:55	04:10	58°33,152`N	01°40.758`E	
12A-68-MC-4	29.06.2012	04:20	04:36	58°33,152`N	01°40.758`E	

Macrofauna samples could not be collected at Sleipner area, because the multicorer could not penetrate the sediment. For this purpose, several attempts were conducted but they did not succeed.

Preliminary results

In the lab macrofauna samples will be extracted under a stereo microscope and identified to species or the lowest taxonomic level possible. Samples are still being processed.

Sedimentary Oxygen Consumption (SOC) rate was estimated to be approx.9.6 ± 7.7 mmol O_2 m^{-2} d^{-1} (n=2). Profiles for pH and alkalinity are still being analysed.

Table 5 lists all successfully collected fluid samples from chamber syringes obtained by both types of lander systems. Preliminary results from dissolved gas analyses point to different flux and concentration patterns for CH_4 and H_2. Methane concentrations sampled from the chamber located above the fracture are about 10 to 20 nM elevated compared to chamber fluid samples collected above background sediments. An identical pattern is not observed in respect to the other measured species. Calculations for pore fluids and dissolved gas fluxes at the sediment-seawater boundary are subject of on-going work. Evaluation and interpretation of the shipboard fluid concentration measurements are not yet fully concluded.

Table 5: Sample collection and type of analyses performed shipboard/shore-based.

Activity	Date/Time deployment	Date/Time recovery	Latitude	Longitude	Depth (m)	CH_4	H_2	pH	Alk	NH_4^+/ HS^-	Nut	DIC
12A-ROV12-C1_S1	26.06.12 / 13:46	26.06.12 / 24:00	58°35.7743´N	02°04.9944´E	91	x	x					
_S2								x	x	x	x	x
_S3						x	x					
_S4								x	x	x	x	x
_S5						x	x					
_S6								x	x	x	x	x
12A-Lander-1_C1-S1	27.06.12 / 14:35	27.06.12 / 18:05	58°35.7678´N	02°04.9596´E	92	x	x					
_C1-S2								x	x	x	x	x
_C1-S3						x	x					
_C1-S4								x	x	x	x	x
_C1-S5						x	x					
_C1-S7								x	x	x	x	x
_C2-S1						x	x					
_C2-S2								x	x	x	x	x
_C2-S3						x	x					
_C2-S4								x	x	x	x	x
_C2-S5						x	x					
_C2-S6								x	x	x	x	x
_C2-S7								x	x	x	x	
12A-Lander-2_C1-S1	27.06.12 / 21:00	28.06.12 / 10:30	58°37.165´N	02°04.962´E				x	x	x	x	x
_C1-S2						x	x					
_C1-S3								x	x	x	x	x
_C1-S4						x	x					
_C1-S5								x	x	x	x	x
_C1-S6						x	x					
_C1-S7								x	x	x	x	x
_C2-S1								x	x	x	x	x
_C2-S2						x	x					
_C2-S3								x	x	x	x	x
_C2-S4						x	x					
_C2-S5								x	x	x	x	x
_C2-S7						x	x					
12A-Lander-3_C1-S1	28.06.12 / 15:24	28.06.12 / 19:45	58°35.077´N	02°04.472´E	92	x	x					
_C1-S2								x	x	x	x	x
_C1-S3						x	x					
_C1-S4								x	x	x	x	x
_C1-S5						x	x					
_C1-S6								x	x	x	x	x
_C1-S7						x	x					
_C2-S1						x	x					
_C2-S2								x	x	x	x	x
_C2-S3						x	x					
_C2-S4								x	x	x	x	x
_C2-S5						x	x					
_C2-S6								x	x	x	x	x

4.3 Water column investigations

In total, 23 CTD- casts were performed during the cruise to the Sleipner area in 2012. Except for four casts, all casts were sampled to analyse for dissolved gas (CH_4/H_2) and/or fluid compositions. Table 6 compiles the distribution of the obtained CTD-rosette water samples.

Table 6: CTD fluid sample distribution.

Cast	^3He	CH_4, H_2	TC	TA	pH	Alk	O_2	Nut	IC	ICP	Iso	Comment
GS12A-CTD1 - Station 163			7									
GS12A-CTD2 - Station 164			6	6								
GS12A-CTD3 - Station 165			7	7								
GS12A-CTD4 - Station 166												no samples
GS12A-CTD5 - Station 167		8	8	8			8					
GS12A-CTD6 - Station 168	10	10			10	10	10	10	10	10		
GS12A-CTD7 - Station 169		6	6	6	6	6	6	6	6	6		
GS12A-CTD8 - Station 170		5	5	5	5	5	5	5	5	5		
GS12A-CTD9 - Station 171		5	5	5	5	5	5	5	5	5		
GS12A-CTD10 - Station 172		5	5	5	5	5	5	5	5	5		
GS12A-CTD11 - Station 173		6	6	6	6	6	6	6	6	6		
GS12A-CTD12 - Station 174		4	3	3	4	4	4	4	4	4		
GS12A-CTD13 - Station 175												no samples
GS12A-CTD14 - Station 176		6	6	6	6	6	6	6	6	6		
GS12A-CTD15 - Station 177												no samples
GS12A-CTD16 - Station 178		9	9	9	9		9	9	9	9		
GS12A-CTD17 - Station 179			5	5								
GS12A-CTD18 - Station 180			4	4								
GS12A-CTD19 - Station 181			4	4								
GS12A-CTD20 - Station 182			5	5								
GS12A-CTD21 - Station 183												no samples
GS12A-CTD22- Station 184	9	9	6	6								
GS12A-CTD23- Station 185	7	7						7	7	7	10	
Total	**26**	**80**	**97**	**90**	**56**	**47**	**64**	**63**	**63**	**63**	**10**	

4.4 Carbon geochemistry

By Abdirahman M. Omar, UniBjerknes, UniResearch Ltd. And Tor de Lange, Geophysical Institute (GFI), University of Bergen

The GFI and UniBjerknes Centre were responsible for the measurement of concentrations of inorganic carbon in the seawater. During the Sleipner cruise 2012 (Figure 2), the objective was to map the background variations while at the same time any potential irregularities connected to the CO2 stored in sub-sea geological formation. Additionally, new sensors for autonomous, in situ determination of CO_2-system parameters have been tested.

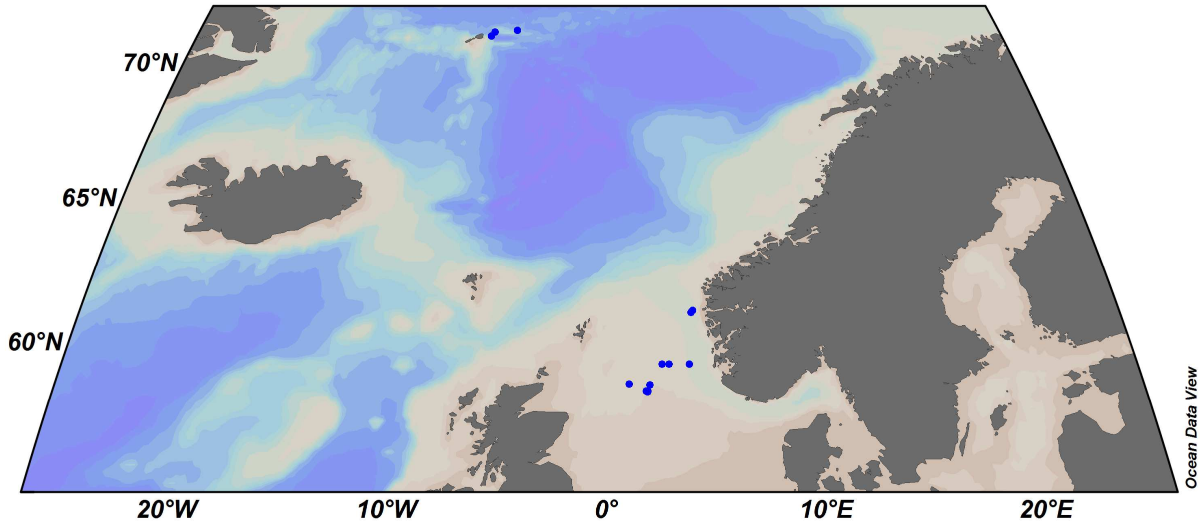

Figure 2: Map of the northern North Atlantic showing the North Sea and Jan Mayen stations (blue dots) visited during the CGB ECO2 cruises in June 26-30 and July 23 – August 5, 2012.

All main variables of the seawater CO_2-system were measured. Seawater samples taken from CTD bottles have been analyzed for:

1) The concentration of **Dissolved Inorganic Carbon (DIC).** This variable has been determined in the lab onboard the ship by using the coulometric method (e.g. Johnson et al., 1993) with the accuracy set by running Certified Reference Material (CRM).

   During the Sleipner cruise DIC was determined for about 20 CTD stations (Figure 2, Table 7). Preliminary analyses of these data indicate that the variability of background concentrations is governed by the processes of dilution and biology.

2) **Total alkalinity (TA)** which has been determined by titrating samples with 0.1 M HCl as described by Haraldson et al. (1997). The accuracy set in the same way as for CT.

   Preliminary analyses of the TA data (about 20 stations) indicate that the variability of background concentrations around the Sleipner area is governed by the processes of dilution and biology.

3) **pH** which has been determined by an instrument developed at GFI/BCCR based on a spectrophotometric principle. No preliminary conclusions can be drawn from these data since they need to be corrected to in situ salinity and temperature.

Additionally, **partial pressure of CO2 (pCO2)** has been measured semi-continuously (every 3 minute) for surface water (pumped from 4 m below the sea surface) using a continuous flow system similar to that described by Feely et al. (1998) and Wanninkhof and Thoning (1993).

Table 7: CTD stations with seawater samples at the Sleipner cruise.

Stat. no	Date time UTC	Lat	Lon	Echo depth	Samples depth [m]
163	230612 0836	59 17.03 N	004 02.00 E	284	275, 239, 220, 120, 91, 50, 9
164	230612 1207	59 16.98 N	003 01.86 E	124	116, 100, 89, 61, 49, 8
165	230612 1400	59 17.03 N	002 41.93 E	119	110, 99, 89, 80, 49, 29, 10
167	240612 1005	58 35.76 N	002 04.97 E	88	85, 70, 59, 49, 40, 29, 19, 9
169	250612 1149	58 23.50 N	001 58.00 E	79	76, 69, 57, 40, 19, 10
170	250612 1238	58 23.50 N	001 56.00 E	80	74, 60, 38, 20, 8
171	250612 1320	58 23.00 N	001 56.99 E	80	75, 60, 30, 20, 9
172	250612 1359	58 22.51 N	001 57.00 E	79	76, 59, 38, 20, 9
173	250612 1435	58 23.00 N	001 58.00 E	79	75, 59, 39, 31, 18, 11
174	250612 1514	58 23.50 N	001 56.99 E	79	75, 50, 10
176	280612 0713	58 37.31 N	002 04.91 E	91	86, 69, 50, 30, 9, 5
178	280612 0929	58 35.72 N	002 04.49 E	89	89, 79, 70, 60, 50, 40, 30, 20, 10
179	290612 0518	58 24.00 N	001 56.50 E	82	81, 69, 31, 10, 4
180	290612 0602	58 24.00 N	001 57.00 E	82	80, 70, 10, 4
181	290612 0644	58 23.00 N	001 56.00 E	82	79, 71, 10, 5
182	290612 0715	58 23.00 N	001 56.50 E	82	80, 70, 19, 10, 4
184	290612 0851	58 24.01 N	001 53.61 E	86	86, 79, 42, 31, 18, 10

4.5 Dissolved gases

By Tamara Baumberger, Anne Stensland, Pål Tore Mørkved, CGB/UoB

Dissolved gases (CH_4 and H_2) were collected from CTD casts performed above the abandoned well 15-9/11 (one cast), above the CO_2-storage site (six casts), above the fracture (four casts) and in background seawaters about 70 km NE from the Sleipner platforms (one cast).

Preliminary data point to an enhanced CH_4 concentration in Sleipner water column compared to a background cast 70 km NE of the area. The highest water column CH_4 concentration was measured right above the well 15/9-11 and suggests that CH_4 leakage at abandoned wells is vital as a CH_4 source in the North Sea. The distribution of the dissolved CH_4 in the water column represents the prevailing water layer density pattern. Thus, most of the CH_4 is accumulated at a water depth of about 40 to 60 m resulting in an overall CH_4 concentration height. Water column CH_4 concentrations in the area above the fracture are not elevated above the local Sleipner water column concentrations. Hydrogen concentration measurements revealed small local enhancements over background concentrations that have to be further investigated.

Selected casts were also measured for dissolved O_2 concentrations. Preliminary data show variations in the concentrations with higher concentrations in the surface seawater as usually seen. The O_2 concentrations also correlate with the water density layers.

4.6 Other water column constituents

Other major and trace constituents will be measured in shore-based laboratories and are not reported her. Some constituents were additionally measured shipboard for later comparison with corresponding shore-based analyses.

4.7 Microbiology

Samples were taken for DNA and RNA analysis, FISH and DAPI staining, several in-situ rate measurements. All microbial analyses are performed within the frame of the FME-SUCCESS project where CGB is a partner.

5. Acknowledgement

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