RV HEINCKE

Impact of CO_2 leakage on marine ecosystems

CRUISE REPORT

HE 377

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Bremerhaven – Bremerhaven

Wenzhöfer F., Asendorf V., Grünke S., Hagemann J., Hoge U., Hovland M., Lehmenhecker S., Shurn K., Weiz E. Wulff T.

Participating Institutions:

Max-Planck-Institut
für Marine Mikrobiologie

AWI

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1. Summary / Zusammenfassung

Cruise HE-377 investigated the effect of CO_2 leakage on benthic ecosystems. Benthic life and communities at two different sites in the North Sea were studied: The industrial CO_2 storage site “Sleipner” and the natural CO_2 seep area “Salt Dome Juist”. During our expedition only weak seismic signs in the water column for gas seepage could be found at the Salt Dome Juist site. AUV dives, mapping the CO2 concentration in the water column over a wider area of potential CO_2 seep sites, did not detect elevated concentrations. Additional video surveys revealed also only one small bubble stream. Sampling of sediments for geochemical characterization was successfully achieved at the two target areas and will help to test the potential effect CO_2 seepage has on biogeochemical processes. A large number of benthic fauna samples (micro-, meio- and macrofauna) were obtained and provide a baseline study for the benthic diversity at both sites. Additionally new interoperable payload modules for biogeochemical investigations were successfully tested during several AUV dives.

Heincke-Fahrt HE-377 untersuchte den Effekt von CO_2 Austritten auf benthische Ökosysteme. Dabei wurden benthische Lebensgemeinschaften in zwei unterschiedlichen Gebieten der Nordsee erforscht: Die industrielle CO_2-Speicherstätte “Sleipner” und das natürliche CO_2-Seep Gebiet “Salt Dome Juist”. Während der Expedition konnten nur schwache seismische Signale von Gasaustritten in der Wassersäule im Salt Dome Juist Arbeitsgebiet detektiert werden. AUV-Tauchgänge im selben Gebiet konnten keine erhöhten CO_2 Konzentrationen in der Wassersäule messen. Zusätzliche Video-Beobachtungen zeigten ebenfalls nur eine einzige kleine Gasaustrittsstelle. Sedimentproben von beiden Arbeitsgebieten konnten erfolgreich gewonnen werden und werden dazu beitragen das geochemische Milieu des Meeresboden zu beschreiben und die potentiellen Effekte von CO_2 Austritten auf biogeochermische Prozesse zu testen. Zahlreiche benthische Faunaproben (Mikro-, Meio- und Makrofauna) wurden genommen und dienen dazu die Diversität zu charakterisieren und werden als Baseline-Studien für beide Gebiete dienen. Darüber hinaus konnte neue interoperable Nutzlast-Module für biogeochemische Untersuchungen erfolgreich während zweier AUV-Tauchgänge getestet und eingesetzt werden.

2. Participants

Name	Discipline	Institution
Wenzhöfer, Frank, Dr.	Chief Scientist	AWI/MPI
Wulff, Thorben	AUV	AWI
Hoge, Ulrich	AUV	AWI
Lehmenhecker, Sascha	AUV	AWI
Shurn, Kimberly	AUV	Bluefin
Hagemann, Jonas	CTD/AUV	AWI
Grünke, Stefanie, Dr.	Microbiology/Biogeochemistry	MPI
Lichtschlag, Anna, Dr.	Biogeochemistry/Fauna	MPI
Weiz, Erika	Biogeochemistry/ Microbiology	MPI
Asendorf, Volker	In Situ Instruments/MUC	MPI
Hovland, Martin	Norwegian Observer	Statoil

AWI	Alfred-Wegener-Institute for Polar- und Marine Research, Germany
MPI	Max-Planck-Institute for Marine Microbiology, Germany
Bluefin	Bluefin Robotics, USA
Statoil	Statoil ASA, Norway

3. Research Program

The cruise HE-377 contributed to two EC's 7th FP projects: ECO2 and EUROFLEETS and investigated the effect of CO2 leakage at two different sites (Fig. 3.1): Sleipner, an industrial CO2 storage site and Salt Dome Juist, a natural CO2 seeping site.
The aims of **ECO2** are to quantify the biological impacts of CO2 leakage, to assess the biological risks associated with CO2 storage and to identify appropriate methods to monitor the marine environment above a storage site. To reach these goals we investigated the biogeochemical processes at the CO2 seep and storage sites and the consequences leaking CO2 has on the biota. We took samples to characterize the geochemical zonation of the seafloor, to quantify benthic fluxes of relevant parameters and to determine the abundance of the fauna along concentration gradients. Two working sites had been selected: The industrial CO2 storage site Sleipner and the Salt Dome Juist area where natural CO2 seepage had been observed. The main objectives for ECO2 were: 1) Quantifying fluxes of fluid and gas across the seawater-sediment interface at natural CO2 seeps and storage sites with the help of new biogeochemical sensor modules developed within the EU-project “Eurofleets“, 2) Quantifying the consequences of CO2 leakage for the health and function of marine organisms and communities and 3) Identify and test biological indicators and monitoring techniques appropriate for detecting episodic events and/or

prolonged low-flux CO2 seepage. The main technologies to study these environments were the AUV Bluefin (AWI) for water column studies and Benthic Lander systems for in situ flux studies. Sediment samples were taken by MUC sampling.
The overall aim in **EUROFLEETS** is the development of a shared and interoperable set of payloads to operate on different underwater systems, e.g. ROV, AUV or observatories. During this cruise two new interoperable payloads were tested and used on the AUV Bluefin (AWI, Bremerhaven):
1) a module for In situ biogeochemical studies (BioGeoChemical -BGC-Module) and 2) a modular Interoperable In situ Chemical Analysis and Sampling Payload (ICASP Module).

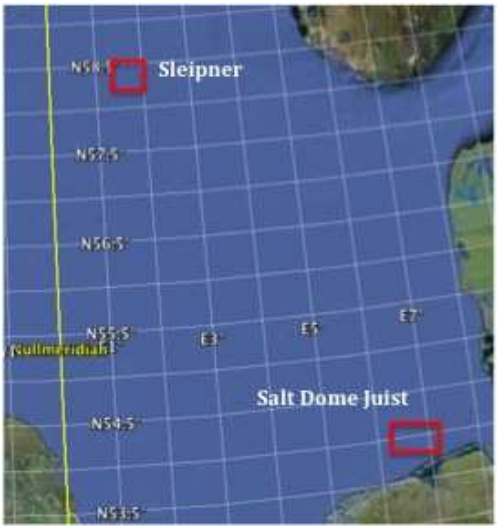

Fig. 3.1: Map of the working sites in the North Sea; natural CO_2 seeps at the Salt Dome Juist (Germany) and the Sleipner industrial CO_2 storage site (Norway)

The **Sleipner** CO2 storage site (Fig. 3.1) has been in operation since 1996 by Statoil. More than 14 million m^3 of CO2 have been injected into a saline aquifer (Utsira sand formation) located in the Norwegian section of the North Sea at ~80 m water depth and ~900 m sediment depth. Sleipner is by far the best-studied and most advanced offshore storage site in the world. The spread of CO2 in the reservoir rock has been studied and monitored in detail by the operator and within other research projects using 3-D time-lapse seismic data (Arts et al., 2004; Chadwick et al., 2009). However, comparatively little is known about the seepage occurring at the seabed. Statoil has observed a number of seeps in the vicinity of the injection site where shallow gas is being emitted into the water column (Heggland, 1997). Some of these active seeps are associated with abandoned exploration wells.

Natural CO2 seeps in the area of “**Salt Dome Juist**” (Fig. 3.1) are studied as analogues for CO2 leakage allowing in situ investigation of a number of key processes controlling leakage pathways and impacts on biota. Areas of gas (bubble) seepage were discovered in the Southern German North Sea during a pre-site mapping study in October 2008 (Alkor cruise AL328). Gas bubbles were observed in these areas together with strong acoustic flares, low pH and high concentrations of CO2 near the seafloor (McGinnis et al., 2011). The area, called “Salt Dome Juist” is located in the Southern North Sea about 30 km offshore the East-Frisian Island Juist, Germany.

Unfortunately only a few sediment and water samples could be retrieved from the Sleipner site due to bad weather conditions. These samples continue the sediment investigations from Alkor cruise AL374 in 2011. Detailed water column and sediment investigations were performed at the Salt Dome Juist Site. Several AUV dives were performed to monitor the water column chemistry together with video guided surveys. The benthic lander deployment was not successful since we lost the lander during recovery. Luckily we were able to get it back after intensive dredging. A high number of sediment samples could be retrieved which will help to characterize the microbial and fauna community at this natural seep site.

4. Narrative of the Cruise

Cruise HE 377 (Fig. 4.1) started in the evening of April 16 with our transit to the first working site, the Sleipner CO_2 storage field. After arrival at the Sleipner platform in the morning of April 18 we started our working program with an Echosounder survey of the working area. This was followed by video camera profiles along an East-West and North-South transect. Unfortunately the video survey had to be aborted because of electrical problems with the video-sledge. Both surveys for gas detection, echosound and video, did not show any gas release from the seafloor. An intensive sampling program for sediments (Multiple corer and Van Veen grab) and water samples (CTD/Rosette sampler) was started afterwards. Sampling followed an East-West and North-South transect according to sites visited during a previous cruise to Sleipner (AL 374, Chief scientist Peter Linke, GEOMAR, Germany) in 2011. Due to stormy weather at the working site and the expectation that these conditions should prevail for the next days we decided to stop working at Sleipner and to move to our second working area at the Salt Dome Juist. On our way south we included another station at the Blow Out Site at Well 22/4-b, where colleges from GEOMAR deployed a lander system in 2011, which they have not been able to recover so far. We arrived at the site on April 19^{th} at 5:00 and started our working program with a CTD/Rosette cast. Afterwards we successfully recovered the missing GEOMAR lander system. We continued our southwards transit passing the Elgin facilities and arrived at the Salt Dome Juist working area in the afternoon of April 20. For the water column and sediment sampling we first revisited a site previously sampled during AL 374 in 2011 and performed our standard sampling program - CTD/Rosette, MUC and Van Veen grab. Subsequent to the sampling we deployed an Eddy correlation lander and a Profiler-Chamber-Lander to conduct in situ flux studies. During the evening an echosound survey was performed covering the Southern Part of the working area at the Juist Salt Dome site. On April 21 we recovered the Eddy lander successfully but during the recovery of the Profiler-Chamber-Lander the mooring rope broke and the Lander stayed at the seafloor. Recovering the Lander by dredging did not work and after several hours of unsuccessful attempts we continued with the sampling program. In the evening the Echosounder survey from the day before was continued covering the northern part of the working area. Weak flares could be observed in the western and north-east part of the survey area. April 22nd started with the second dive of the AUV Bluefin (AWI, Bremerhaven). For the dive the AUV was equipped with sensors (e.g. pCO_2, PAR), CTD, water sampling system and a BGC-Module (BioGeoChemical-Module for pCO_2, oxygen and pH). During the 5-hour mission the AUV was able to perform a monitoring grid in the northwest part of the working area. Afterwards the sediment and water column sampling was continued and a 1-hour Video-sledge survey was performed. During the north-south transects in the southern part of the working area a small gas bubble stream was detected. In the night, after several attempts to dredge the lander frame, we were able to recover the Profiler-Chamber-Lander. Except some minor damage on the frame the lander system was finally back on deck without any damage on the electronic modules. On April 23rd we started with sediment and water column sampling in the northern part and continued also our video survey in this area. Unfortunately no gas bubbles could be observed this time. A second 5-hour AUV dive was performed to cover the northern part of the Salt Dome Juist site. The AUV completed a survey grid 5 m above ground searching for spots of CO_2 release. Our work program ended with the recovery of the AUV in the evening of April 23rd after which we started our transit to Bremerhaven. In the morning of April 24th we arrived at the AWI pier where our expedition ended.

Fig. 4.1: Track chart of RV HEINCKE cruise HE-377

5. Preliminary Results

5.1 Echolot Mapping

The navigation echosounder of RV Heincke was used for the determination of water depth, to visualize the sediment surface and to determine gas flares by their seismic reflection. Two large Echosounder tracks were completed at the Salt Dome Juist covering the investigated area (Fig. 5.1.1). A rectangular box was virtually placed above our site and Heincke mapped the area according to a pre-defined grid.

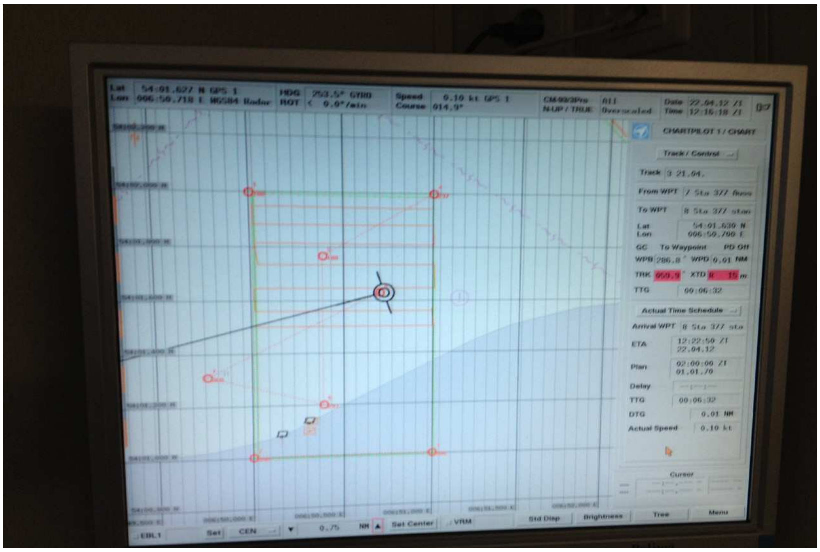

Fig. 5.1.1 Mapping grid for the Echosounder survey at Salt Dome Juist.

Seismic reflections from the whole water column and bottom water observations indicated only weak seepage activities during our mapping activities (Fig. 5.1.2; see Station list).

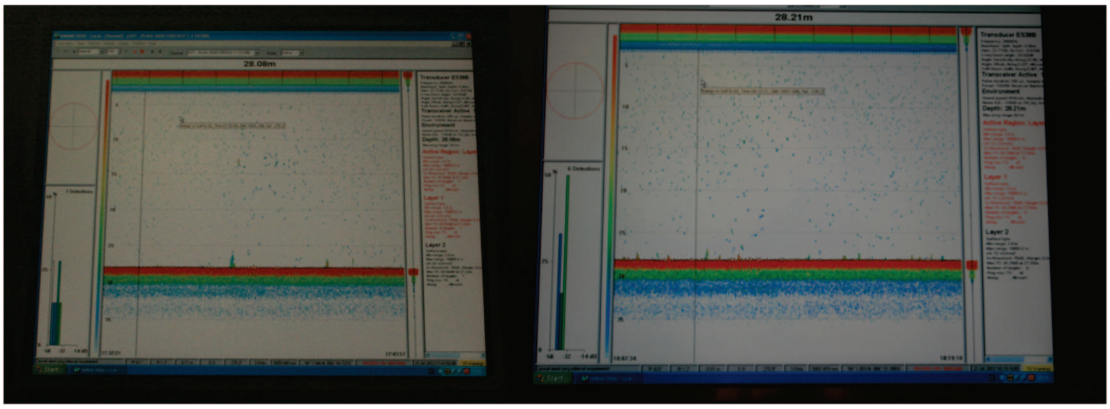

Fig.5.1.2: Example of weak bubble streams escaping the seafloor detected with the echolot in the Salt Dome Juist area

5.2 Water Column sampling and observation

Water column samples were taken with the CTD/Rosette water column sampler. CTD tracks were recorded at all sites where sediment samples were taken. Bottom water and selected water column samples were taken for DIC, oxygen and pH analyses. Samples will be analysed back home in the laboratory.

Water column gas bubble observations were performed with the Ocean Floor Observation System (OFOS, Marum; Fig. 5.2.2). During several hours of video survey only one small bubble stream could be detected.

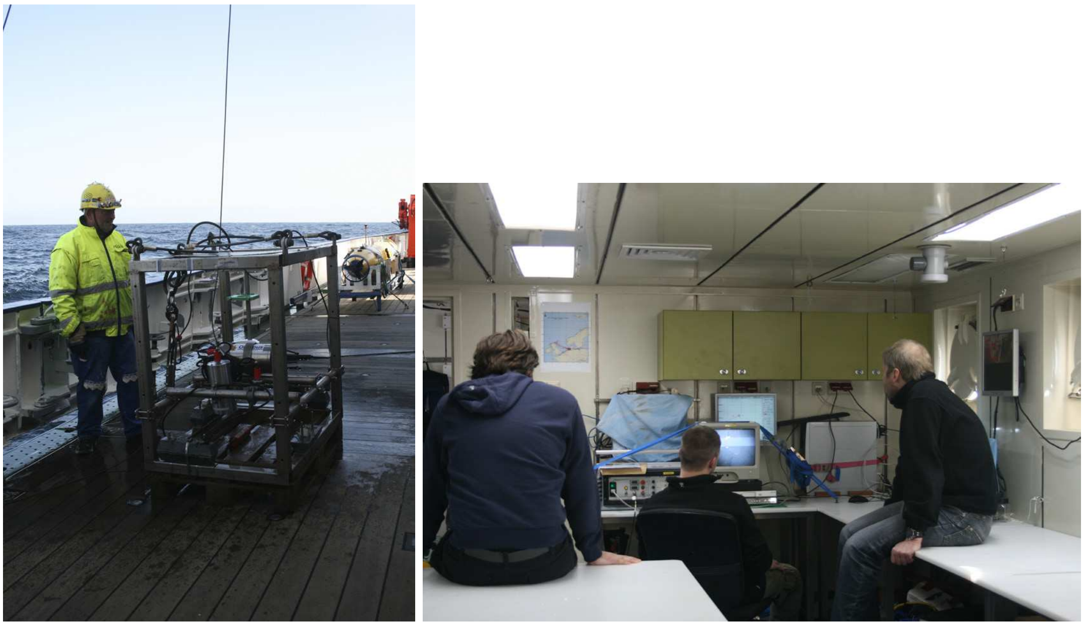

Fig. 5.2.2: (A) OFOS camera system for seafloor observations and gas bubble detection (B) Monitoring the on-line video for gas bubble emission at the seafloor

5.3 Autonomous underwater vehicle (AUV)

Autonomous Underwater Vehicles (AUV) offers the possibility to investigate large sea floor areas comprehensively without consuming ship time. Due to its sensors the AUV of the Alfred Wegener Institute (AWI) is especially adapted to detect biochemical parameters like for example CO_2 (Fig. 5.3.1). Thus, during HE-377, extensive search grids with the AUV closely above the sea floor were performed in order to find natural CO_2 seeps or CO_2 leaks at the seafloor. To detect CO_2 the vehicle was equipped with a CO_2 sensor manufactured by Contros (Kiel, Germany) and CO_2 microelectrodes of the American manufacturer Microelectrodes Inc. (Bedford, New Hampshire). The microelectrodes were mounted on the so-called BioGeoChemical (BGC)

Module, which was developed at the Max Planck Institute for Marine Microbiology (MPI) in Bremen

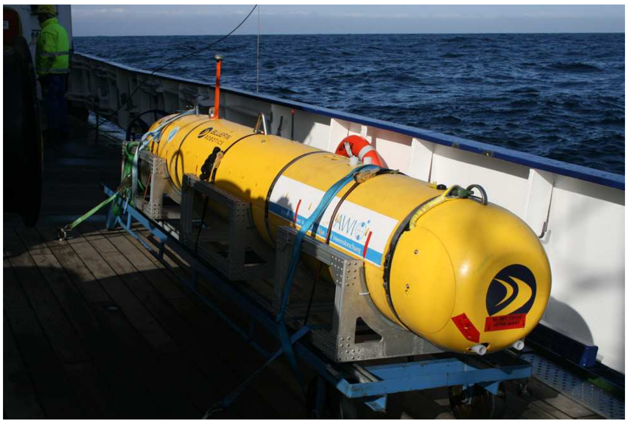

Fig. 5.3.1: AUV (AWI) for water column studies above the seafloor

In total, the AUV accomplished three dives during HE-377. Submerged, the vehicle covered a distance of 68 km and investigated an area of 2.5 km² with a spatial resolution of 60 m. Due to weather and sea state deploying the AUV at the Sleipner storage site was not possible. In the second selected survey site, north of the island of Juist, it was possible to trim and test the vehicle (1. Dive) and to accomplish two search grids (2. + 3. Dive). The search grids of both dives overlapped a little to ensure a gapless investigation of the area. The search grids of the dives 2 (22.04.12) and 3 (23.04.12) can be seen in Figure 5.3.2. During both dives the vehicle kept a distance of 5 m to the sea floor and moved at a speed of 1.5 m/s.

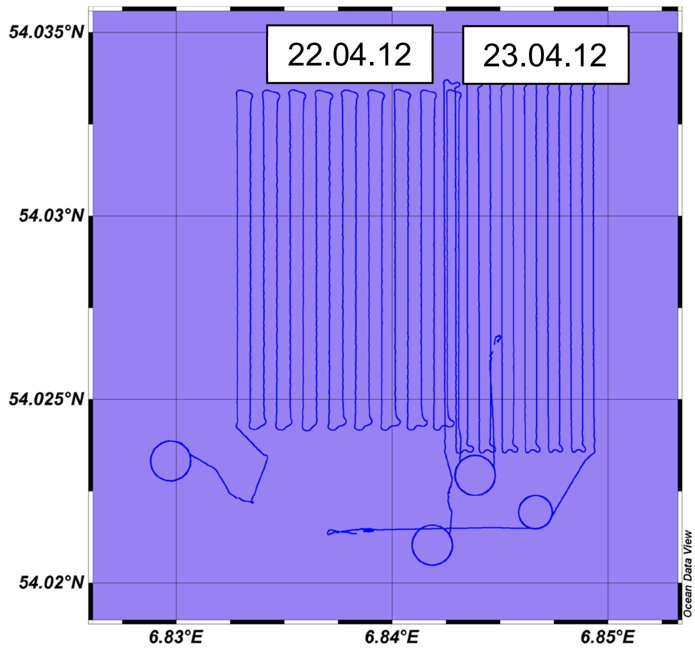

Fig. 5.3.2: AUV search grids during HE-377

Figure 5.3.3 shows the monitored water column CO_2 value 5-m above seafloor in the investigated area graphically. The CO_2 map reveals that the CO_2 value was generally higher during the third dive but no gradients could be detected. In contrast a smooth gradient of 2 µatm in the CO_2 partial pressure could be observed a day before (2. Dive; 22.04.12). As this gradient was very small and apparently parallel to the tracks of the search grid, it was most likely caused by tidal effects. Thus it rather was a “temporal” than a “spatial” gradient and it could not be traced back to gas seeps on the sea floor.

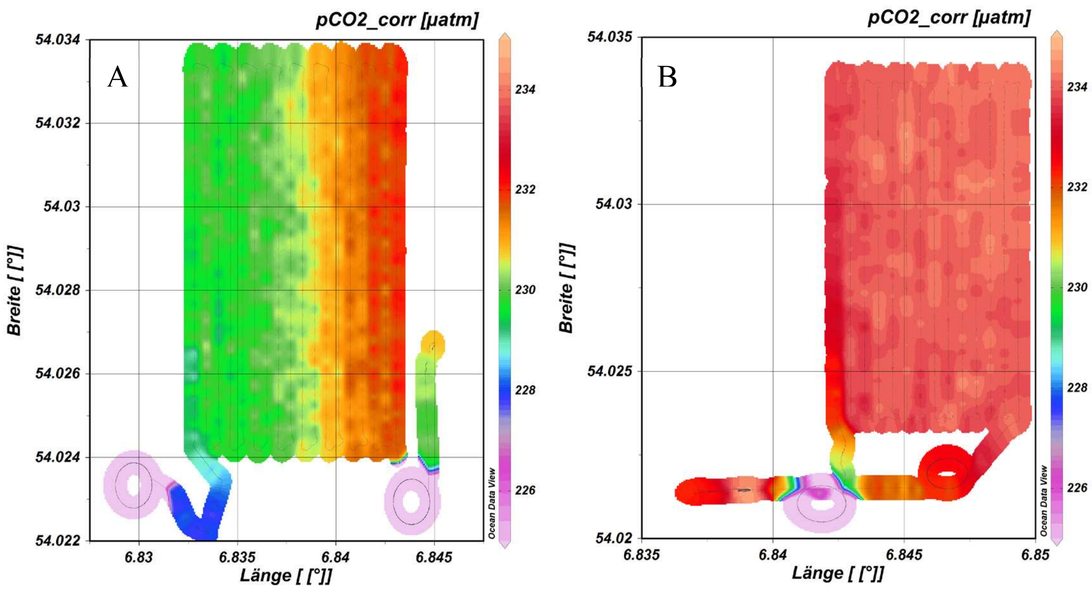

Fig. 5.3.3: a) CO_2 distribution during Dive 2 (22.04.12) and b) CO_2 distribution during Dive 3 (23.04.12)

Although the sonar of RV Heincke was able to detect weak gas flares, the AUV bound measurements did not show point-shaped CO_2 sources. It is possible that the response time of currently available CO_2 sensors are too long to clearly detect such small sources with a relatively fast moving platform like an AUV.

On the other hand the distance of the vehicle to the sea floor plays a key role. The vehicle´s sensors can only detect dissolved substances. The closer the vehicle comes to the sea floor the less time is available for the gas bubbles to dissolve in the water. At the same time, as water currents push the bubbles around, a relatively small distance between the vehicle and the sea floor is an important precondition to exactly detect the location of the gas seeps. By keeping a greater distance from the sea floor the possibility to find seepage will increase. However the information of where to find the source of the gas gets lost. In this respect the right distance from the sea floor during these missions will remain a compromise between “as close as possible, as far as necessary”.

5.4 Bio-Geochemistry

Sampling of sediments for geochemical characterization was successfully achieved at the 2 main target areas of HE377: the Salt Dome Juist and the CO_2 plume area at Sleipner. At the Salt Dome Juist geochemical analyses were done to test the potential effect of CO_2 seepage on the biogeochemical cycles in North Sea sediment (Fig. 5.4.1). The goal of the geochemical analyses of sediments from the Sleipner plume area was to describe the general geochemical characteristics of this area and to look for potential signs of CO_2 leakage. At both sites the upper 10 to 20 cm of the near surface sediment layers were recovered with a multiple corer at several stations (Table 1). Pore water and sediments were sampled in parallel to the microbiological samples (i.e. from the same multiple corer).

Pore water was extracted from the sediments using Rhizons (19.21.23F, mean pore size 0.15 µm; Rhizosphere Research Products, Wageningen, Netherlands). The Rhizons were inserted horizontally into the cores through pre-drilled holes, which had been sealed with diffusion-tight tape prior to sediment sampling. Pore-water extraction from the sediment was done by connecting the Rhizons to 5 mL-syringes (luer-lock fittings, PVC tubing) and building up an under-pressure by drawing the piston. Owing to the high-resolution sampling, pore water obtained from two different cores had to be combined for some stations.

For DIC (dissolved inorganic carbon) and TA (total alkalinity), 2 mL of the pore water was filled into glass vials without leaving any headspace and stored at 4°C. In addition, samples of bottom water overlying the sediment in the multiple corer tubes, were fixed with approx. 5µL of $HgCl_2$ to prevent biological turnover. For sulfide, sulfate and chloride concentration analysis, 1 mL of pore water was fixed in plastic vials pre-filled with 0.5 mL 2% ZnAc and stored at 4°C. Samples dedicated to nutrient analyses (NH_4^+, PO_4^{3-}, NO_2^-, NO_3^-/NO_2^-, Si), were first analysed regarding their pH (pH 96 by WTW, Weilheim, Germany) and were then frozen (-20°C, plastic vials). Fe and Mn concentrations will be determined from samples fixed in 0.2 mL 1M HCl (plastic vials) and stored at 4°C. All analyses are pending and will be finished within the coming months at MPI. In addition, pore waters will be analyzed for their B content in cooperation with Dr. M. Haeckel from Geomar (Kiel, Germany). Therefore, pore water was filled into 4 mL-Polyvials V (PETG; Zinsser Analytic, Northridge, CA) that had been thoroughly washed with diluted HNO_3 (for trace analyses; Roth, Karlsruhe, Germany) and deionized/filter-sterile water. To reduce the pH, 30 µL of 69% HNO_3 (for trace analyses; Roth) were added to each sample. Storage of the samples was at 4°C.

For porosity, sediment was stored at 4°C in 5 mL capped, cut-off syringes. Methane concentrations will be determined from the headspace above a 5 mL sediment / 10 mL NaOH (2.5%) mixture stored in 20 mL gas-tight glass vials (storage at 4°C). The analyses are still ongoing (MPI).

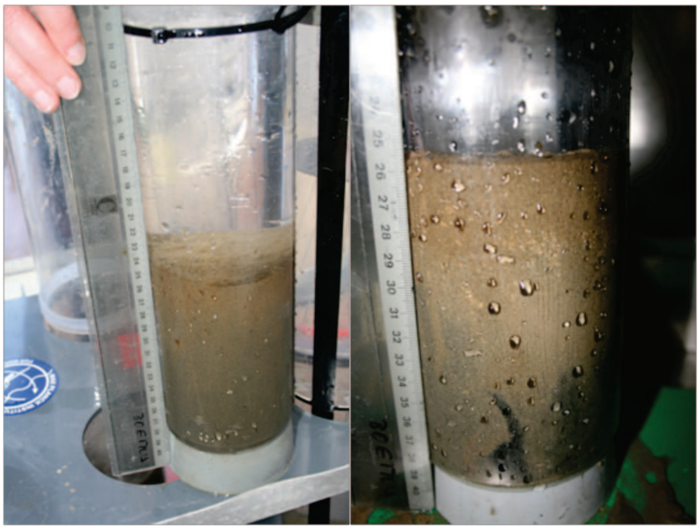

Fig. 5.4.1: Typical sediment sample retrieved with a multiple corer from the Sleipner plume area and the Salt Dome Juist.

The in situ flux studies using benthic lander systems (Benthic Chamber Lander with 3 chambers and one microprofiler as well as an Eddy-lander) failed because we lost our lander during the recovery of the first deployment. The in situ studies were intended to determine benthic exchange rates, fluid/gas fluxes and to measure high-resolution microprofiles. With intensive dredging during the nights we were able to retrieve our lander back but only at the end of the expedition thus no further deployments were possible.

5.5 Microbiology & Meiofauna

The initial goal of this study was to investigate the effects of high CO_2-low pH on benthic microbial communities at the natural seep site Salt Dome Juist (SDJ), and to investigate the current status of microbial diversity at the storage site Sleipner. However, as only weak signals of gas ebullition could be detected at SDJ, recovered sediment samples will now be used for a baseline study at both sites.

Sediments were recovered in parallel to the biogeochemical samples (Tab. 5.5.1), and were preserved for DNA analyses (bacterial community composition, MPI), total microbial cell counts (MPI) and meiofaunal diversity (Ghent University). Upon recovery, cores were either sectioned immediately or were stored at *in situ* temperature until further use (maximum one day). For DNA analyses, at least triplicate samples were taken at each station and stored in sterile tubes or bags at -20°C. Sediment sections dedicated to cell counts were fixed as follows: either 2 mL of sediment was fixed in 9 mL formaldehyde/seawater at 4°C, or 0.5 mL was first fixed in approx. 3 mL formaldehyde/seawater, was then washed twice with 1 × PBS (phosphate buffered saline) before it was preserved in 2-3 mL PBS/EtOH at -20°C. Regarding meiofauna, approx. 15 mL of sediment were transferred to a sterile 50 mL-tube and filled up with 4% formaldehyde/seawater. The samples were resuspended and stored at *in situ* temperature (6-7°C).

Analyses of microbial communities are currently in process at the MPI. Molecular techniques will include community fingerprinting by Automated Ribosomal Intergenic Spacer Analysis (ARISA), acridine orange direct cell counts (AODC) and fluorescence *in situ* hybridization (FISH). The meiofaunal composition within the sediments will be analyzed by Katja Guilini and Ann Vanreusel (Ghent University, Belgium).

In addition to sediment recovery with a multiple corer, a few samples were also retrieved by using a Van Veen Grab (Table 1). These samples were stored in plastic containers at *in situ* temperature and will serve as natural back up samples.

Table 5.5.1: Sediment sampling during cruise He377 (2012). MMUC: Mini Multiple Corer, SG: sediment grab (Van Veen Grab). The positions correspond only to one sampling event at each station.

Station	*Site*	*Sampling device*	*Water depth*	*Position*	*Date*
3	Sleipner	MMUC	80 m	58.386 1.946	18.04.2012
5	Sleipner	SG	80 m	58.386 1.947	18.04.2012
6	Sleipner	SG MMUC	78-79 m	58.387 1.959	18.04.2012
9	Sleipner	MMUC	79-80 m	58.377 1.946	18.04.2012
11	Sleipner	SG	79 m	58.376 1.946	18.04.2012
12	Sleipner	SG	84 m	58.368 1.868	18.04.2012
13	Outside Sleipner	MMUC	84 m	58.369 1.869	18.04.2012
17	Juist	MMUC	26 m	54.018 6.835	20.04.2012
18	Juist	MMUC	27 m	54.018 6.835	20.04.2012
19	Juist	SG	27 m	54.018 6.835	20.04.2012
23	Juist	MMUC	28-29 m	54.029 6.84	21.04.2012
30	Juist	MMUC	27 m	54.02 6.839	21.04.2012
35	Outside Juist	MMUC	28 m	54.034 6.766	22.04.2012
40	Juist	MMUC	28 m	54.033 6.85	23.04.2012

5.6 Macrofauna

At both target areas, the Salt Dome Juist and in the Sleipner CO_2 plume area, samples were taken for studying benthic community structure and diversity of macrofauna. Results will be used to identify possible indicator species for elevated CO_2 content in the sediment.

Samples were taken with a Van Veen grab sampler (volume: 17L), sieved to individuals > 1mm size and fixed in plastic containers in buffered formaldehyde for later taxonomic analysis (Fig. 5.6.1). Altogether, 9 stations have been sampled and at each station four replicate samples were taken. Metadata of the samples is displayed in Table 5.6.1. To be able to correlate the data to environmental parameters and further biological abundances, macrofauna samples were taken in parallel to meiofauna and microbial samples and samples for geochemical analyses.

Samples have been passed on to GEOMAR (F. Melzner) for analyses.

Fig. 5.6.1: Macrofauna sampling with Van Veen Grab. A: Emptying of grab into washing table; B: carful transfer of sample into container with mesh at the bottom (size 1mm); C: example of sea urchin found at Sleipner.

Table 5.6.1: Metadata of macrofauna samples taken during HE 377.

Station/Event No.	*Area*	*Date*	*Latitude*	*Longitude*	*Depth (m)*
HE377/005-1		18.04.12	58° 23.19' N	1° 56.83' E	79.4
HE377/005-2		18.04.12	58° 23.18' N	1° 56.86' E	78.9
HE377/005-3	Sleipner	18.04.12	58° 23.20' N	1° 56.81' E	80.2
HE377/005-4		18.04.12	58° 23.19' N	1° 56.77' E	80.6
HE377/006-1		18.04.12	58° 23.20' N	1° 57.53' E	78.9
HE377/006-2		18.04.12	58° 23.19' N	1° 57.55' E	78.7
HE377/006-3	Sleipner	18.04.12	58° 23.19' N	1° 57.52' E	79.1
HE377/006-4		18.04.12	58° 23.19' N	1° 57.52' E	78.4
HE377/011-1		18.04.12	58° 22.60' N	1° 56.82' E	78.5
HE377/011-2		18.04.12	58° 22.57' N	1° 56.82' E	79.1
HE377/011-3	Sleipner	18.04.12	58° 22.58' N	1° 56.77' E	78.7
HE377/011-4		18.04.12	58° 22.57' N	1° 56.78' E	79.0
HE377/012-1		18.04.12	58° 22.14' N	1° 52.14' E	84.5
HE377/012-2		18.04.12	58° 22.14' N	1° 52.11' E	84.8
HE377/012-3	Sleipner	18.04.12	58° 22.14' N	1° 52.12' E	84.4
HE377/012-4		18.04.12	58° 22.11' N	1° 52.11' E	84.1
HE377/019-1		20.04.12	54° 1.08' N	6° 50.12' E	26.5
HE377/019-2		20.04.12	54° 1.08' N	6° 50.14' E	26.6
HE377/019-3	Salt Dome	20.04.12	54° 1.08' N	6° 50.13' E	26.8
HE377/019-4	Juist	20.04.12	54° 1.08' N	6° 50.12' E	26.6
HE377/024-1		21.04.12	54° 1.76' N	6° 50.40' E	28.7
HE377/024-2	Salt Dome	21.04.12	54° 1.76' N	6° 50.41' E	28.9
HE377/024-3	Juist	21.04.12	54° 1.76' N	6° 50.41' E	28.7
HE377/024-4		21.04.12	54° 1.76' N	6° 50.41' E	28.8
HE377/031-1		21.04.12	54° 1.21' N	6° 50.38' E	26.7
HE377/031-2	Salt Dome	21.04.12	54° 1.21' N	6° 50.38' E	26.8
HE377/031-3	Juist	21.04.12	54° 1.21' N	6° 50.39' E	26.8
HE377/031-4		21.04.12	54° 1.20' N	6° 50.39' E	27.2
HE377/034-1		22.04.12	54° 2.01' N	6° 46.00' E	28.6
HE377/034-2	Salt Dome	22.04.12	54° 2.00' N	6° 46.02' E	28.6
HE377/034-3	Juist	22.04.12	54° 2.00' N	6° 46.03' E	28.5
HE377/034-4		22.04.12	54° 2.00' N	6° 46.03' E	28.3
HE377/041-1		23.04.12	54° 1.98' N	6° 50.99' E	28.4
HE377/041-2	Salt Dome	23.04.12	54° 1.97' N	6° 51.00' E	28.1
HE377/041-3	Juist	23.04.12	54° 1.97' N	6° 51.00' E	28.7
HE377/041-4		23.04.12	54° 1.98' N	6° 51.00' E	28.7

6. Station List

Station	Date	Time	Position Lat	Position Lon	Depth [m]	Gear
HE377/0001-1	18.04.12	06:24:00	58° 23,21' N	1° 56,84' E	79,5	Echosounder
HE377/0002-1	18.04.12	07:26:00	58° 23,24' N	1° 58,37' E	78,1	OFOS
HE377/0002-2	18.04.12	08:14:00	58° 23,22' N	1° 57,90' E	79,0	OFOS
HE377/0003-1	18.04.12	09:52:59	58° 23,19' N	1° 56,79' E	79,1	Multi corer
HE377/0003-2	18.04.12	09:53:59	58° 23,19' N	1° 56,77' E	80,6	Multi corer
HE377/0003-3	18.04.12	10:08:59	58° 23,20' N	1° 56,77' E	79,5	Multi corer
HE377/0003-4	18.04.12	10:16:59	58° 23,15' N	1° 56,80' E	79,1	Multi corer
HE377/0003-5	18.04.12	10:23:59	58° 23,16' N	1° 56,75' E	80,1	Multi corer
HE377/0003-6	18.04.12	10:38:59	58° 23,17' N	1° 56,80' E	79,0	Multi corer
HE377/0003-7	18.04.12	10:45:59	58° 23,18' N	1° 56,81' E	81,1	Multi corer
HE377/0003-8	18.04.12	10:54:59	58° 23,17' N	1° 56,79' E	79,6	Multi corer
HE377/0003-9	18.04.12	11:03:59	58° 23,16' N	1° 56,78' E	79,7	Multi corer
HE377/0004-1	18.04.12	11:16:00	58° 23,22' N	1° 56,82' E	80,0	CTD/rosette water sampler
HE377/0005-1	18.04.12	11:51:59	58° 23,19' N	1° 56,83' E	79,4	van Veen grab
HE377/0005-2	18.04.12	12:01:59	58° 23,18' N	1° 56,86' E	78,9	van Veen grab
HE377/0005-3	18.04.12	12:09:59	58° 23,20' N	1° 56,81' E	80,2	van Veen grab
HE377/0005-4	18.04.12	12:16:59	58° 23,19' N	1° 56,77' E	80,6	van Veen grab
HE377/0005-5	18.04.12	12:22:59	58° 23,18' N	1° 56,80' E	80,1	van Veen grab
HE377/0006-1	18.04.12	12:47:59	58° 23,20' N	1° 57,53' E	78,9	van Veen grab
HE377/0006-2	18.04.12	12:53:59	58° 23,19' N	1° 57,55' E	78,7	van Veen grab
HE377/0006-3	18.04.12	13:00:59	58° 23,19' N	1° 57,52' E	79,1	van Veen grab
HE377/0006-4	18.04.12	13:06:59	58° 23,19' N	1° 57,52' E	78,4	van Veen grab
HE377/0006-5	18.04.12	13:12:59	58° 23,21' N	1° 57,53' E	78,5	van Veen grab
HE377/0006-6	18.04.12	13:19:00	58° 23,21' N	1° 57,51' E	78,7	CTD/rosette water sampler
HE377/0006-7	18.04.12	13:43:59	58° 23,20' N	1° 57,55' E	78,6	Multi corer
HE377/0006-8	18.04.12	13:47:59	58° 23,20' N	1° 57,54' E	79,1	Multi corer
HE377/0006-9	18.04.12	13:55:59	58° 23,21' N	1° 57,51' E	79,3	Multi corer
HE377/0006-10	18.04.12	14:03:59	58° 23,20' N	1° 57,53' E	78,8	Multi corer
HE377/0006-11	18.04.12	14:11:59	58° 23,19' N	1° 57,53' E	78,0	Multi corer
HE377/0006-12	18.04.12	14:20:59	58° 23,19' N	1° 57,53' E	78,1	Multi corer
HE377/0006-13	18.04.12	14:35:59	58° 23,22' N	1° 57,51' E	78,9	Multi corer
HE377/0006-14	18.04.12	14:46:59	58° 23,24' N	1° 57,47' E	79,2	Multi corer
HE377/0006-15	18.04.12	14:58:59	58° 23,23' N	1° 57,48' E	78,3	Multi corer
HE377/0008-1	18.04.12	15:09:59	58° 23,22' N	1° 57,46' E	79,0	Multi corer
HE377/0009-1	18.04.12	15:41:59	58° 22,57' N	1° 56,77' E	79,8	Multi corer
HE377/0009-2	18.04.12	15:56:59	58° 22,60' N	1° 56,72' E	79,3	Multi corer
HE377/0009-3	18.04.12	16:09:59	58° 22,60' N	1° 56,74' E	78,9	Multi corer
HE377/0010-1	18.04.12	16:20:00	58° 22,62' N	1° 56,67' E	79,4	CTD/rosette water sampler

HE377/0011-1	18.04.12	16:44:59	58° 22,60' N	1° 56,82' E	78,5	van Veen grab
HE377/0011-2	18.04.12	16:52:59	58° 22,57' N	1° 56,82' E	79,1	van Veen grab
HE377/0011-3	18.04.12	16:59:59	58° 22,58' N	1° 56,77' E	78,7	van Veen grab
HE377/0011-4	18.04.12	17:07:59	58° 22,57' N	1° 56,78' E	79,0	van Veen grab
HE377/0011-5	18.04.12	17:07:59	58° 22,57' N	1° 56,78' E	79,0	van Veen grab
HE377/0012-1	18.04.12	17:39:59	58° 22,14' N	1° 52,14' E	84,5	van Veen grab
HE377/0012-2	18.04.12	17:43:59	58° 22,14' N	1° 52,11' E	84,8	van Veen grab
HE377/0012-3	18.04.12	17:47:59	58° 22,14' N	1° 52,12' E	84,4	van Veen grab
HE377/0012-4	18.04.12	17:50:59	58° 22,11' N	1° 52,11' E	84,1	van Veen grab
HE377/0012-5	18.04.12	17:54:59	58° 22,11' N	1° 52,07' E	83,6	van Veen grab
HE377/0013-1	18.04.12	18:02:59	58° 22,12' N	1° 52,12' E	84,5	Multi corer
HE377/0013-2	18.04.12	18:09:59	58° 22,13' N	1° 52,10' E	84,4	Multi corer
HE377/0013-3	18.04.12	18:25:59	58° 22,12' N	1° 52,12' E	84,1	Multi corer
HE377/0014-1	18.04.12	18:35:00	58° 22,11' N	1° 52,15' E	84,2	CTD/rosette water sampler
HE377/0015-1	19.04.12	05:05:00	57° 55,33' N	1° 37,55' E	94,0	CTD/rosette water sampler
HE377/0015-2	19.04.12	05:15:00	57° 55,33' N	1° 37,55' E	94,3	Geomar-Lander recovery
HE377/0016-1	20.04.12	15:57:00	54° 1,05' N	6° 50,06' E	26,4	Bathysonde
HE377/0017-1	20.04.12	16:01:00	54° 1,06' N	6° 50,10' E	26,5	CTD/rosette water sampler
HE377/0017-2	20.04.12	16:13:59	54° 1,07' N	6° 50,12' E	26,5	Multi corer
HE377/0017-3	20.04.12	16:19:59	54° 1,07' N	6° 50,13' E	26,2	Multi corer
HE377/0018-1	20.04.12	16:26:59	54° 1,07' N	6° 50,11' E	26,7	Multi corer
HE377/0018-2	20.04.12	16:35:59	54° 1,08' N	6° 50,11' E	26,7	Multi corer
HE377/0019-1	20.04.12	16:37:59	54° 1,08' N	6° 50,12' E	26,5	van Veen grab
HE377/0019-2	20.04.12	16:40:59	54° 1,08' N	6° 50,14' E	26,6	van Veen grab
HE377/0019-3	20.04.12	16:42:59	54° 1,08' N	6° 50,13' E	26,8	van Veen grab
HE377/0019-4	20.04.12	16:46:59	54° 1,08' N	6° 50,12' E	26,6	van Veen grab
HE377/0019-5	20.04.12	16:49:59	54° 1,08' N	6° 50,12' E	26,8	van Veen grab
HE377/0020-1	20.04.12	17:12:59	54° 1,07' N	6° 50,11' E	27,2	Benthic Lander deployment
HE377/0021-1	20.04.12	17:59:59	54° 1,13' N	6° 50,30' E	27,5	Eddy-Lander deployment
HE377/0022-1	21.04.12	04:55:00	54° 2,12' N	6° 49,98' E	28,0	Echosounder
HE377/0023-1	21.04.12	06:38:59	54° 1,76' N	6° 50,39' E	28,4	Multi corer
HE377/0023-2	21.04.12	06:48:59	54° 1,76' N	6° 50,40' E	28,6	Multi corer
HE377/0024-1	21.04.12	06:59:59	54° 1,76' N	6° 50,40' E	28,7	van Veen grab
HE377/0024-2	21.04.12	07:04:59	54° 1,76' N	6° 50,41' E	28,9	van Veen grab
HE377/0024-3	21.04.12	07:08:59	54° 1,76' N	6° 50,41' E	28,7	van Veen grab
HE377/0024-4	21.04.12	07:12:59	54° 1,76' N	6° 50,41' E	28,8	van Veen grab
HE377/0025-1	21.04.12	07:19:00	54° 1,76' N	6° 50,43' E	28,6	CTD/rosette water sampler
HE377/0026-1	21.04.12	07:44:00	54° 1,15' N	6° 50,26' E	28,0	CTD/rosette water sampler

HE377/0027-1	21.04.12	08:02:00	54° 1,05' N	6° 50,12' E	28,0	Eddy-Lander recovery
HE377/0028-1	21.04.12	08:16:00	54° 1,13' N	6° 50,33' E	28,3	Benthic-Lander recovery
HE377/0029-1	21.04.12	14:55:00	54° 1,20' N	6° 50,36' E	26,8	CTD/rosette water sampler
HE377/0030-1	21.04.12	15:07:59	54° 1,21' N	6° 50,36' E	27,0	Multi corer
HE377/0030-2	21.04.12	15:13:59	54° 1,21' N	6° 50,36' E	26,8	Multi corer
HE377/0030-3	21.04.12	15:20:59	54° 1,20' N	6° 50,37' E	27,0	Multi corer
HE377/0031-1	21.04.12	15:27:59	54° 1,21' N	6° 50,38' E	26,7	van Veen grab
HE377/0031-2	21.04.12	15:30:59	54° 1,21' N	6° 50,38' E	26,8	van Veen grab
HE377/0031-3	21.04.12	15:33:59	54° 1,21' N	6° 50,39' E	26,8	van Veen grab
HE377/0031-4	21.04.12	15:35:59	54° 1,20' N	6° 50,39' E	27,2	van Veen grab
HE377/0032-1	21.04.12	17:26:00	54° 2,00' N	6° 49,73' E	28,1	Echosounder
HE377/0033-1	22.04.12	06:45:00	54° 1,38' N	6° 49,79' E	28,1	AUV-2
HE377/0034-1	22.04.12	13:04:59	54° 2,01' N	6° 46,00' E	28,6	van Veen grab
HE377/0034-2	22.04.12	13:06:59	54° 2,00' N	6° 46,02' E	28,6	van Veen grab
HE377/0034-3	22.04.12	13:09:59	54° 2,00' N	6° 46,03' E	28,5	van Veen grab
HE377/0034-4	22.04.12	13:12:59	54° 2,00' N	6° 46,03' E	28,3	van Veen grab
HE377/0035-1	22.04.12	13:19:59	54° 2,01' N	6° 46,01' E	28,2	Multi corer
HE377/0035-2	22.04.12	13:25:59	54° 2,02' N	6° 45,97' E	28,4	Multi corer
HE377/0035-3	22.04.12	13:32:59	54° 2,03' N	6° 45,98' E	28,2	Multi corer
HE377/0035-4	22.04.12	13:38:59	54° 2,03' N	6° 45,98' E	28,4	Multi corer
HE377/0035-5	22.04.12	13:46:59	54° 2,00' N	6° 45,97' E	28,1	Multi corer
HE377/0036-1	22.04.12	13:54:00	54° 2,01' N	6° 45,96' E	28,0	CTD/rosette water sampler
HE377/0037-1	22.04.12	14:40:00	54° 1,96' N	6° 50,96' E	28,3	OFOS
HE377/0038-1	22.04.12	16:34:00	54° 2,00' N	6° 51,11' E	0,0	CTD/rosette water sampler
HE377/0039-1	23.04.12	06:02:00	54° 1,98' N	6° 50,99' E	27,9	CTD/rosette water sampler
HE377/0040-1	23.04.12	06:37:59	54° 1,99' N	6° 50,99' E	28,0	Multi corer
HE377/0040-2	23.04.12	06:45:59	54° 1,98' N	6° 51,00' E	28,1	Multi corer
HE377/0040-3	23.04.12	06:52:59	54° 1,98' N	6° 51,00' E	28,5	Multi corer
HE377/0041-1	23.04.12	07:00:59	54° 1,98' N	6° 50,99' E	28,4	van Veen grab
HE377/0041-2	23.04.12	07:03:59	54° 1,97' N	6° 51,00' E	28,1	van Veen grab
HE377/0041-3	23.04.12	07:07:59	54° 1,97' N	6° 51,00' E	28,7	van Veen grab
HE377/0041-4	23.04.12	07:10:59	54° 1,98' N	6° 51,00' E	28,7	van Veen grab
HE377/0041-5	23.04.12	07:22:00	54° 1,98' N	6° 51,01' E	28,6	Video camera
HE377/0042-1	23.04.12	10:36:00	54° 1,54' N	6° 50,54' E	29,2	AUV-3

7. Data and Sample Storage and Availability

Post-cruise data archival will be hosted by the information system PANGAEA at the World Data Center for Marine Environmental Sciences (WDC-MARE), which is operated on a long-term base by the Alfred Wegener Institute for Polar and Marine Research, Bremerhaven (AWI) and the MARUM, Bremen. The ship's station list and all metadata from sampling and observations will be stored in the WDC MARE database PANGAEA (http://www.pangaea.de/). Further scientific data retrieved from observations, measurements and home-based data analyses will also be submitted to PANGAEA either upon publication or with password protection by the individual P.I.s as soon as the data are available and quality-assessed. This includes oceanographic, physical, geological, chemical and biological data, for most of which parameters are already defined in PANGAEA. For benthic images a photo and video database is under construction at the research center MARUM (Bremen), which can be accessed by taxonomic specialists. Molecular data will be deposited in globally accessible databases such as GenBank. All microbiological samples are stored at the MPI. Samples will be made available upon request and specification of scientific collaboration.

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9. References

Arts, R., Eiken, O., Chadwick, A., Zweigel, P., van der Meer, L., and Zinszner, B. (2004). Monitoring of CO2 injected at Sleipner using time-lapse seismic data. Energy 29, 1383-1392

Chadwick, R. A., Noy, D., Arts, R., and Eiken, O. (2009). Latest time-lapse seismic data from Sleipner yield new insights into CO2 plume development. Energy Procedia 1, 2103-2110

Heggland, R., 1997. Detection of gas migration from a deep source by use of exploration 3D seismic data. Marine Geology 137, 41-47

McGinnis DF, Schmidt M, DelSontro T, Themann S, Rovelli L, Reitz A, Linke P (2011) Discovery of a natural CO2 seep in the German North Sea: Implications for shallow dissolved gas and seep detection. Journal of Geophysical Research, doi:10.1029/2010JC006557