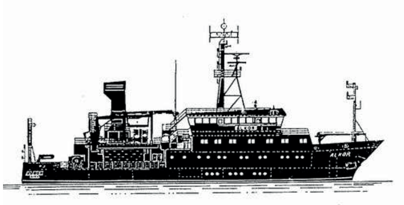
IFM-GEOMAR REPORT

IFM-GEOMAR

Leibniz-Institut für Meereswissenschaften
an der Universität Kiel

RV ALKOR
Fahrtbericht / Cruise Report
AL374



29.05. – 14.06.2011
Kiel - Kiel

ECO$_2$

Sub-seabed CO$_2$ Storage:
Impact on Marine Ecosystems

Berichte aus dem Leibniz-Institut
für Meereswissenschaften an der
Christian-Albrechts-Universität zu Kiel

Nr. 51

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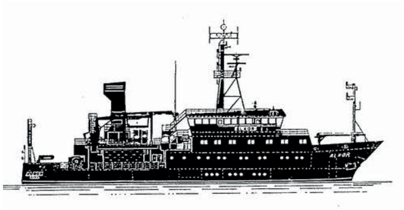

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1. OBJECTIVES

ALKOR cruise 374 was the first cruise conducted in the framework of the EU project ECO2 (funded through the EU call “Ocean of Tomorrow”), which sets out to assess the risks and long-term impacts associated with the storage of CO_2 below the seabed. Carbon Capture and Storage (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. The EU decided to support a selected portfolio of demonstration projects to promote, at industrial scale, the implementation of CCS in Europe. Several of these projects aim to store CO_2 below the seabed. However, 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 in the North Sea (Sleipner) for more than 14 years and for 1 year in the Barents Sea (Snøhvit). In this regard, ECO2 will assess the likelihood and impact of leakage on marine ecosystems, apply novel monitoring techniques to detect and quantify the fluxes of formation fluids, natural gas, and CO_2 from storage sites, and, finally, develop a best practice guide for the management of sub-seabed CO_2 storage sites considering the precautionary principle and estimate the costs of monitoring and remediation. Therefore, the project partners will study existing sub-seabed storage sites in the Norwegian sector of the North Sea and the Barents Sea as well as natural gas seeps at the seafloor. The expedition AL374 included both facets of the project.

The first destination of the cruise was the Salt Dome Juist working area where indications of natural CO_2 seepage have been found during a pre-site mapping study in October 2008 (AL328). Gas bubbles were observed in areas where strong acoustic flares, low pH and high concentrations of CO_2 were determined near the seafloor (McGinnis et al., 2011). The specific area has been revisited in July 2009 (RV Celtic Explorer), showing no elevated seepage activity at Salt Dome Juist, e.g. by CO_2, pH anomaly, or by acoustic flares. However, pH in surface sediment dropped down to about 5, probably indicating both, transport of dissolved CO_2 from a deeper source and respiration. We planned to reinvestigate the Southern North Sea to extend our sampling campaign to salt dome related fracture zones and seismic “gas chimney” structures, determined in TGS-NOPEC seismic data. Localisation of seepage and determination of background concentration was performed by the newly developed video-guided pump-CTD, connected to Membrane Inlet Mass Spectrometry on board the vessel. Varying contributions in the fluids from shallow or deep sources and secondary degradation processes in the benthic filter, affecting the C-, O-, S-, and N-cycle, will be investigated by (isotope-) geochemical analyses. Furthermore, samples for the study the associated benthic fauna and microorganisms were obtained.

The other major working area was the industrial CO_2 storage site Sleipner in the Norwegian sector. Here, 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 to look for any signs of gas seepage. Again video-guided sensors to detect for methane, carbon dioxide, and pH were deployed and bottom water was pumped directly into a mass spectrometer on board the ship for analysis. Additionally, sediment samples were taken at Sleipner for geochemical analysis and physiological experiments 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.

Although the main research focus of the cruise was in the southern German and Norwegian EEZ of the North Sea we visited also the UK sector. Station work focused on the abandoned well site 22/4b which has been intensively studied by our institution during previous research cruises with ALKOR (AL66, 259, 290). During this cruise a short survey with water sampling and deployment of two small landers was planned in preparation of a larger survey involving ExxonMobil and the Department of Energy and Climate Change (DECC) to quantify the emission of methane from the crater on the seafloor into the water column and the atmosphere.

2. CRUISE NARRATIVE

Cruise AL374 started on Sunday, 29 May at 10:00 from the pier of the west-shore IFM-GEOMAR building with 11 scientists on board. RV ALKOR passed through the locks at Kiel/Holtenau and headed through the Kiel Kanal towards Brunsbüttel. The scientists used the time to establish the laboratories and prepare the instruments for the station work. At 18:00 the vessel passed through the locks at Brunsbüttel into the River Elbe and arrived at 5:00 a.m. at the first station in the working area Salt Dome Juist in the German EEZ.

Here, we deployed the Video CTD and conducted a transect where flares of gas discharge had been observed during cruise AL372 about 3 weeks before. During this transect, flares were observed in the 38 kHz fish finder echosounder and the discharge of gas bubbles could be observed in the video. This transect was followed by a parallel transect with OFOS which was equipped with micro electrodes. After this, another cast with the CTD was performed to record the physical oceanographic parameters and derive the sound velocity profile of the water column for the calibration of the multibeam array. This cast was followed by another video-guided CTD transect, where the CTD-rosette was connected by a hose to a submerged pump mounted on the wire and water was pumped towards a Membrane Inlet Mass Spectrometer in the dry lab of the vessel. Unfortunately, the flares observed in the morning had vanished. During the evening and the night the calibration of the multibeam array and 2 dense bathymetric grids were performed. As this did not show any features in the water column, we started after a short survey of 3 additional potential flare positions the transit to Sleipner Vest in the Norwegian EEZ. Here, we arrived on June 1 in heavy swell with Bft. 7 and had to stay in stand-by next to the platform (Fig. 1).

***Fig. 1**: Arrival at the Sleipner platform.*

During the night the wind slowed down and in the morning of June 2nd we started with a survey at Well 15/9-13 with the 38 kHz echosounder and a Video CTD transect along the southern part of the subbottom CO_2 reservoir. At the well site we found an actively degassing methane seep with bacterial mats. This survey was followed by a sampling program with sediment grab and multicorer. During the night a multibeam survey was started above the reservoir.

On June 3rd we deployed a satellite lander next to well 15/9-13 and performed E -> W transects with OFOS and video CTD in the north of the reservoir followed by sediment sampling along this transect. In the night the multibeam survey was extended towards Well 15/7-02 in the north and Well 15/9-11 in the north-west.

During the morning of June 4 the wind peaked up to Bft. 7 from the north, but we were able to deploy the Video CTD again and started a long profile from the south over the reservoir towards Well 15/7-02in the north. Here, again we found a flare and elevated methane concentrations. In the evening we completed sediment sampling for pore water and fauna on the northern E -> W transect started on the previous day. This was followed by a multibeam survey at Well 15/9-16 in the west.

On June 5 we conducted a long Video CTD profile from Well 15/9-16 over Well 15/9-13 and crossing the central injection point towards the north. The abandoned Well 15/9-13 was passed 3 times and we saw bacterial mats and gas bubbles rising from the seafloor causing high methane concentrations in the water column. The sediments above the central injection point (approx. 1000 m below the sediment surface) were sampled for pore water and fauna.

On June 6 sediment sampling was performed on a control station in the west near Well 15/9-16 and deployed the BIGO-Lander near the central injection point. This was followed by sediment sampling at the methane seep of Well 15/9-13 and the successful recovery of the satellite lander. After the recovery we headed towards the Blowout site at Well 22/4-b in the UK sector (Fig. 2) where we arrived at 19:00 and started to conduct a dense bathymetric grid.

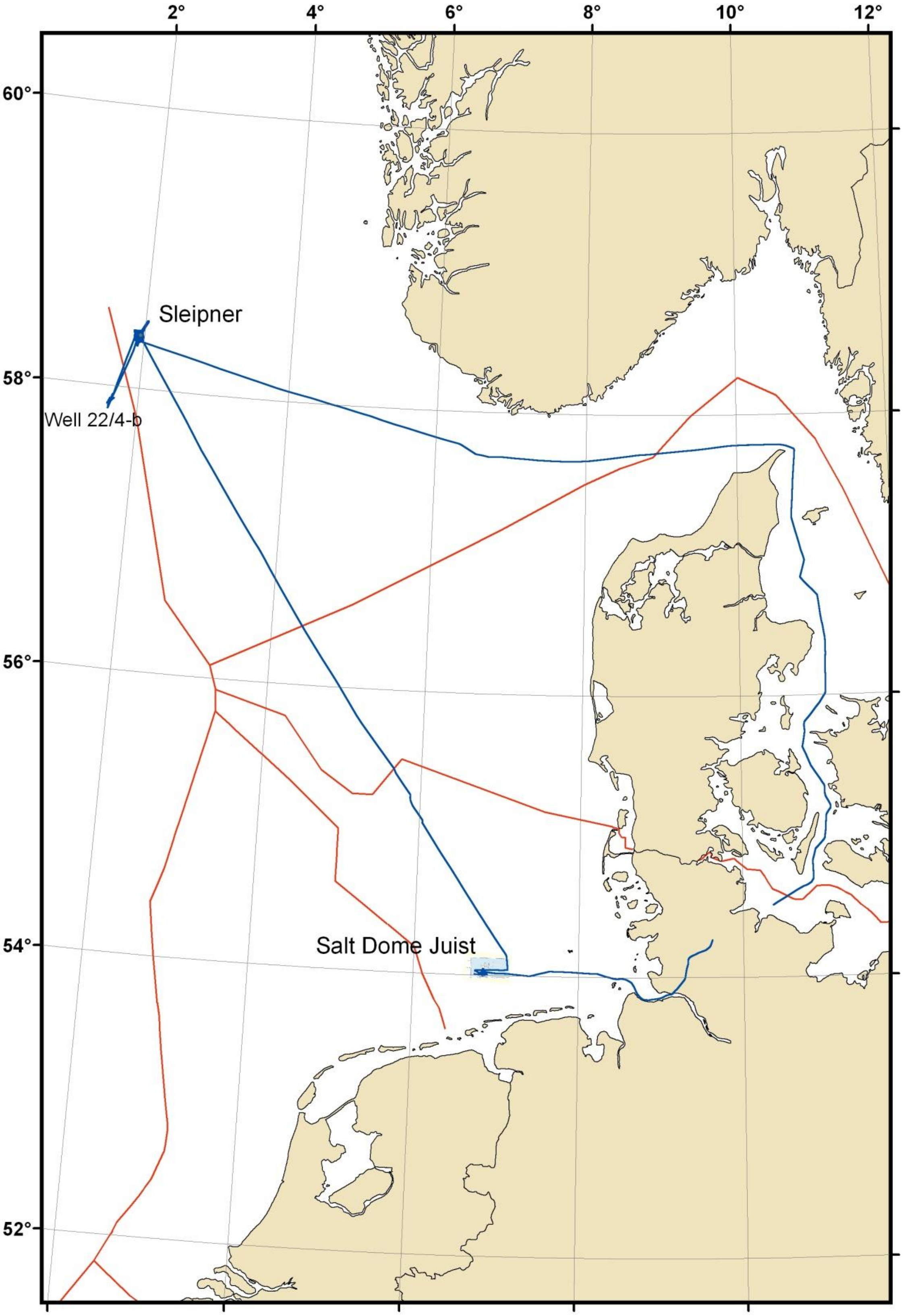


***Fig. 2**: Cruise track and working areas Salt Dome Juist, Sleipner Vest, and Well 22/4-b ("Blowout") of ALKOR cruise 374. EEZ borders of surrounding European countries are plotted as red lines.*

In the morning we were crossed several times in close distance by fishing vessels which tried to force us away. After this decision was made that only one instead of two satellite landers shall be deployed. Until 18:00 we conducted an intense video-CTD transect in various depth layers above the crater to understand the impact of the gas emission on the physical oceanography. After this we deployed the satellite lander at a small terrace in the SW of the crater to obtain some protection against fishing activity. After the deployment RV ALKOR went on transit to Sleipner.

At Sleipner we retrieved the BIGO lander in the morning of June 8. After this we conducted a long profile from Well 15/9-11 in the NW over the central injection point to the SE. This was followed with a vertical pump CTD cast at the central injection point. Mapping the Sleipner area was completed by multibeam lines in the south of the rig. During the night the ship went on transit back to the blowout site.

Here, we conducted on the following two days an intense grid in 3 depth levels with the pumped CTD to resolve the gas flux and spreading of the flare in the water column. On the evening of June 10 we went on transit to Sleipner again to look for flares which we had seen during the previous multibeam survey in the south west of the rig.

On June 11, we started with the search for flares with the 38 kHz echosounder, but without success. Nevertheless, we deployed the video CTD and performed two transects along the south west of the rig between a pipeline south-west of Sleipner and Well 15/9-16. After retrieval of the CTD station work ended at 15:00 and we started the transit back to Kiel through the Skagerrak.

Due to the favorable weather conditions we arrived at Kiel already at 17:00 on June 13 and interrupted the cruise for an overnight stay at the pier of the west shore building. On the next morning, we made a short trip with journalists to Kiel Fjord and arrived at 10:00 on the pier at the sea fish market to unload the vessel, where cruise AL374 ended.

3. CRUISE PARTICIPANTS

	Name	First name	Function	Institute
1	Linke	Peter	Chief scientist	IFM-GEOMAR
2	Sommer	Stefan	MIMS, CTD	IFM-GEOMAR
3	Schmidt	Mark	MIMS, CTD	IFM-GEOMAR
4	Türk	Matthias	Lander engineer	IFM-GEOMAR
5	Bodenbinder	Andrea	O_2 measurements	IFM-GEOMAR
6	Wefers	Peggy	CH_4 measurements	IFM-GEOMAR
7	Syre	Stephanie Helga	Ecology	IFM-GEOMAR
8	Karstens	Jens	Multibeam	IFM-GEOMAR
9	Lichtschlag	Anna	Microsensors	MPI-Bremen
10	Wigand	Cäcilia	Sensor calibration	MPI-Bremen
11	Stiens	Rafael	MUC technician	MPI-Bremen

4. GEOPHYSICAL MEASUREMENTS

J. Karstens

Equipment

Two different geophysical instruments, an Innomar SES-2000 Sub-Bottom-Profiler and an Elac Seabeam 1000 multibeam system, were used during the cruise. Both systems acquired data simultaneously. The travelling velocity of the vessel was between 4 and 6 knots.

Elac SeaBeam 1000 multibeam

For the bathymetric survey, the Elac SeaBeam 1000 multibeam system was installed in the moon pool of the vessel. The Seabeam 1000 operates with a swath of 126 beams perpendicular to the travelling direction, which are generated by two transducers. The system operates at a frequency of 180 kHz and with an opening angle of 150°. This yields a swath width of three to four times the water depth. To avoid gaps in the acquired bathymetric grid, it was necessary to have an overlap of 1/3 between each survey line. A motion sensor linked to the acquiring system delivered information about the ship's movement, such as pitch, roll and heave. Combined with information about the relative positions of the GPS-antennae, the motion sensor and the two transducers of the system can automatically correct for the ship's motion. The multibeam system had to be calibrated before usage to avoid imprecision due to small variations of the transducers orientation to a horizontal plane. The most important calibration is the role-correction. The results of the calibration were correction angles of 2.06° STBD and 2.98° PORT for the Salt Dome Juist survey, and 1.95° STBD and 2.01° PORT for the Sleipner and Blowout surveys.

Innomar SES-2000 sub-bottom profiler

The Alkor has a permanently installed "Innomar SES-2000 medium" sub-bottom profiler. The system is only used by the scientific party. The sub-bottom profiler works with two frequencies. While the primary frequency is fixed to 100 KHz, the secondary can be adjusted between 3 and 15 kHz. The low frequency was changed during the survey to achieve an optimal image of the surveys targets; flares and shallow gas. A frequency of 5 kHz resulted in good imaging in the unprocessed data, and was therefore selected for ongoing acquisition. During the acquisition it is possible to change various processing parameters, such as the gain, stacking, and noise reduction filter. These changes only affected the acquisition monitor and did not have an influence on the acquired data. Only changes in the transmission energy and frequency had an impact on the raw data. To accomplish a high comparability within and between different sub-surveys, these parameters were not changed after calibration.

Acquisition

The geophysical measurements were carried out during night time because no day light or crew involvement was needed. The acquisition had a duration of 8 days (Table 1).

Table 1: Geophysical measurement schedule

Date	Site	Start of acquisition (UTC)	End of acquisition (UTC)
30.05.2011	Salt Dome Juist	19:00	7:00
02.06.2011	Sleipner	19:00	7:00
03.06.2011	Sleipner	18:40	05:10
04.06.2011	Sleipner	20:45	23:45
06.06.2011	Blowout	17:50	02:00
08.06.2011	Sleipner	18:00	22:00
09.06.2011	Blowout	15:00	18:00

Acquisition maps of the three different working areas Salt Dome Juist, Sleipner, and Blowout can be seen in figures 3, 4, and 5, respectively. A List of the multibeam and echosounder profiles is given in appendix II.

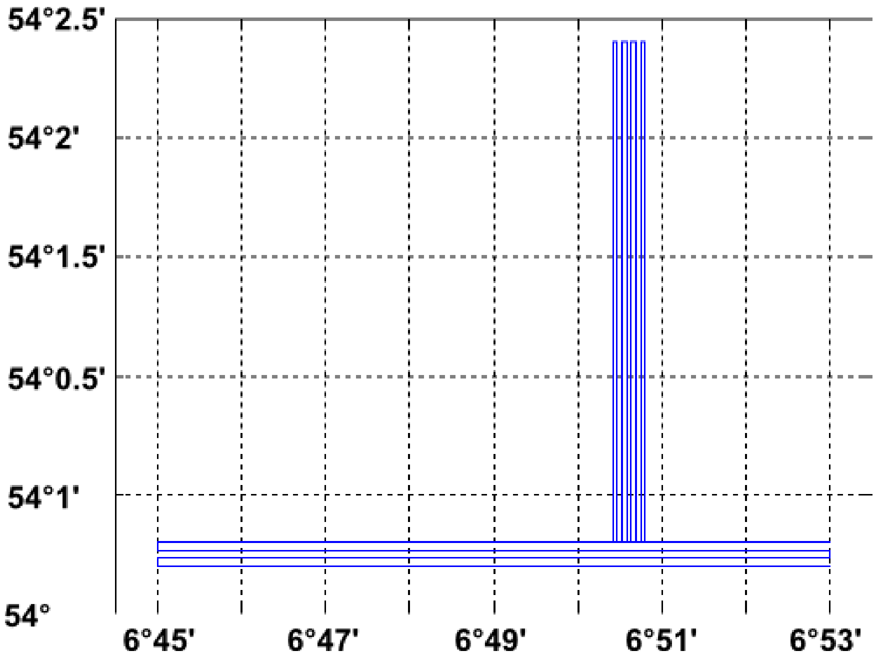


***Fig. 3**: Acquisition map at the Salt Dome Juist working area.*

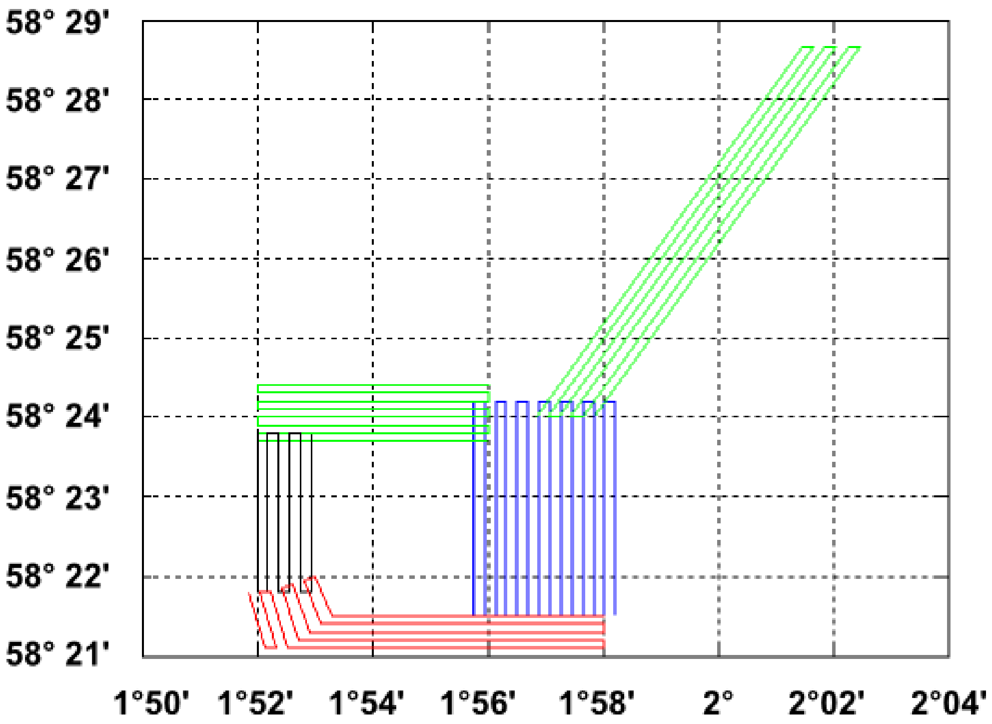


***Fig. 4**: Acquisition map at the Sleipner working area.*

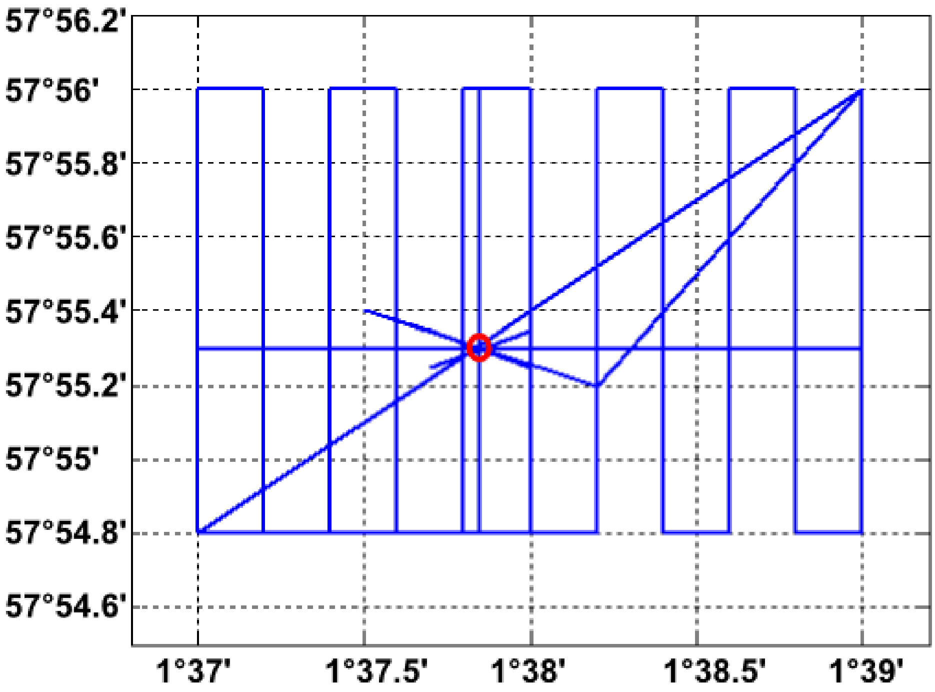


***Fig. 5:** Acquisition map at the Blowout site; red circle shows the location of the crater.*

First results

All processing will be done after the cruise, but first results of the raw data are shown in the following figures.

Multibeam

Figure 6 shows a bathymetric map of the Blowout-site in the UK sector of the North Sea. The data are unprocessed and unfiltered, but already show a quite homogeneous water depth of 100 m. The blowout crater and a flare (white) can be seen in the upper right corner. The processing should deliver a smoother and more detailed map.

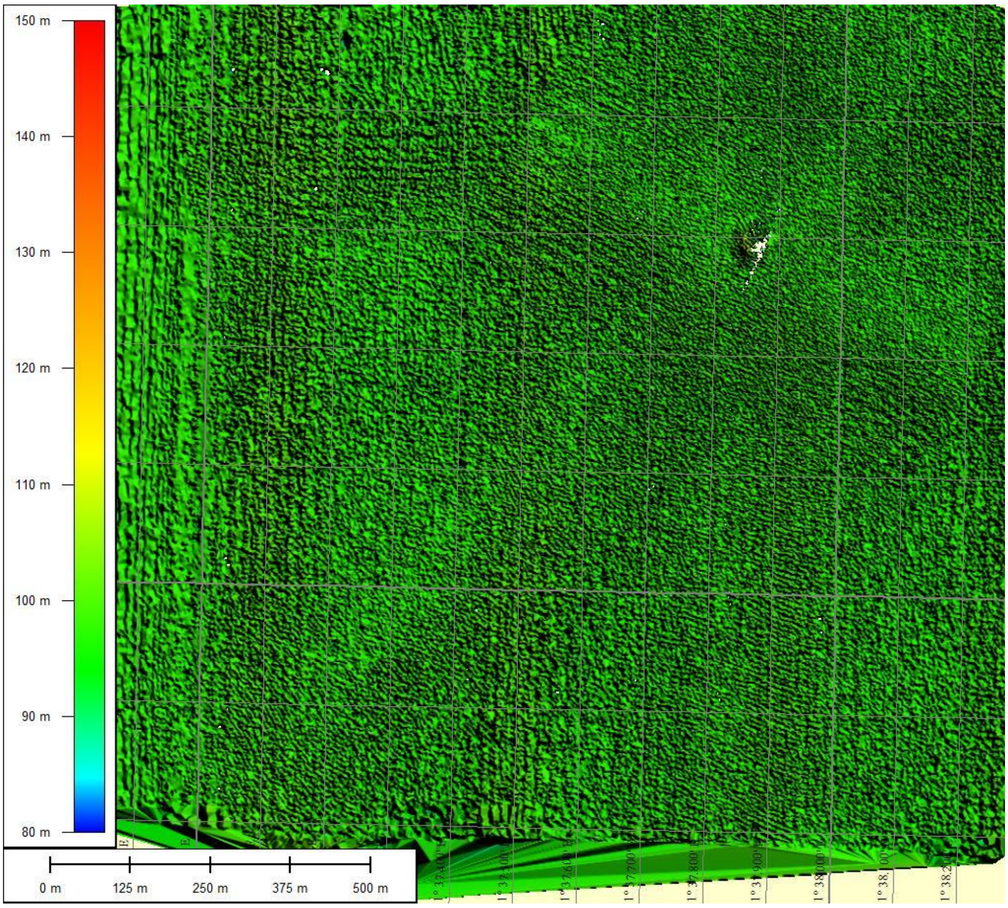


Fig. 6: *Bathymetric map of the Blowout site (unfiltered and unprocessed data)*

An overview of all multi beam survey lines recorded at Sleipner is given in figure 7. The seafloor near the offshore injection/production platform, located southwest of the actual subsurface injection point, had not been investigated as it is a restricted area for non-DP vessels (~700 m radius around the platform). The multi beam data were used to create a 3D map (Fig. 8) where acoustic reflections are indicated which are probably caused by rising gas bubbles.

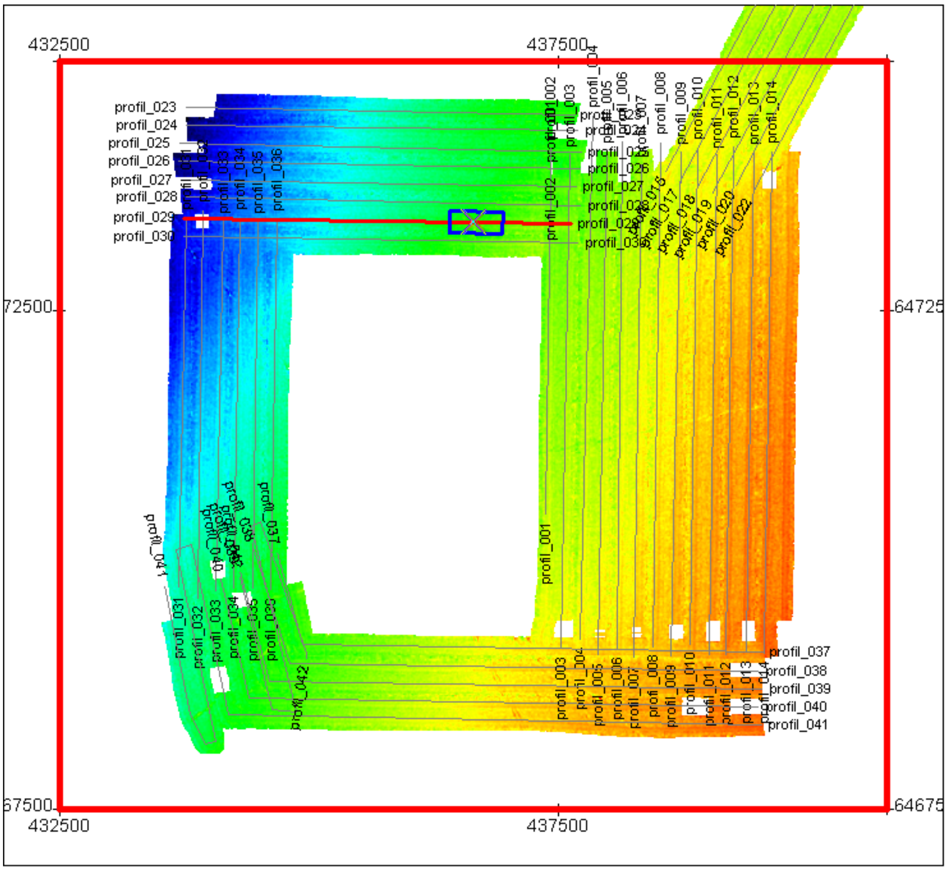


Fig. 7: *Over-view map showing all multi beam survey lines at Sleipner. The position of the sub-bottom profiler images is marked with a blue box.*

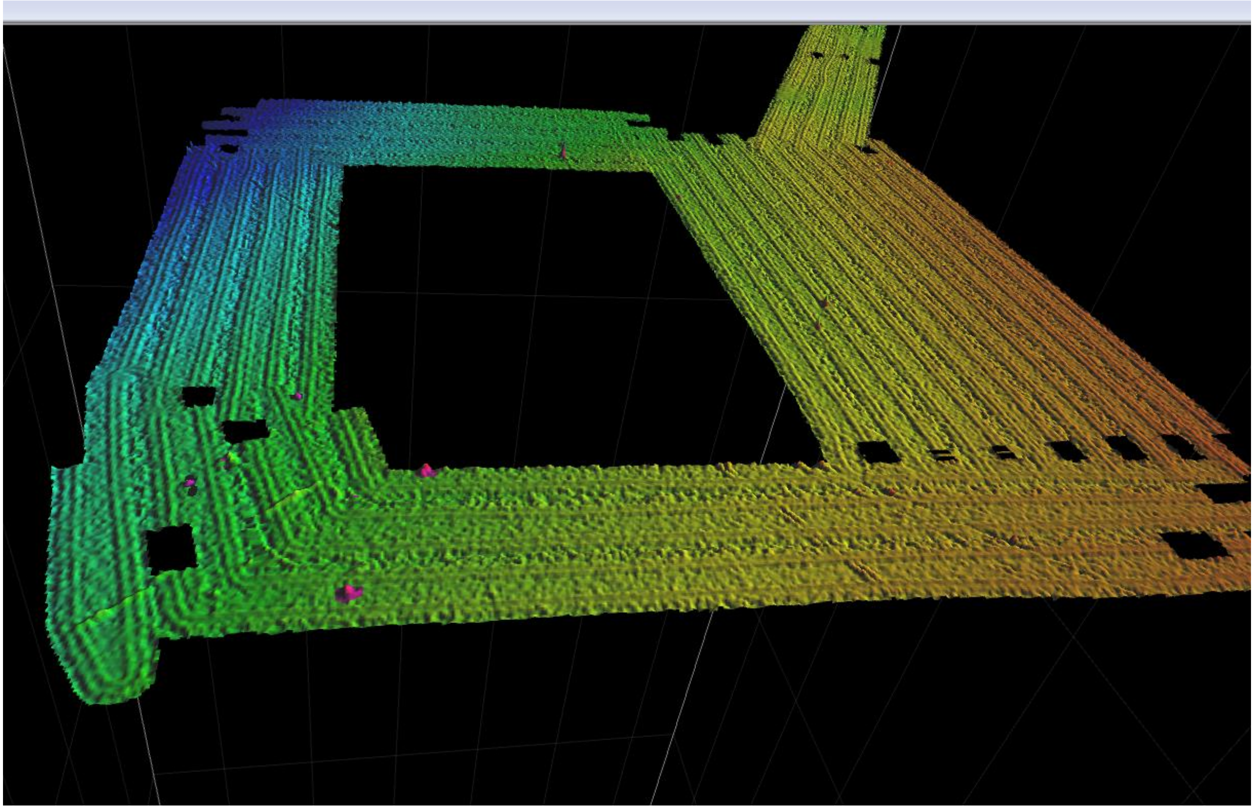


Fig. 8: *3D-map of the Sleipner survey area. The pink-marked peaks indicate acoustic reflections in the water column which are probably caused by rising gas bubbles.*

Sub-bottom profiler

Figure 9 shows examples of raw data acquired by the sub-bottom profiler. The left half shows the low frequency record, and the right half the high frequency record. The wavy topography is a result of the ship's motion and will be suppressed by processing. The two diffraction hyperbolae are caused by pipelines. The vertical penetration and the signal to noise ratio will be improved by post-processing.

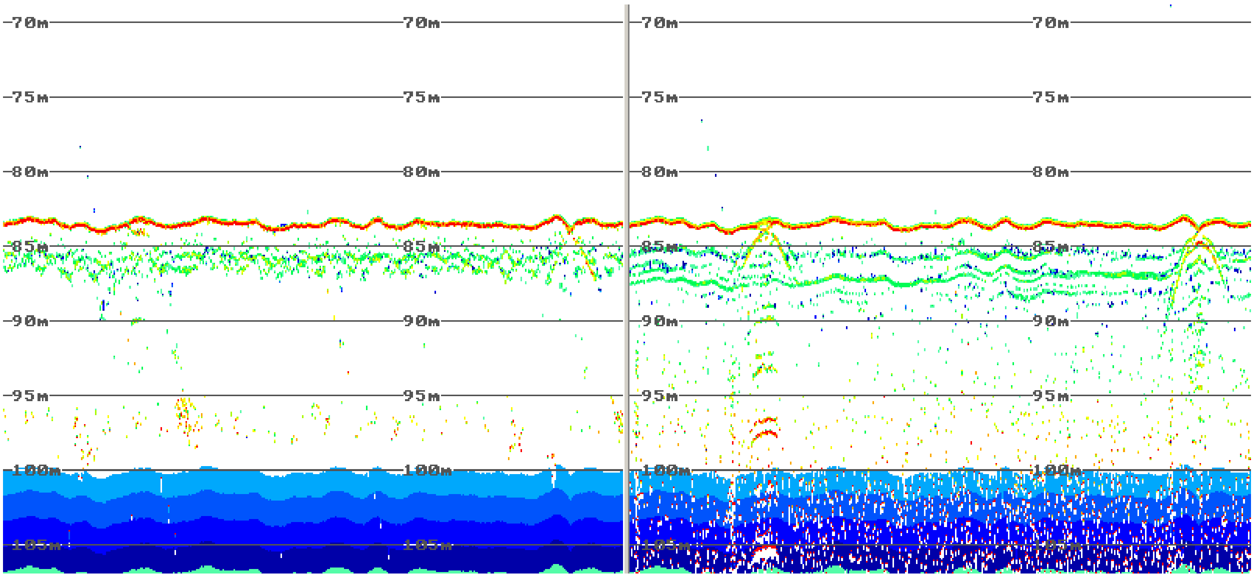


Fig. 9: *Unprocessed sub-bottom profiler data; 5 kHz (left) and 100 kHz (right) at Sleipner.*

The rising of gas bubbles from the abandoned well can be clearly seen in the record of the sub-bottom profiler (Fig. 10).

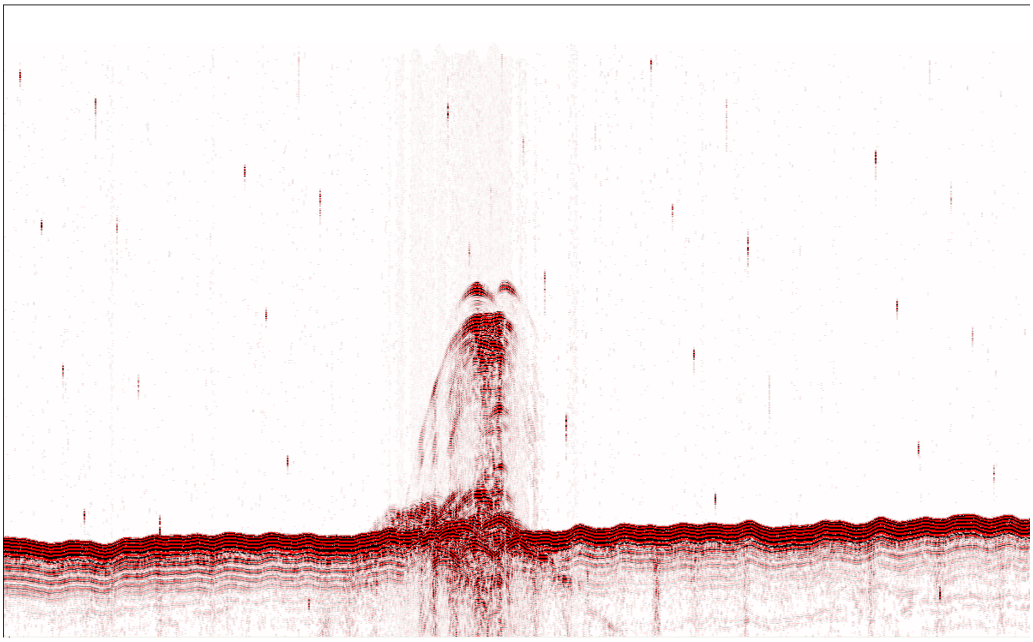


Fig. 10: *Image of the unprocessed sub-bottom profiler data with an acoustic flare at the abandoned well 15/9-D-1H; 5 kHz.*

5- WATER/GAS SAMPLING AND HYDROGRAPHIC MONITORING

M. Schmidt, S. Sommer, P. Linke, P. Wefers, A. Bodenbinder

Sampling areas

Salt Dome Juist

Areas of gas (bubble) seepage were located in the Southern German North Sea during a pre-site mapping study in October 2008 (Alkor cruise AL328). Gas bubbles were observed in areas where strong acoustic flares, low pH and high concentrations of CO2 were determined 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. Shallow seismic investigations indicate Quaternary sediment structures i.e. valleys and depressions which are probably filled with organic rich deposits (e.g. peats and lignites). Decomposition of the organic matter led to the accumulation of shallow gas (Streif, 2002). Furthermore, deep seismic exploration in this area has revealed a complex structure of salt diapirism, tectonic faults, bright spots, and several kilometres deep gas/fluid migration patterns reaching the seafloor in certain areas.

Sleipner

The Sleipner CO_2 storage site, which is located in the Southern Norwegian EEZ, has been in operation since 1996 by Statoil. More than 14 million m^3 of CO_2 have been injected into a saline aquifer (Utsira sand formation) at about ~900 m sediment depth. The spread of the so called “CO_2 plume” in the reservoir rock has been studied and monitored in detail by the operator using 3-D time-lapse seismic data. The outer dimension of the CO_2 plume is shown in the respective maps for time intervals between 1999 and 2008 (see “Sleipner” maps below). Statoil has observed a number of gas seeps at the seafloor located near (several 100 m to several 1000 m distances) the area of the stored CO_2 (Heggland, 1997). However, no gas seepage was observed at the seafloor above the plume. Some of the seeps are associated with abandoned exploration wells. During Alkor 374 cruise we investigated whether any shallow gas (methane, higher hydrocarbons, CO_2, nitrogen, argon) is expelled directly at or above the CO_2 plume and if the seepage activity of the known natural seeps is somehow related to the ongoing storage activity at the Sleipner site.

Abandoned Well 22-4b (“Blowout”)

In November 1990 a gas blowout was accidently created in the central North Sea (~57°55‘N, 01°38‘E; British EEZ) by drilling activities of the British oil and gas company “Mobil North Ltd”.

Methane probably derived from penetrated shallow gas pockets is released into the North Sea since then and first attempts to quantify the amount of released methane released to the atmosphere were made in late 90th (Rehder et al, 1998). However, determining the total volume of bubble released at the seafloor, gas composition changes in gas bubbles during uplift, and dissolved gas distribution in the water column is still a challenge.

To study the lateral and vertical distribution of dissolved methane and other trace gases at the "Blowout" site several towed CTD tracks were conducted at selected water depths. The influence of stratified water column and tides were investigated.

Methodology

"Multi-purpose" rosette

The newly designed Water Sampler Rosette system (for technical details see below) was used to study dissolved gas concentrations at selected water depths between 10 to 120 m in the North Sea. The system was towed by winch 2 from the starboard site of RV Alkor and water depths were controlled by pressure readings of the attached Seabird CTD (SBE9plus). A digital video telemetry system (Sea & Sun, Trappenkamp - SST) providing real-time monitoring of the seafloor was used to control the distance to the seafloor in "bottom view" mode. The telemetry provides a bidirectional transmission of serial data (e.g. CTD or compass data) and video data with a resolution of 720 x 576 pixels at 25 color pictures per second via a standard coaxial cable with a length of up to 8000 m. The main video camera consists of a full HD camcorder which can be controlled via the telemetry (zoom, start/stop internal recording with a resolution of 2.3 Mpixel). By using the integrated Ethernet interface several IP cameras can be controlled and their video data transmitted in parallel. During AL374 an analog b/w camera (Rovtech) was used. Light is provided by 3 LED lights (Bowtech) which can be dimmed and adjusted to the required light conditions and turbidity. The telemetry provides power of up to 1.2 kW for external consumers. Due to the shallow water depth of this cruise, an external cable was attached to the winch cable (Fig. 11). Moreover, an in situ multi-phase pump was attached to the winch cable connecting an on board Membrane Inlet Mass Spectrometer (MIMS) with the rosette by a 1 inch plastic tube (the technique is fully described in chapter 6).

***Fig. 11**: Water sampler (12x10 L Niskin) rosette including SBE9plus CTD, pH sensor (SBE27), and the HydroC/CH_4/CO_2/PAH sensor package with power pack. The orange cable attached to the winch cable is connected to the digital video telemetry system.*

SBE9plus CTD

The SBE 9plus underwater unit was equipped with 2 pressure sensors, 2 temperature sensors, 2 oxygen sensors and 2 conductivity sensors. The decks unit SBE11plus provided power supply and online data control. Data collection was performed with SEASAVE software (version 4.21). CTD data were recorded with 24 Hz. GPS position data was logged parallel to the CTD data from an external GPS device mounted near the CTD winch. 4 analogue channels at the SBE underwater unit were needed for external sensor reading (pH-, CO_2-, CH_4-, PAH-sensor), therefore, the bottom detector unit was disabled. The distance between CTD and the seafloor was controlled by video observation instead. Hydrocasts and hydrographic data from towed CTDs were processed by using SBE software SBE7.21d. Usually data files of 5 second bins were created from raw data files and exported to ASCII. 5s interval CTD data was then combined with 5s interval data sets derived from Membrane Inlet Mass Spectrometry (MIMS). All data sets are correlated with their UTC time stamps.

SBE27-pH/O.R.P. sensor

The sensor (SBE27-0198) combines a pressure balanced glass-electrode, Ag/AgCl reference probe, and a platinum O.R.P. electrode (1200 m rated). The recent calibration equation provided by Seabird is used in the output data files. However, the sensor was also calibrated at IFM-GEOMAR in a T-controlled test tank by using AMPY/BIS seawater buffer solutions (http://www.ifm-geomar.de/index.php?id=1909&L=1). This calibration still has to be applied to the data.

HydroC-CH_4/CO_2/PAH sensors

The HydroC instrument package capable of measuring CO_2, polyaromatic hydrocarbons, and methane in situ (Contros, Systems and Solutions, Germany), is mounted to the Video-CTD frame (Fig. 11). The sensor package is powered by an external NiMH-power unit (~10h/sensor at ~6°C water temperature). The sensors (CH_4, CO_2) store internal high resolution binary data, moreover, the sensors (PAH, CO_2, CH_4) are also connected to the SBE9plus unit by serial cable and analogue data signals (0-5 V) are recorded online during CTD stations. The sensors analogue data is stored in the SBE data file. To allow the sensors internal temperature to reach thermal stabilisation, the methane and CO_2 sensors were powered-up half an hour before the CTD tracks began. An overview of the Contros HydroC sensors and their features is shown in Table 2.

Table 2: HydroC sensor specifications given by CONTROS.

	HydroC TM / CH_4	HydroC TM / PAH	HydroC TM / CO_2
Measuring range	200 nM – 50µM	0-500 ppm	200-1000 ppm
Resolution	15-19 nM	0.1 ppm	1 ppm
Response time (t63)	2 min	0.5 s	1 min
Warm-up time	~ 30 min	Less than 10 s	~30 min
Operational depth	4000 m	500 m	4000 m

Water sampling

Dissolved gas and DIC sampling

Niskin water samplers were fired at selected depth and locations during CTD tracks and casts. Video observation and online sensor data (CH_4 and CO_2 data) were helpful to locate gas seepage locations and to decide where to fire the Niskin bottles. After CTD recovery, about 1.8 L of seawater was transferred from each Niskin bottle into pre-evacuated glass bottles according to Keir et al., 2008. The extracted gas was then transferred in a vacuum extraction line (Fig. 12) into 20 ml headspace vials and stored gas tight with 3 ml of saturated sodium chloride solution. Methane concentrations were measured onboard by using a Trace ultra GC equipped with FID, RTX1-60m capillary column, Ø= 0.53 mm, N_2 carrier gas). Concentrations and stable isotope ratios of higher hydrocarbons, and permanent atmospheric gases will be measured at IFM-GEOMAR.

***Fig. 12**: Vacuum gas extraction line.*

For dissolved inorganic carbon (DIC), and alkalinity titration seawater samples were transferred from Niskin bottles to 500 ml Schott glass bottles. The bottles were closed, after adding 100 µl saturated $HgCl_2$-solution, with a greased glass stopper leaving a head space of about 3-5 ml. The DIC and alkalinity determinations will be conducted at IFM-GEOMAR laboratories. pCO_2 calculations will be performed according to Dickson et al., 2007. Calculated pCO_2 values will then be compared with calibrated HydroC-CO_2 sensor data, and MIMS pCO_2 data. The station numbers, and further details for the sampled DIC and dissolved gas samples are listed in Appendix III.

Preliminary results

Salt Dome Juist

Towed CTD tracks at Salt Dome Juist (Stations CTD01 and -03) were performed on the 30th of May, 2011 at a water depth of about 29 m (Fig. 13, and 14). Gas bubbles emanating from the seafloor were observed early in the morning during the first part of CTD01-2. Gas flares in the water column (Fig. 15) could be imaged at the same time by using the ships own Simrad 38 kHz echosounder. Note that no flares were recorded after 6 am on the 30th for the next 24 hours in the working area "Salt Dome Juist". The CO_2-concentrations determined by the Contros HydroC sensor during the near-seafloor tracks (at about 29 mbsl) are constant at about 335 ppm (Fig. 16). However, the CO_2-concentrations changed from 335 to 345 ppm during slack water (Fig. 17; CTD03 track). Methane concentrations in Niskin water samples, determined by gas chromatography, ranged between 1.6 and 2.4 nM. No CH_4 concentration changes were measured by HydroC-CH_4 in the Salt Dome Juist area (detection limit ~200 nM). The CTD02 hydrocast was conducted to get sound velocity depth profiles for precise Multibeam data calibration. A well-mixed water column with salinity values of about ~33.196 PSU and slightly elevated temperatures near the sea surface is indicated for the Salt Dome Juist area (Fig. 18).

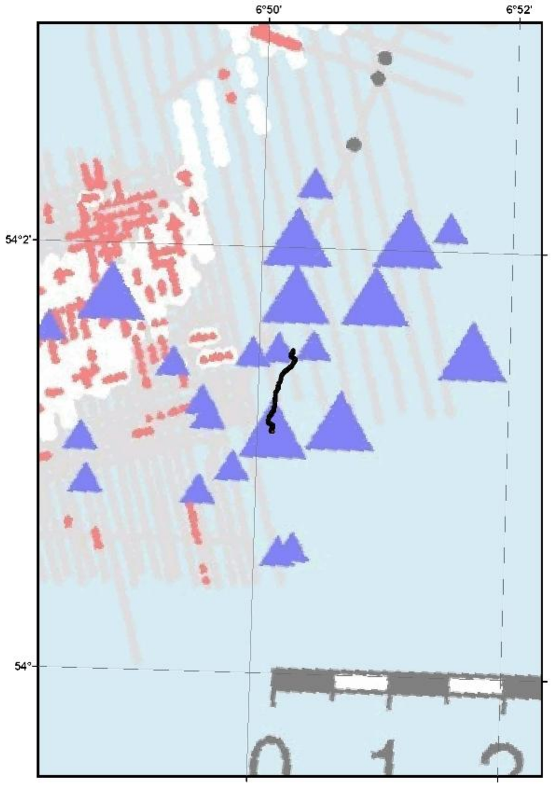


Fig.13: *CTD01-2 track (black line) in the Salt Dome Juist area. Blue triangles mark gas flare locations imaged during Heincke 295 cruise by using the ships 38kHz echosounder.*

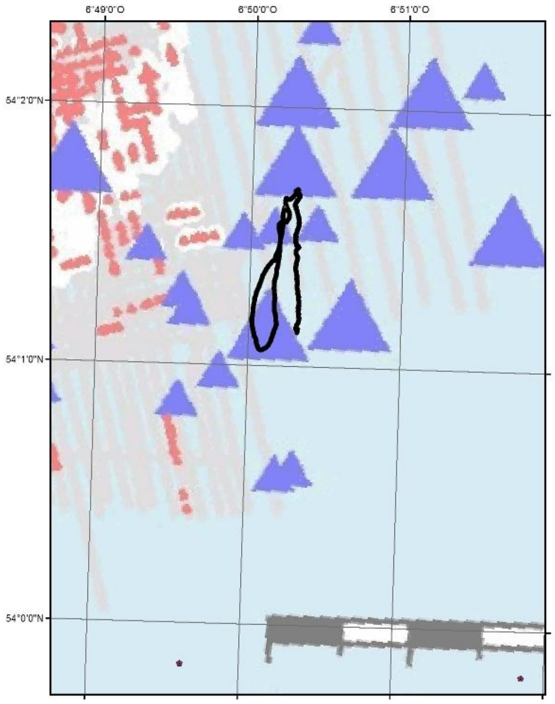


Fig.14: *CTD03 track (black line) at Salt Dome Juist.*

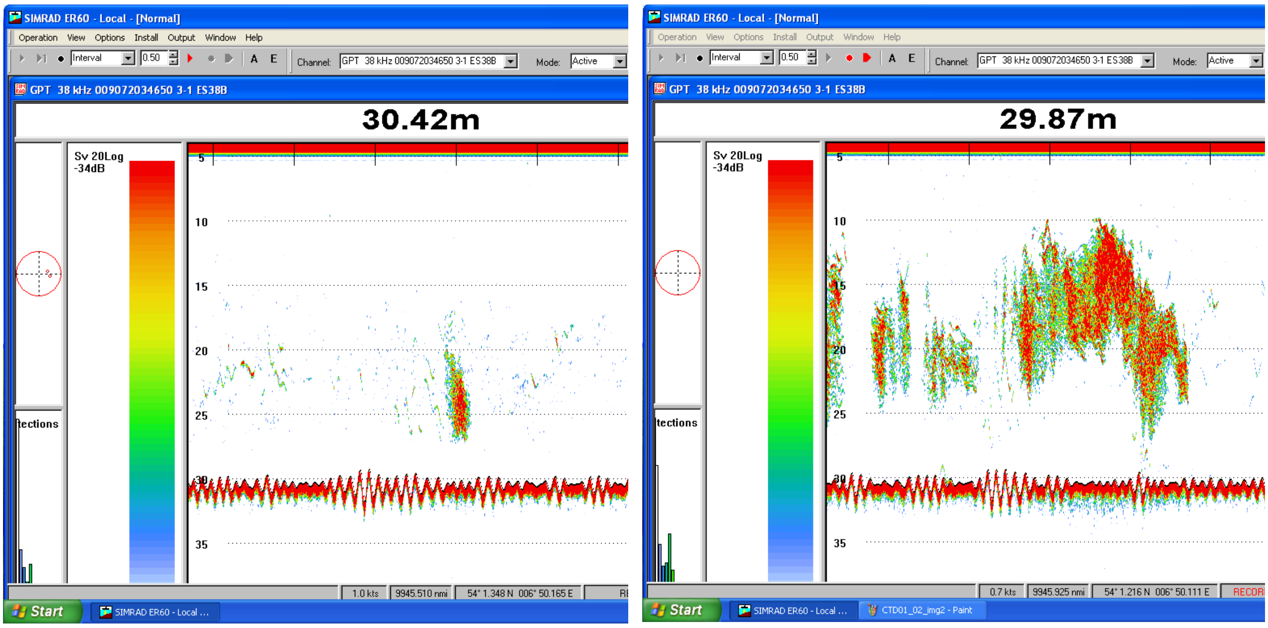


***Fig. 15**: Gas flares recorded with the 38 kHz echosounder during Alkor 375 cruise at Salt Dome Juist (CTD01-2).*

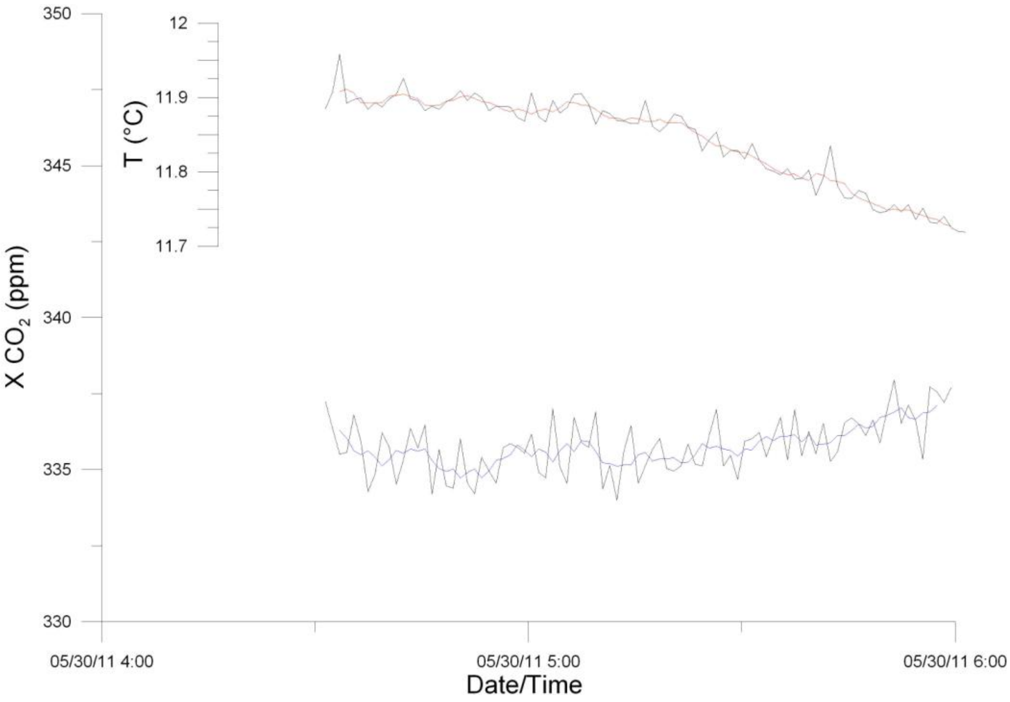


***Fig. 16**: CO_2 concentrations measured by HydroC-CO_2 sensor during CTD01-2 track at about 29 mbsl (bottom view mode).*

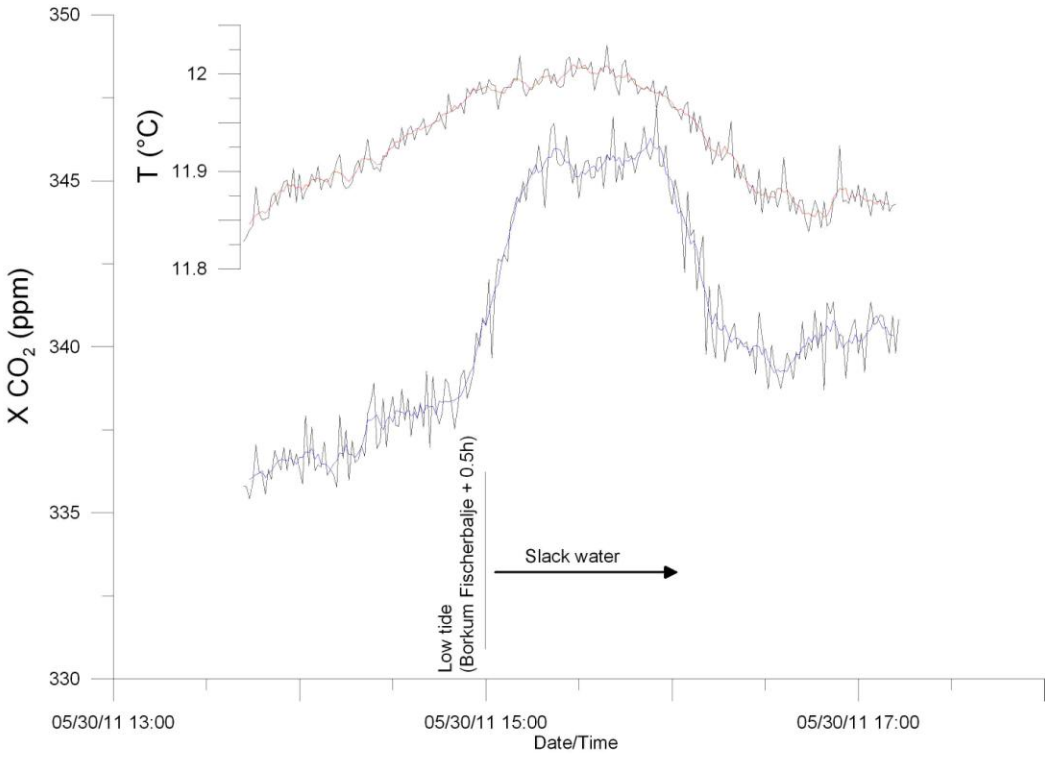


Fig. 17: *Temperature and CO_2 concentration change during CTD03-track at 29 mbsl (slack water time is indicated).*

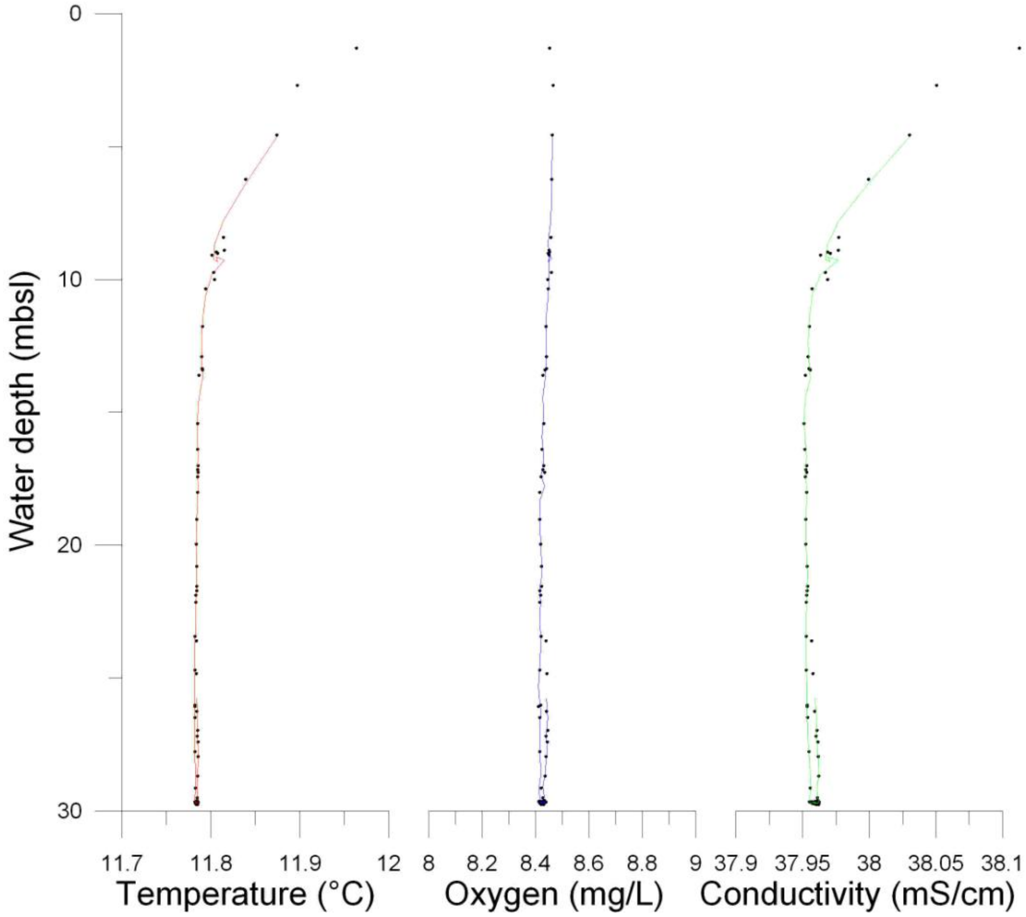
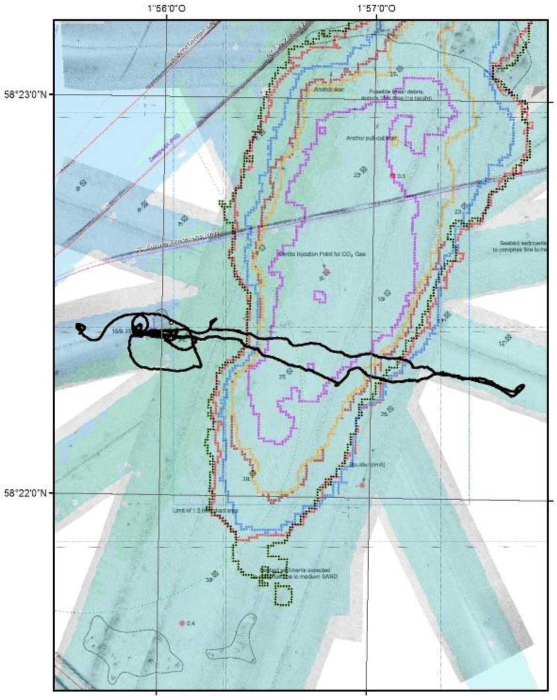


Fig. 18: *Hydrographic data of the water column recorded at the Salt Dome Juist area (CTD02).*

Sleipner Vest

Six CTD tracks were conducted at the Sleipner CO_2 storage site (figures 19 to 25). The maps had been provided by Statoil. The CTD tracks followed the general strategy of crossing the actual CO_2-plume boundaries and the abandoned wells nearby. An exceptionally long CTD track, heading SW to NE (Fig. 22) was performed to get sufficient background data offsite the CO_2 storage site but along the extension of the Utsira formation. The seafloor near the offshore injection/production platform (Fig. 19), located southwest of the actual subsurface injection point, had not been investigated as it is a restricted area for non-DP vessels (~700 m radius around the platform).

Fig. 19: *CO_2 injection/CH_4 production platforms located at the Sleipner Vest gas field.*



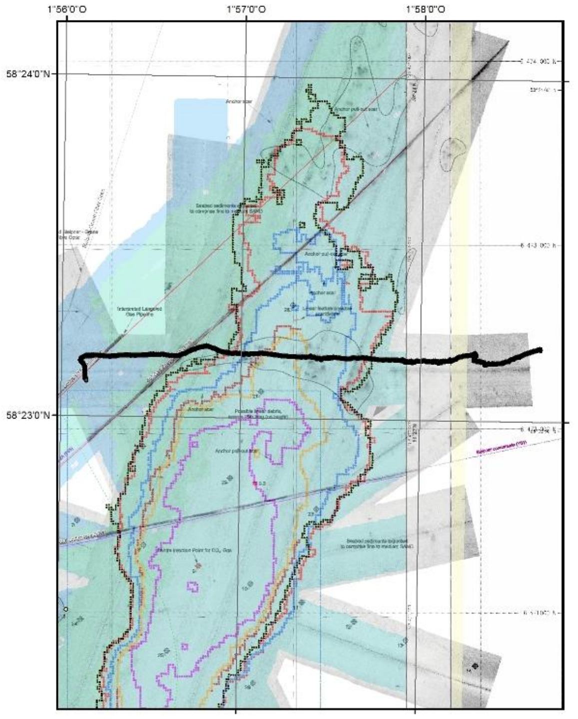
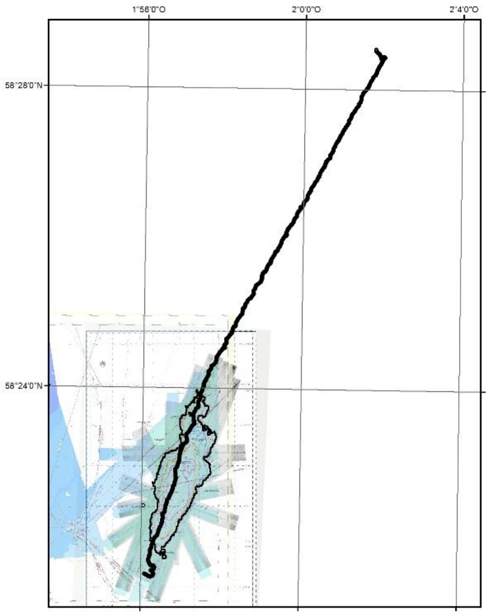


***Fig. 20**: CTD04 track (black line). The base map presents seafloor morphological features and the extensions of the CO_2 plume in the subsurface (coloured polylines).*

***Fig. 21**: CTD05 track.*



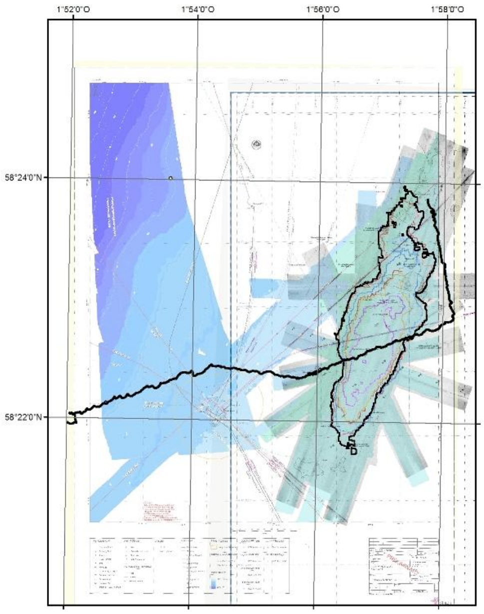


***Fig. 22**: CTD06 track.*

***Fig. 23**: CTD07 track.*

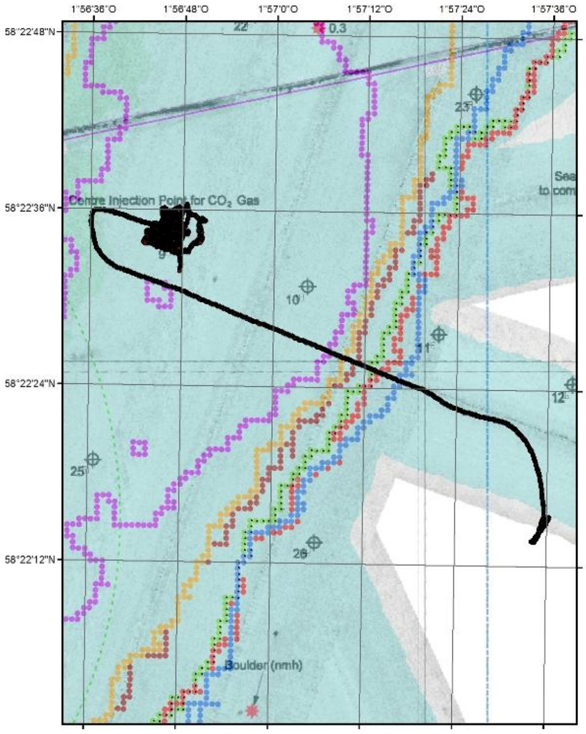


Fig. 24: *CTD09 track.*

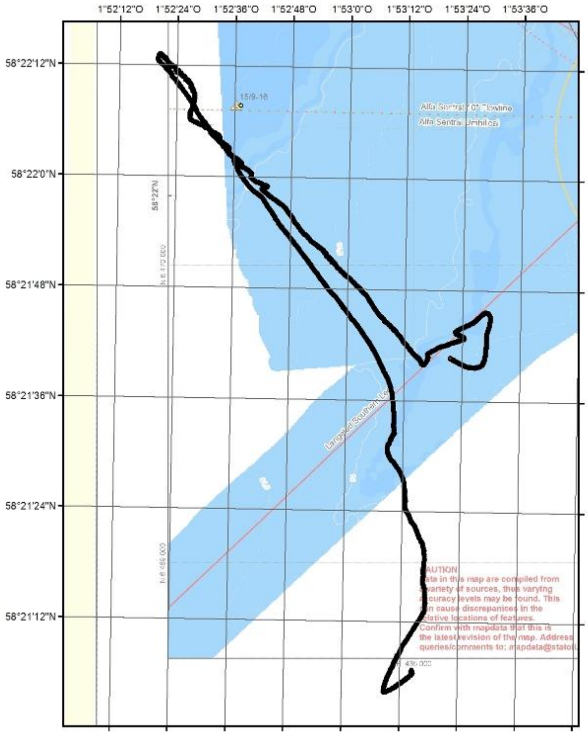


Fig. 25: *CTD13 track.*

In general the North Sea water column at Sleipner is stratified during June showing a thermocline at water depths between 50 and 60 mbsl (Fig. 26). The water temperatures in the area changed from 11.5 (sea surface) to 6.75°C at 80 mbsl. The bottom water (60-80 mbsl) shows salinities of about 35.06 PSU and oxygen contents of about 8.6 mg/L. Salinities of about 35.04 PSU, and oxygen content variations between 8.8 and 9.3 mg/L were measured above the thermocline (Fig. 26).

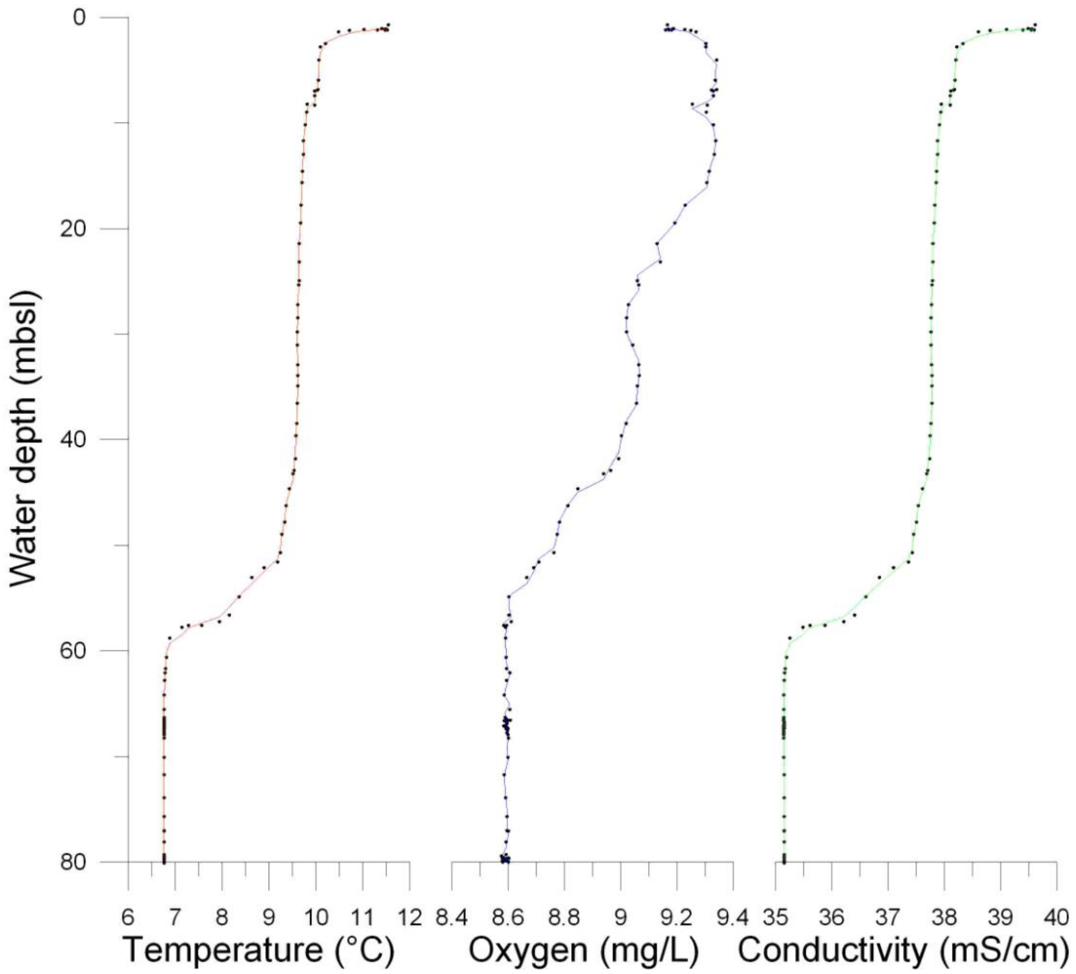


Fig. 26: *Water temperature, oxygen content, and conductivity profiles at 58.3851°N and 21.9356°E (CTD05).*

CO_2 concentrations of about 410 ppm (e.g. Fig. 27) were measured by the HydroC-CO_2 sensor in water masses below the thermocline (~60-80 mbsl). The CO_2-concentration changes to less than 320 ppm above the thermocline (Fig. 28). About 310 ppm CO_2 was measured near the sea surface. This pattern is in general accordance to Thomas et al. 2004, and probably indicates CO_2-consumption by photosynthesis above the thermocline during summer and CO_2 production by respiration below.

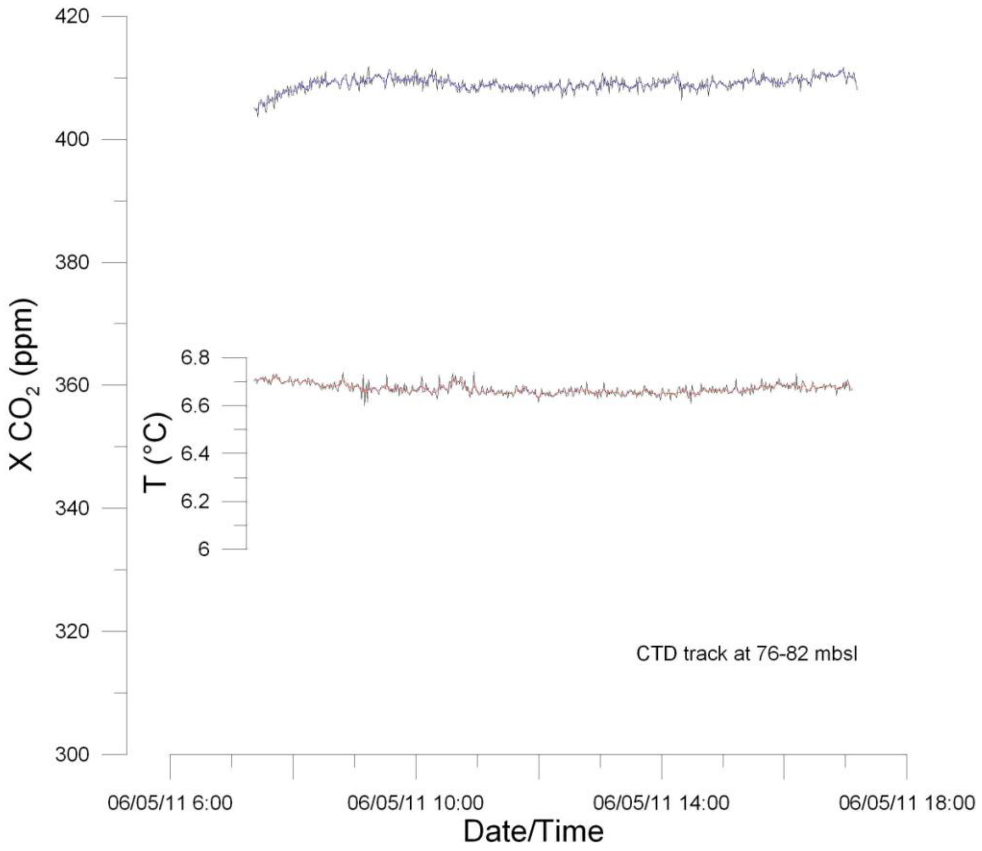


Fig. 27: *CO_2 concentrations determined by HydroC-CO_2 sensor during station CTD09.*

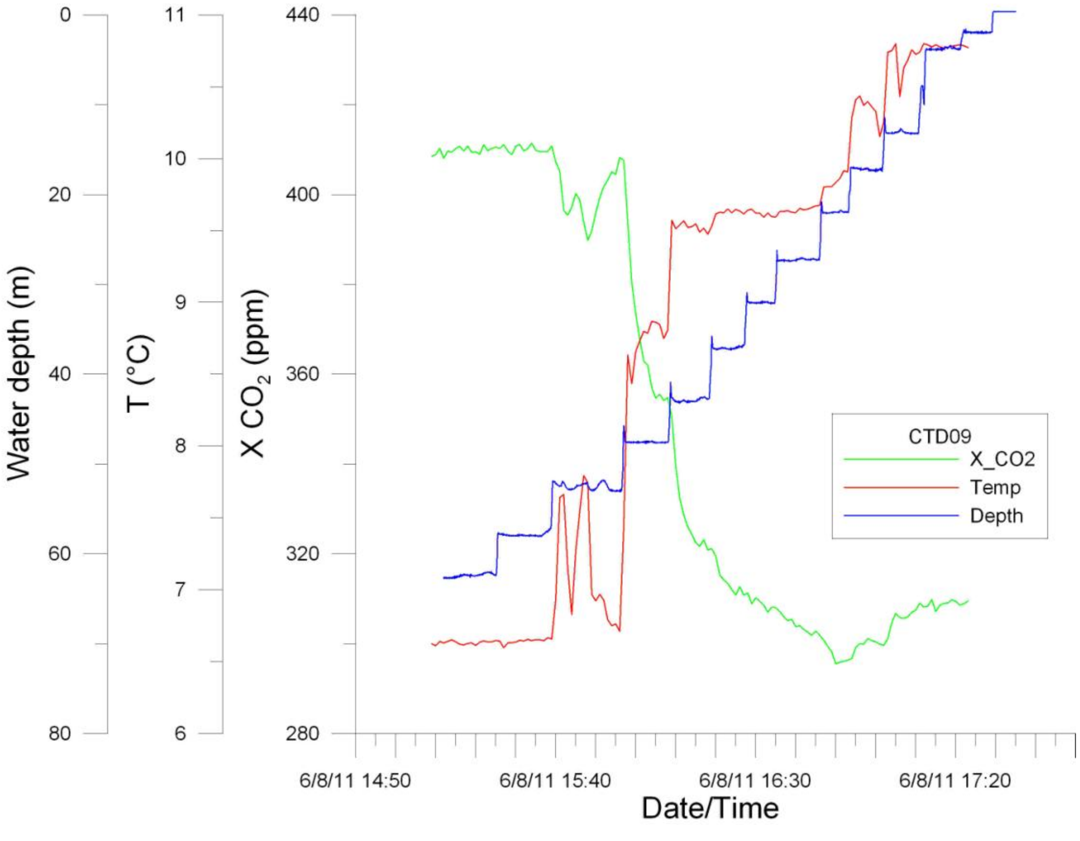


Fig. 28: *Stepwise CTD uplift (CTD09) indicates CO_2 concentration changes in the stratified water column of the northern North Sea (during summer).*

Abandoned Well 22/4-b (“Blowout”)

Five CTD tracks (Figs. 30-34) were conducted at the Blowout site (well 22/4-b, UK EEZ) to monitor dissolved gas concentrations in the surrounding of the main bubble stream emanating from the seafloor at about 57°55’18’’N and 1°37’52’’E. Gas bubbles reaching the sea surface were observed during each station at variable places (Fig. 29). Plume dimensions and headings, monitored by 38 kHz echosounder, changed with tides and currents (e.g. Fig. 35).

***Fig. 29**: Gas bubbles observed at the sea surface above the Blowout site.*

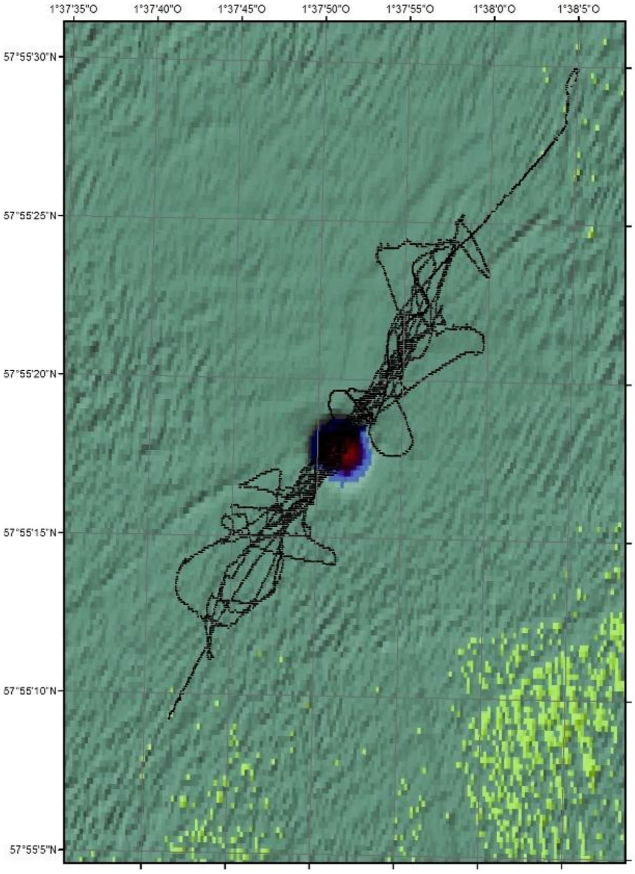


***Fig. 30**: CTD08 track crossing the “Blowout” site (bathymetric map was provided by J. Schneider v. Deimling).*

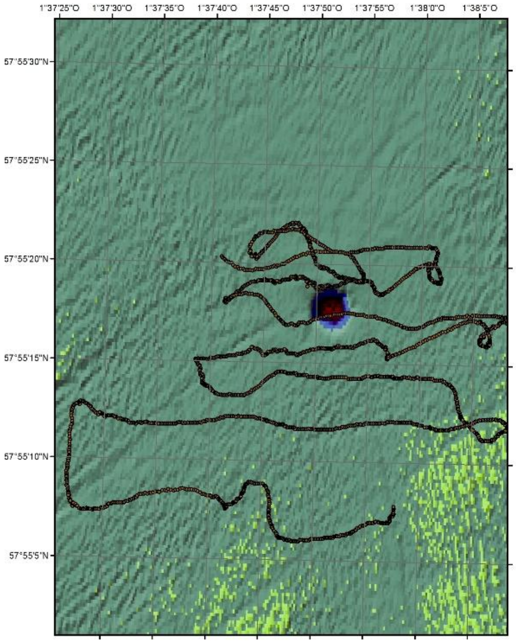


Fig. 31: *CTD10-1 track*

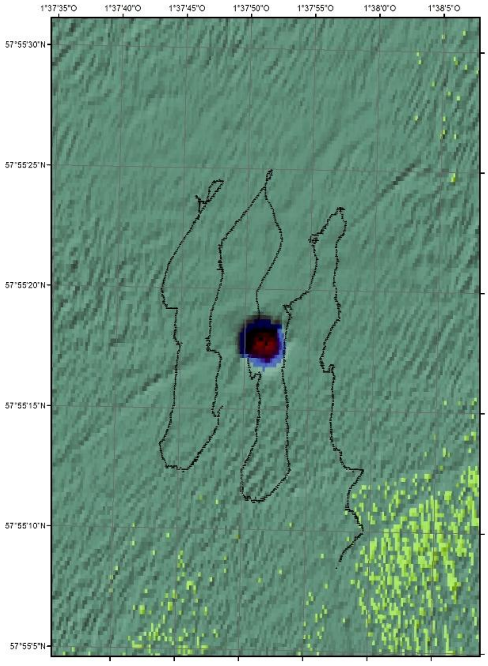


Fig. 32: *CTD10-2 track.*

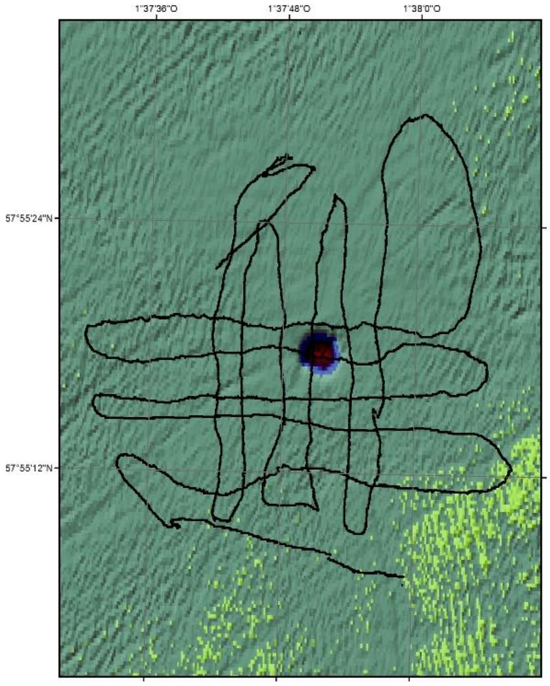


Fig. 33: *CTD11-1/2 track.*

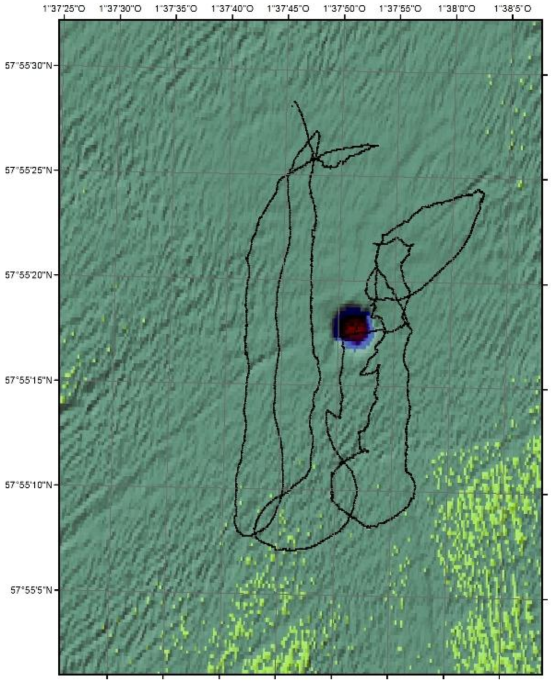
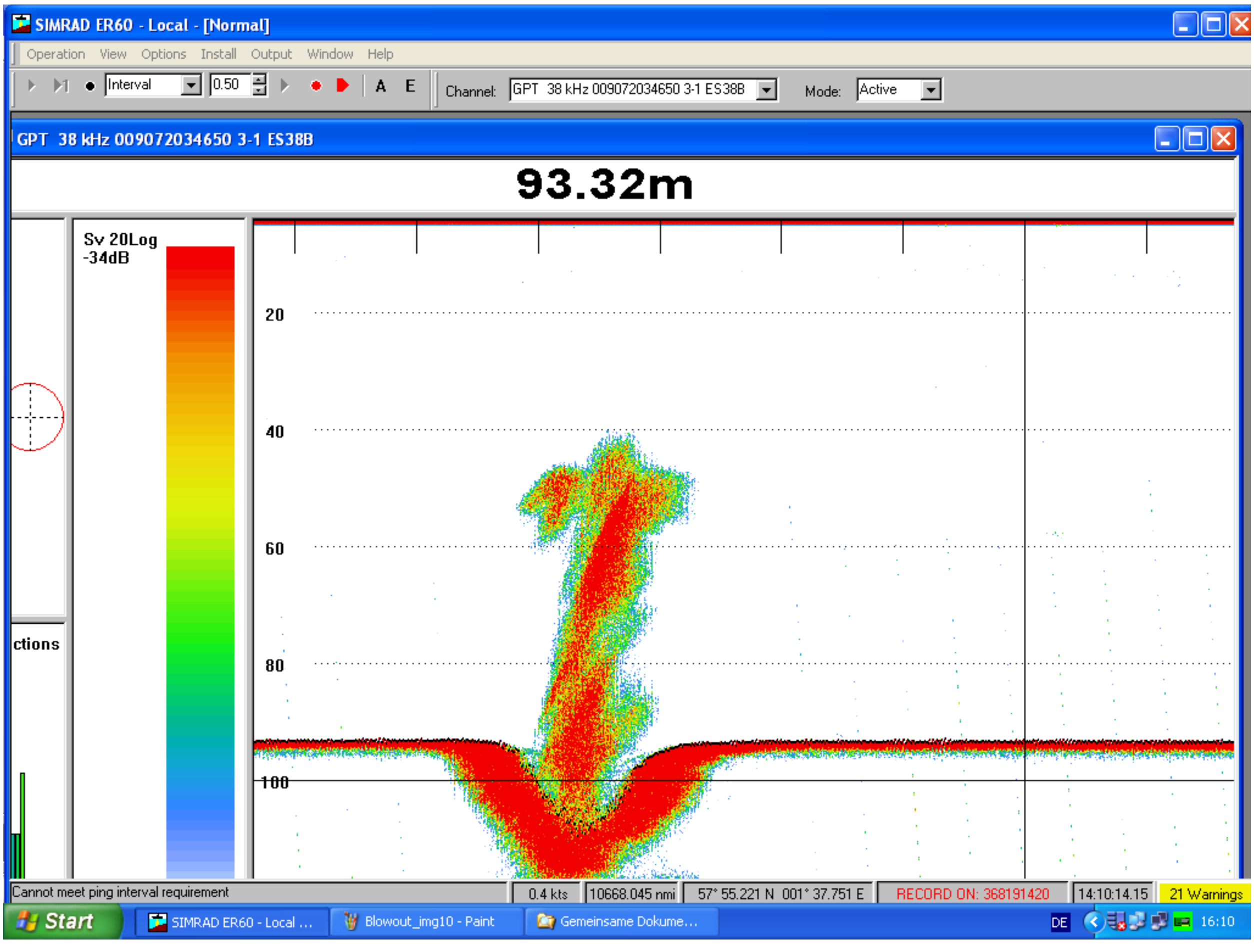


Fig. 34: *CTD12*



Interval 0.50

Channel: GPT 38 kHz 009072034650 3-1 ES38B

Mode: Active

Cannot meet ping interval requirement

0.4 kts | 10668.045 nmi | 57° 55.221 N 001° 37.751 E | RECORD ON: 368191420 | 14:10:14.15 | 21 Warnings

Fig. 35*: Bubble plume recorded with 38 kHz echosounder during slack water time at the “Blowout” site.*

The water body at “Blowout” site is stratified by a thermocline between 40 and 55 mbsl (Fig. 36). The salinity changes from 34.94 PSU (surface waters) to 36.07 PSU (below the thermocline). The oxygen content varies between 8.4 and 9.6 mg/L, showing a maximum at about 25 mbsl (photic zone). Highest methane (5-8 μM) and CO_2 (~430 ppm) concentrations were measured below the thermocline between 50 and 90 mbsl (Fig. 36). Dissolved gas concentrations (i.e. methane) decrease with increasing water depth, with methane concentrations which are below the detection limit of the HydroC-CH4 sensor at 12 mbsl. The measured CO_2 concentration (HydroC-CO_2) varies between 290 and 430 ppm which is in accordance to the normal background CO_2 known for the Northern North Sea during summer (Thomas et al., 2004).

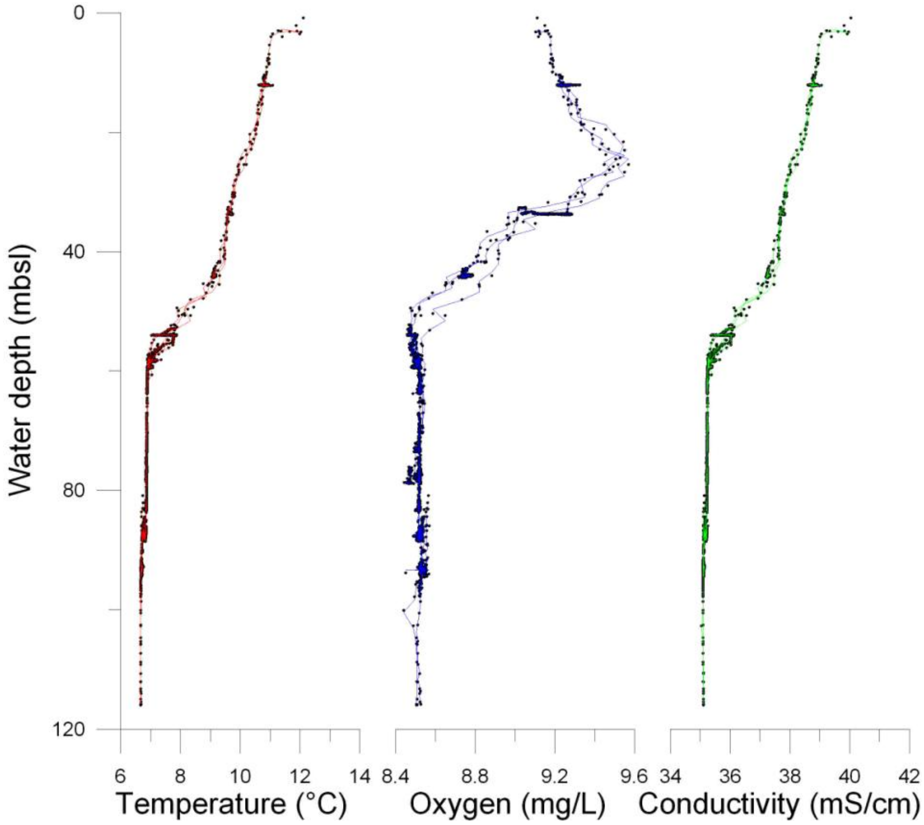


Fig. 36*: Selected CTD data show a stratified water body at the “Blowout” site (station CTD08).*

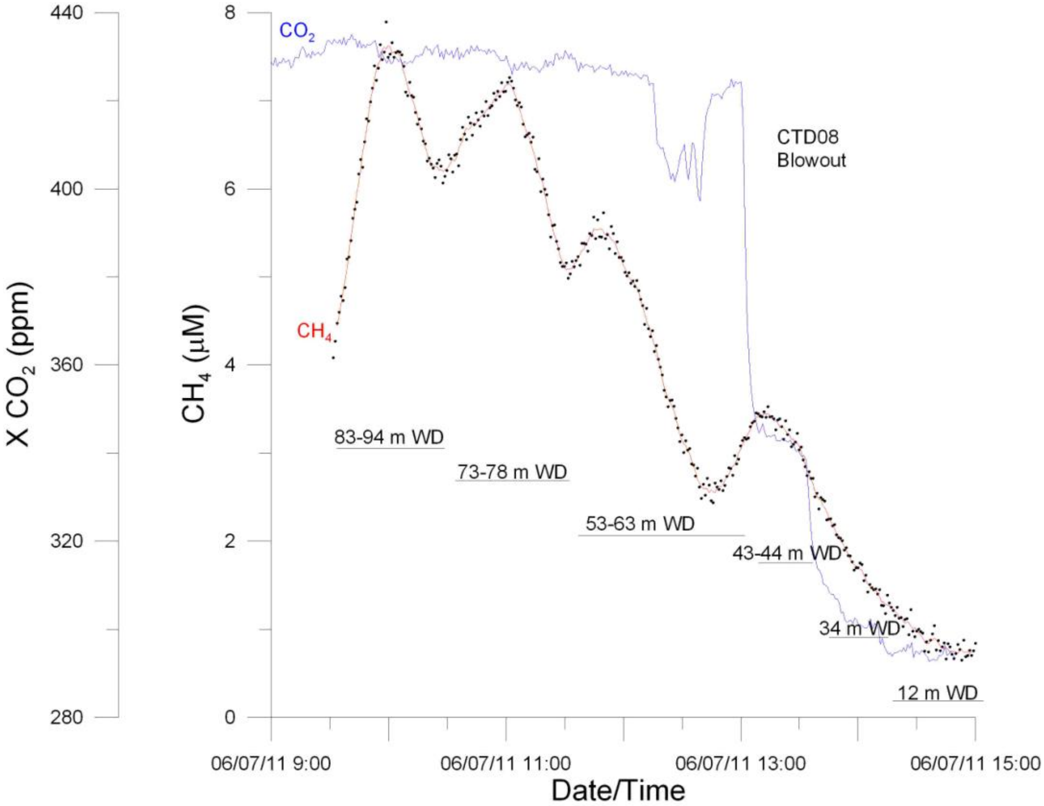


Fig. 37*: HydroC-CO_2/CH_4 measurement at the Blowout site.*

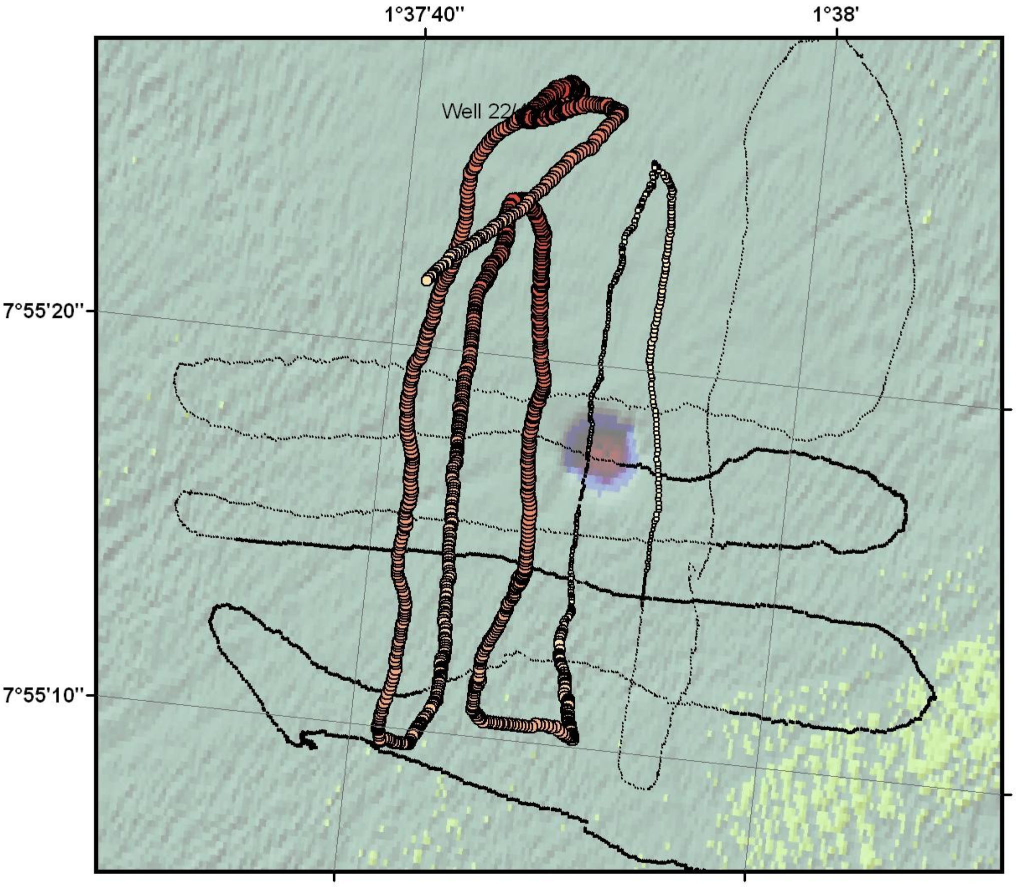


Fig. 38: *Methane concentration distribution profil (CTD11)*

The lateral dimensions of the methane plume are demonstrated by figure 38. Whereas the bubble plume diameter observed at the sea surface does not exceed more than 20 m in diameter, the plume of dissolved methane at a water depth of about 60 mbsl (measured by using the HydroC-CH_4 sensor) covers an area which is more than 400 times bigger.

Methane concentrations determined by vacuum extraction of discrete Niskin water samples range between background data of ~ 2-3 nM, and 0.9 µM CH_4 (CTD12), 4.7 µM (CTD11), and one exceptionally high value of ~16 µM (CTD11). All extracted gases will be measured in detail by continuous flow isotope mass spectrometry and GC-HCD at IFM-GEOMAR. The dissolved gas concentrations, CTD data, and ADCP data will be used to determine dissolved gas fluxes and transport processes from the seafloor to the stratified water at this site.

6. CONTINUOUS AND SIMULTANEOUS GAS MEASUREMENTS

S. Sommer, M. Schmidt, P. Linke, A. Bodenbinder

Sampling areas

Bottom water gas measurements using the MIMS were predominantly conducted along several transects at the Sleipner CO_2 storage site in the Norwegian EEZ (CTD 4, 5, 6, 7, 9, 13) but also in the Saltdome Juist area (CTD 3) and at a blow out structure (Well 22-4b) in the central North Sea (CTD 10, 11, 12). These sampling areas have been described in detail in section 5.

Methods

Ex situ gas measurements using MIMS

For continuous and simultaneous dissolved gas measurements of pCO_2, CH_4, N_2, Ar, O_2 in the bottom water a towed video-equipped CTD water sampling rosette was deployed that was connected to a MIMS (Fig. 39). Distance to the seafloor was visually controlled online using a video system. The towing speed of this CTD system ranged between 0.5 – 0.8 kts.

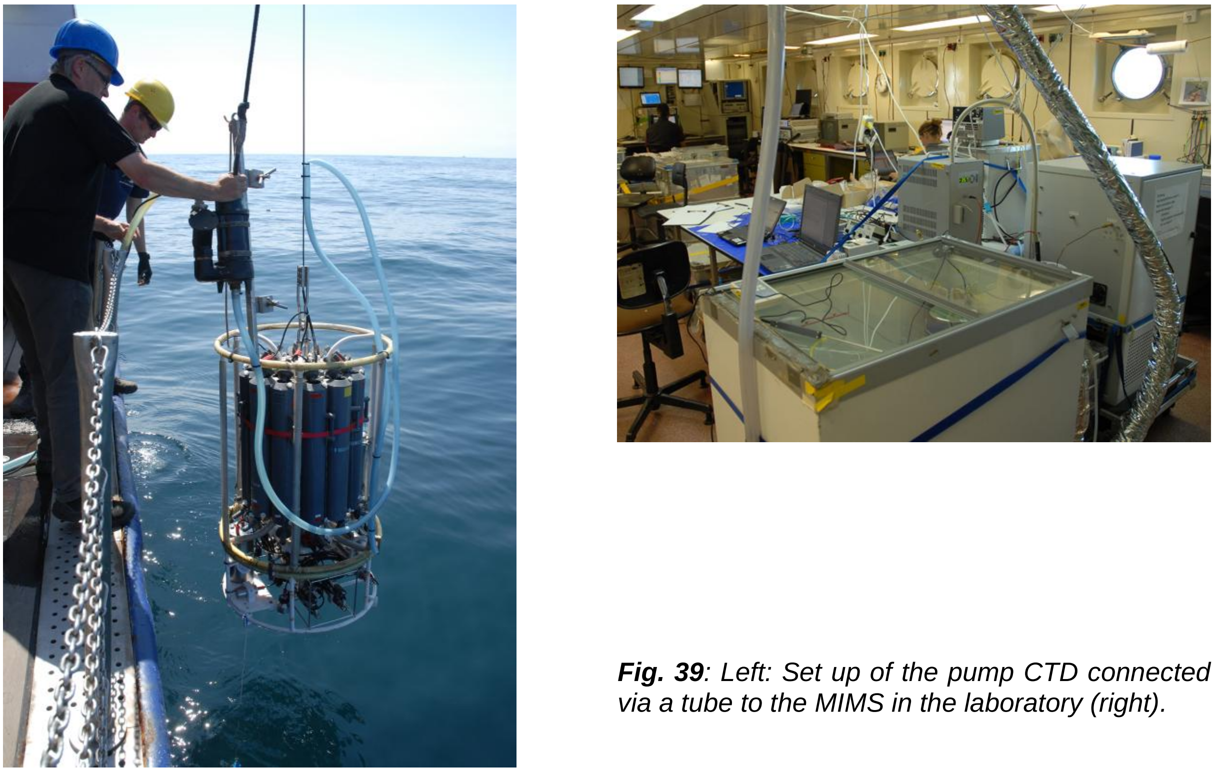


***Fig. 39**: Left: Set up of the pump CTD connected via a tube to the MIMS in the laboratory (right).*

For the ex situ gas measurements bottom water was continuously pumped to the laboratory through a tube (i.d.: 2.5 cm) and analyzed using a membrane inlet mass spectrometer (GAM 200, InProcessInstruments). The inlet of the tube was mounted on the CTD frame at the height of the in situ CO_2 and CH_4 sensors described in section 5. An underwater pump yielding a flow rate of 31.88 L min^{-1} was clamped onto the CTD wire at a water depth of about 10-15 m. The tube on deck and throughout its way to the laboratory was insulated and wrapped into rescue cover sheets to prevent warming of the water. In the laboratory continuous sub-sampling took place from the tube using a steel capillary that was connected to the membrane inlet. The distance between the sub-sampling port and the inlet was about 100 cm. Along this distance this capillary was permanently cooled to in situ temperature (11°C at Juist area, 6.7° at the Sleipner Area, 6.8 °C at the blow out) using a silicone tubing that was mounted aside the steel capillary. This arrangement was enclosed by insulation and again wrapped into a rescue cover sheet. Inside the silicone tube there was a permanent water flow at a defined temperature that was maintained using a Julabo thermostat. To enable best possible temperature stability of the inlet itself it was kept in a water bath using a Dewar vessel that was placed in a refrigerator. Between sampling of the bottom water and its arrival at the inlet where the actual gas extraction took place there was a delay time of up to 2.1 min (water depth 83 m). Sub-sampling from the tube and water flow through the inlet took place at a constant flow rate of 3.5 ml min^{-1} using a pulse-reduced peristaltic pump (Ismatec). The design of the glass membrane inlet followed that of G. Lavik (Max Planck Institute for Marine Microbiology, Bremen). Within the glass inlet the water was sucked through a permeable silicone tube (length 40 mm, i.d. 1.4 mm). Flow of extracted gas from the inlet to the mass spectrometer was supported with Helium that was supplied through a fused silica capillary (i.d. 100 µm). An inline cryo-trap (– 35°C ethanol) between the inlet and the mass spectrometer was used to minimize water vapor. Concentration of CO_2, CH_4, N_2, and Ar were obtained from ion currents at the mass to charge ratios 44, 15, 28 and 40 respectively. A Secondary Electron Multiplier was used as a detector.

Ion currents of CO_2 were calibrated using CO_2 standards of 100, 500 and 1000 ppm, respectively. These standards were produced by equilibrating pre-filtered (0.2 µm) seawater (80 ml) with the standard gases at the respective in situ temperature in a thermostat water bath (Julabo). Ion currents of CH_4 where calibrated using CH_4 standards of 1.8 ppm (air), 10, 100, 1000, and 10000 ppm. Similarly to CO_2 standards the methane standards were produced by equilibrating pre-filtered (0.2 µm) seawater samples. Standards for N_2 and Ar were produced by aerating pre filtered seawater (0.2) of different salinities. Different salinities were produced by appropriate dilution of bottom water from the respective working areas. The dissolved gas concentrations of the saturated air equilibrated water standards were calculated using the solubility equations of Hamme and Emerson (2004). Sea water was bubbled with the respective gases in 100 ml glas bottles (Schott) which were closed with a septum. The volume of sea water was 80 ml the resulting headspace was 58.8 ml. Equilibration with the respective gases took place for at least 60 min. Calibrations were conducted after each measurement session. Ion currents for methane were only calibrated for CTD casts conducted at the blow out structure. However discrete water samples were taken during the different pump CTD tracks using Niskin bottles allowing for the adjustments of the two different data sets.

In situ flux measurements of pCO_2 and O_2

Total fluxes of pCO_2 and O_2 across the sediment-water interface were measured in benthic chambers using the Biogeochemical Observatory (BIGO) as described in detail by Sommer et al. (2009). In brief, the BIGO contained two circular flux chambers (internal diameter 28.8 cm, area 651.4 cm2), hereafter referred to as chamber 1 (C1) and chamber 2 (C2). A TV-guided launching system allowed smooth placement of the observatory on the sea floor. Four hours after the observatories were placed on the sea floor the chambers were slowly driven into the sediment (~ 30 cm h^{-1}). During this initial time period where the bottom of the chambers was not closed by the sediment, the water inside the flux chamber was periodically replaced with ambient bottom water. The water body inside the chamber was once further replaced with ambient bottom water after the chamber has been driven into the sediment to flush out solutes that might have been released from the sediment during chamber insertion. For the gas analysis of pCO_2 N_2, and Ar 4 water samples were taken from inside each benthic chamber using a peristaltic pump which slowly filled glass tubes. To monitor the ambient bottom water another series of four glass tubes were used. The positions of the sampling ports were about 30 – 40 cm above the sediment water interface. Until measurement these samples were stored at in situ temperature. For the gas analysis the glass tubes were directly connected to the membrane inlet, without the need of transferring the samples into different vials where they might be exposed to the atmosphere. O_2 was measured inside the chambers and in the ambient sea water using optodes (Aandera) that were calibrated before each lander deployment.

Preliminary results

Simultaneous CO_2 and CH_2 gas measurements at Sleipner

Goal of this study was to conduct baseline measurements of primarily pCO_2 as well as CH_4 in the bottom water above the Sleipner sub-seabed CO_2 storage site. Based on geophysical measurements the extension of the injected CO_2 has been resolved as an elongated plume that is orientated from the southwest to the northeast (Data provided from Statoil), Figure 40.

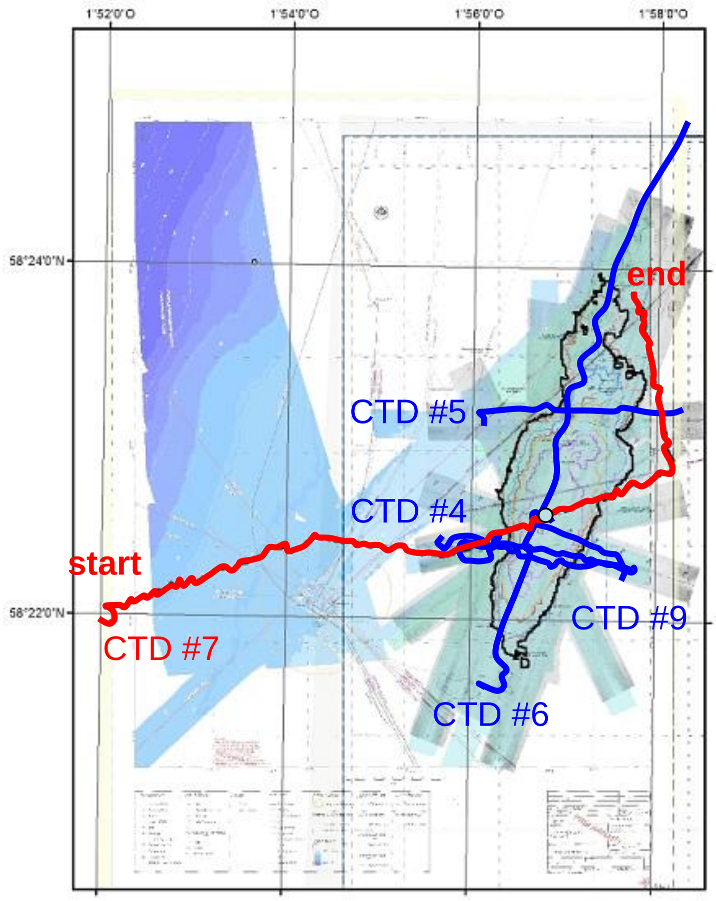


***Fig. 40**: Pump CTD tracks over the Sleipner CO_2 storage site (track of CTD 13 not shown). The extension of the CO_2 plume in the sub-seabed is indicated by the black contour line. The circle denotes the injection point of the CO_2.*

During this study three pump CTD transects were conducted across the west-east extension of the sub-seabed CO_2 plume (CTD tracks 4, 5, 7) and one along its major south-west to north-east orientation (CTD track 6), Figure 41. During deployment of CTD track 4 and 7 abandoned wells were included into the survey. CTD track 7 and 9 crossed the central injection point of the CO_2. For the deployment time as well as start and end positions of the different CTD tracks, see appendix I.

Along all CTD-tracks the variability of bottom water pCO_2 was low and the pCO_2 level corresponded to background concentration. An example for bottom water pCO_2 and CH_4 during CTD track 7 is shown in figure 41. At the abandoned wells the pCO_2 level was not elevated. However, during CTD 4 and 7 the well 15/9-13, which was crossed several times from different directions, elevated bottom water CH_4 concentrations were measured and were found to be associated with small patches of microbial mats (Fig. 41). With regard to all transects, the bottom water pCO_2 data do not indicate any anomalous seabed CO_2 emissions. The pCO_2 recordings by the MIMS revealed short time fluctuations representing the noise of the instrument and the experimental set up. Fluctuations on longer time scales as resolved from the moving average might be induced by tidally driven exchange of water masses with slightly different pCO_2 levels.

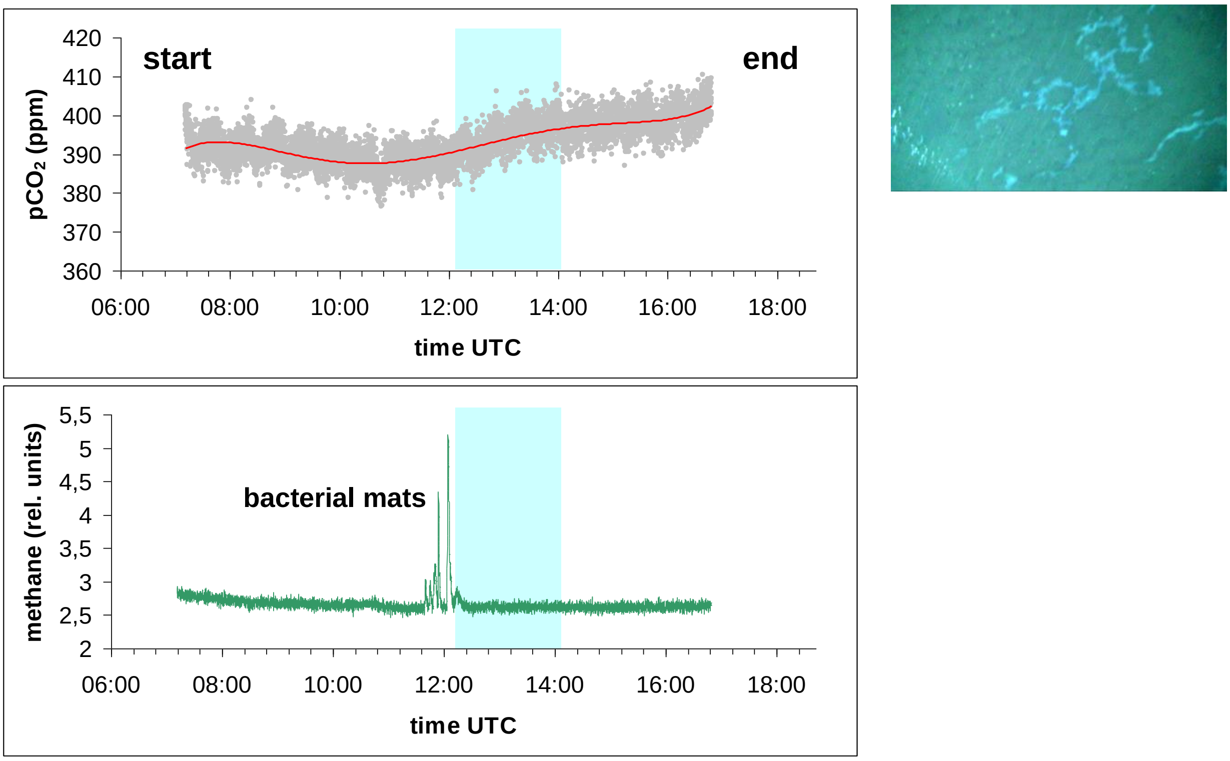


__Fig. 41__: upper panel left: bottom water pCO_2 levels along CTD track 7. Grey dots represent single measurements, red line represents a moving average; lower panel: left, respective bottom water CH4. The blue rectangle indicates extension of the sub-seabed CO_2 plume. Right: Screen shot with bacterial mats and free gas emission corresponding to the CH_4 increase at well 15/9-13.

Background seabed fluxes of pCO_2 and O_2

Background seabed emission of pCO_2 was measured inside two benthic chambers deployed during BIGO II 1 lander deployment (Fig. 42). In both chambers pCO_2 increased (Fig. 43) whereas O_2 (data not shown) decreased due to benthic respiration.

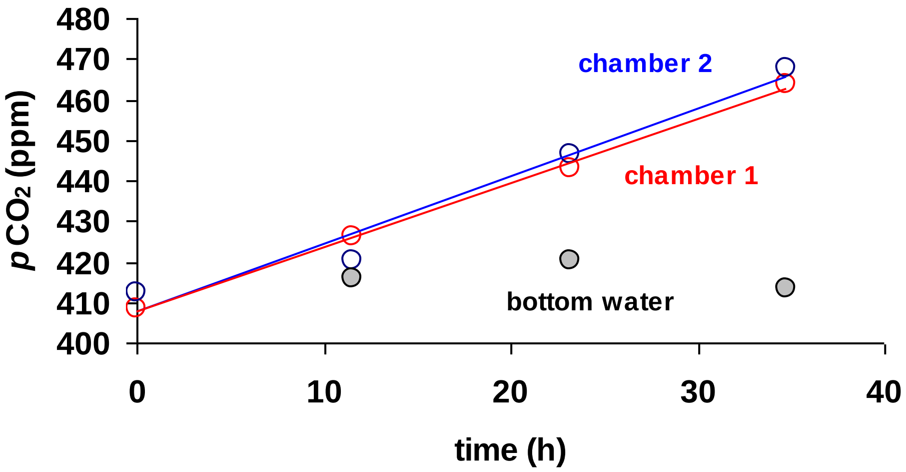


__Fig. 42__: BIGO II-1 lander ready for deployment.

__Fig. 43__: pCO_2 increase inside the two benthic chambers deployed during BIGO II-1 in comparison to bottom water pCO_2.

Blowout structure (Well 22-4b) in the central North Sea

Major aim of the investigations at the Blowout site was to trace the fate of methane that is released from the seabed into the water column and to assess the proportion of the released methane that reaches the sea surface and is emitted into the atmosphere. Spatial distribution of dissolved methane was investigated by measuring methane concentrations along pump CTD tracks which were conducted on three different depth horizons. CTD track 10 was conducted in 83 m water depth just above the sea floor, CTD track 11 was carried out in 60 m water depth which was below the thermocline, and CTD track 12 was conducted at 10 m water depth.

An example of the horizontal methane distribution above the seafloor is depicted in figure 44. These data has been corrected for the delay between the water sampling and its arrival at the inlet of the mass-spectrometer. Furthermore, only data from a certain time period of the entire track are shown in order to account for the tide and the associated current regime.

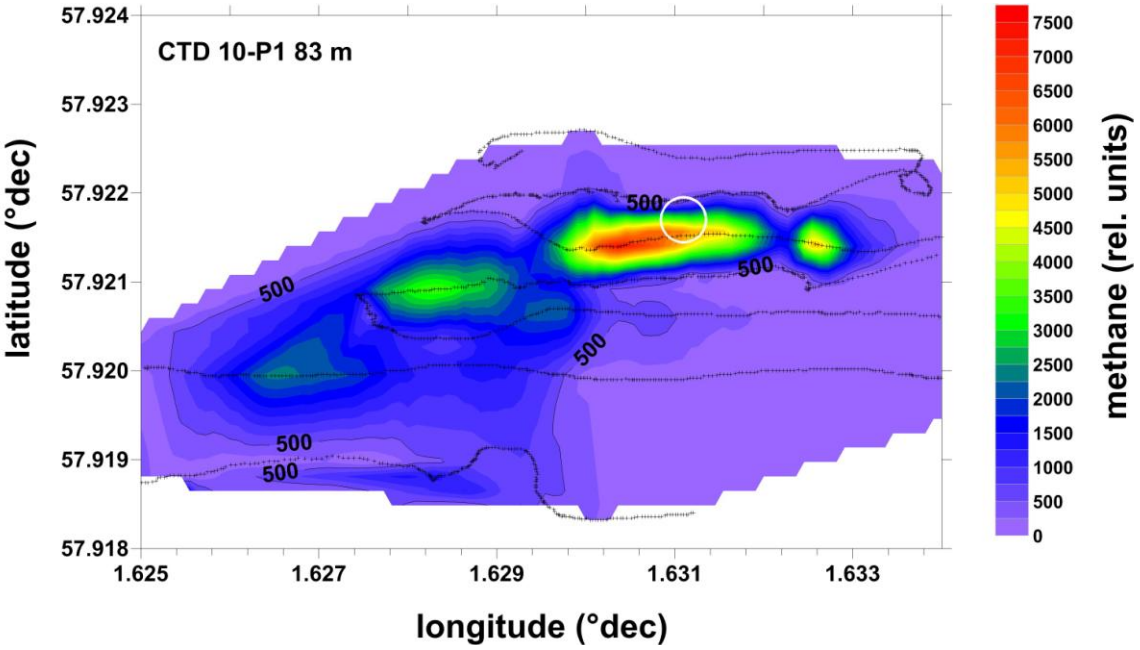


Fig. 44: *Isopycnal distribution of dissolved methane during CTD track 10 in 83 m water depth around the blow out structure (white circle). The black crosses indicate positions of the different methane measurements.*

7. WATER COLUMN MONITORING, SEDIMENT BIOGEOCHEMISTRY AND MICROBIOLOGY

A. Lichtschlag, C. Wigand, R. Stiens

Water column monitoring

In situ monitoring of water column CO_2 concentrations and other environmentally important parameters was done with a microprofiler unit from the MPI attached to the Ocean Floor Observatory System (OFOS) from the IFM-GEOMAR (Fig.45a, b). OFOS is a deep-towed camera sled used to identify and document seafloor expressions as well as associated flora and fauna. The sled was equipped with a digital still camera (Ocean Imaging Systems) and two xenon lights. The autonomously measuring microprofiler unit was equipped with sensors for CO_2, pH (Microelectrodes Inc.), temperature (PT 1000, Umweltsensortechnik), O_2 and redox potential (self-made). Sensors were calibrated on board at *in situ* temperature and salinity. During the deployment, the sensor array was protected by a cage (Fig.45b). The whole unit was run with a deep-sea battery.

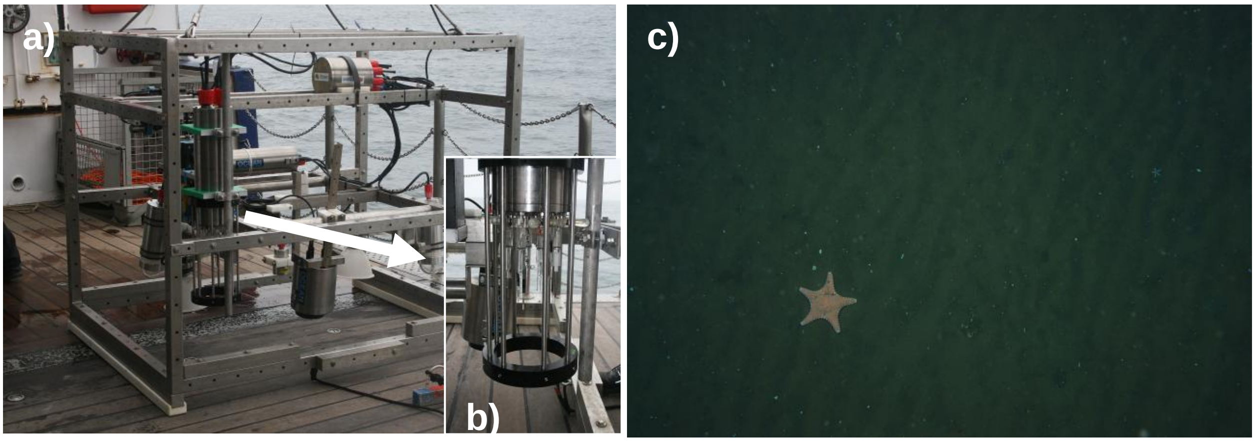


***Fig. 45**: a) OFOS equipped with camera, xenon lights and the microprofiler, b) close-up on sensors within a protecting cage at the lower end of the microprofiler unit, c) picture of the seafloor with starfish, taken during OFOS seafloor exploration at the Sleipner site.*

During the 3 deployments, the OFOS was towed at 1-2 knots along a pre-defined track for 2-4 hours (see Table 3) approximately 1 m above the seafloor. The microprofiler sensors recorded in 1 sec. intervals, while OFOS concurrently took images of the seafloor in 5 sec. intervals (Fig. 45c). Data are currently processed.

Table 3: OFOS tracks during the AL 374 cruise.

Stat.	Site	Water depth	Start of transect	End of transect	Date	Duration (time UTC)
496	Salt Dome Juist	30 m	54°2.093' 6°50.293'	54°2.096' 6°50.296'	30.05.2011	7:58-10:11
512	Sleipner	79 m	58°23.216' 1°58.689'	58°23.204' 1°58.603'	03.06.2011	9:25-11:41
537	Sleipner	85 m	58°24.226' 1°52.771'	58°24.223' 1°52.948'	08.06.2011	9:16-13:13

Sediment Biogeochemistry and Microbiology

In order to monitor the distribution of solutes and the microbial composition at potential CO_2 seepage sites, sediment samples were retrieved either with a Mini Multiple Corer (MMUC, core length of up to 20 cm) or with a Van Veen Grab (SG, approximately upper 10 cm of sediment). Sampling details and sediment description can be found in Table 4. Sediment samples were transferred to a cold room (12°C at Salt Dome Juist; 7°C at Sleipner) and immediately processed. All samples were taken in parallel to macrofauna samples (see chapter 8).

Table 4: Description of pore water and sediment sampling sites during AL374. MMUC: Mini Multiple Corer, SG: sediment grab (Van Veen Grab).

Station	*Site*	*Sampling device*	*Water depth*	*Position N / E*	*Date*	*Core description*
499	Salt Dome Juist, *potential CO_2 seepage site*	MMUC	30 m	54°1.010' 6°50.157'	30.05.2011	sandy sediment, no stratification, lower part with shell debris
507	Sleipner, *close to* abandoned *well with gas bubbles and bacterial mat*	MMUC	80 m	58°22.406' 1°55.958'	02.06.2011	sandy sediment, some black spots, bioturbation close to sediment surface
514	Sleipner *E-W transect*	SG	80 m	58°23.193' 1°56.771'	03.06.2011	sandy sediment (homogenised)
515	Sleipner *E-W transect*	SG	79.5 m	58°23.207' 1°56.900'	03.06.2011	sandy sediment (homogenised)
516	Sleipner *E-W transect*	SG	79 m	58°23.197' 1°57.257'	03.06.2011	sandy sediment (homogenised)
517	Sleipner *E-W transect*	SG	78.7 m	58°23.196' 1°57.563'	03.06.2011	sandy sediment (homogenised)
518	Sleipner *E-W transect*	SG	78.3 m	58°23.203' 1°58.244'	03.06.2011	sandy sediment (homogenised)
521	Sleipner *centre of E-W transect*	MMUC	78.2 m	58°23.196' 1°57.508'	04.06.2011	sandy sediment, no stratification
525	Sleipner *centre of CO_2 storage site*	MMUC	80 m	58°22.572' 1°56.798'	05.06.2011	sandy sediment, no stratification
527	Sleipner *Reference site*	MMUC	84.1 m	58°22.104' 1°52.128'	06.06.2011	sandy sediment (coarser than previous stations), greenish, no stratification
530	Sleipner *close to* abandoned *well*	MMUC	80 m	58°22.392' 1°55.916'	06.06.2011	sandy sediment, stratification with the upper cm beige, below darker sediment

Pore water was sampled directly from the sediment using Rhizone soil moisture samplers. For the MMUC samples, the Rhizones were inserted horizontally into the cores through pre-drilled holes sealed with diffusion-tight tape during deployment and connected to standard syringes using luer-lock fittings and PVC tubing. Evacuating the syringe by drawing the piston was sufficient to withdraw filtered pore water from the sediments. 5 or 10 mL syringes were used to sample pore water every 1 cm for the first 5 cm of sediment and every 2 cm until the end of the core (2 arrays for each core). For the SG pore water samples, sediment was filled in 50 mL vials, the vials were sealed with Parafilm and the Rhizones connected to a 5 mL syringe were directly inserted into the sediments.

To determine the concentrations of hydrogen sulphide, sulphate and chloride, 1 mL of pore water was fixed in Eppendorf tubes with 500 µL ZnAc at 4°C. For nutrient analyses, approx. 4 mL of pore water was frozen without fixation in 15 mL plastic vials at -20°C. For DIC/alkalinity, 2 mL of pore water was stored headspace-free in glass vials at 4°C. In addition, 2 mL of pore water was stored under the same conditions for DIC isotope measurements. For determining porosity, sediment was sampled and stored at 4°C in 5 mL capped, cut-off syringes. For methane concentration analyses, 5 mL of sediment was added to 10 mL NaOH (2.5%) in 20 mL gas-tight Crimpvials and stored at 4°C.

Samples will be processes in the laboratories of the MPI. In order to evaluate the potential influence of increased CO_2 concentrations (low pH) on microbial communities in the upper sediment layer, several samples were preserved for the analysis of microbial diversity at the respective sites. Molecular techniques will be applied in the home laboratories of the MPI and include acridine orange direct cell counts (AODC), fluorescence *in situ* hybridization (FISH) and DNA extraction. Therefore, 2 mL of sediment was fixed for AODC in 9 mL formaldehyde/seawater at 4°C during the cruise. Additionally, a 0.5 mL-subsample was preserved in 2 mL Et-OH at -20°C for FISH. DNA samples were taken in triplicates and stored in 50 mL tubes at -20°. These samples will serve as background data for our diversity and biogeochemical analyses at natural CO2 seeps.

To complement the investigations on microbial communities, 25 mL of sediment (MMUC: 0-5 cm and 5-10 cm; SG: bulk) were fixed in 50 mL of a formaldehyde/seawater mixture (4%) in Kautex flasks for meiofauna analyses. The meiofaunal composition within the sediments will be analyzed by Ann Vanreusel (Ghent University, Belgium).

8. STUDIES ON BENTHIC COMMUNITY STRUCTURE AND DIVERSITY

S. Syre

In order to elucidate the effects of potential CO_2 leakage from sub-seabed storage sites (Sleipner) and natural CO_2 leakage sites (Juist, southern North Sea) on benthic community structure and diversity, macrobenthos samples were obtained. A second aim of these explorative investigations was to identify abundant species / taxa that could be used as sensitive indicator species for monitoring purposes.

Macrobenthos samples of the surface sediment were taken with a 17L Van Veen grab sampler at 9 stations. Each 4 replicate samples were taken at station 498 (southern North Sea) and at 8 stations along a transect across the Sleipner CO2 storage site (stations 508, 514, 515, 516, 517, 522, 526, 528). Seawater pH was >8.0 at all sites. At each station, four samples were washed and sieved (1 mm mesh) in order to obtain macrofauna. Three samples per station were fixed in buffered formaldehyde for later taxonomic analysis and a fourth sample was analysed immediately. Typical species frequently found were *Cryptocelides loveni, Platynereis dumerilii, Pectinaria spp., Phascolion strombus, Lutraria lutraria, Antalis entalis, Luidia sarsi, Amphiura chiajei, Echinocyamus pusillus, Echinocardium cordatum* as well as many echinopluteus larvae undergoing metamorphosis.

The high abundance of various calcifiying echinoderms is encouraging, as these are typically very sensitive to increases in seawater pCO_2 and could thus be used as indicator species. Ongoing laboratory experiments will test their suitability as CO_2 indicator species.

9. SATELLITE LANDER DEPLOYMENTS

P. Linke, M. Türk

In order to record the environmental control parameters on fluid and gas discharge a small satellite lander was deployed by a video-guided launcher. The lander was equipped with a 300 kHz ADCP (RDI-Teledyne Instruments) and a storage CTD (SBE16plus V2) with a Paroscientific digiquartz pressure sensor. Furthermore, it carried a HARP hydrophone (Scripps Research Institute, La Jolla) with a data logger and a battery casing to record the sound of bubble release.

During the cruise, two deployments were performed: a test deployment at Sleipner and a long-term deployment in the crater of the 22-4b well site (Fig. 46) until recovery in September 2011. The deployment at Sleipner lasted for 3 days and revealed stable oceanographic conditions with tidal pressure fluctuations of < 1 dbar and current velocities of up to 35 cm/s (Fig. 47).

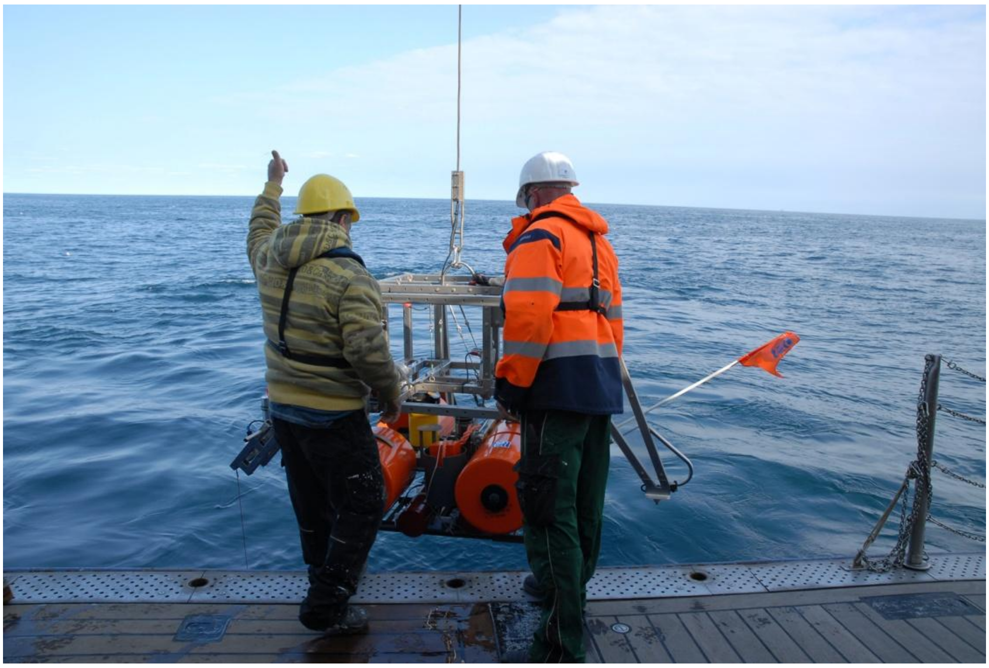


Fig. 46: *Satellite lander deployment at the 22-4b well site.*

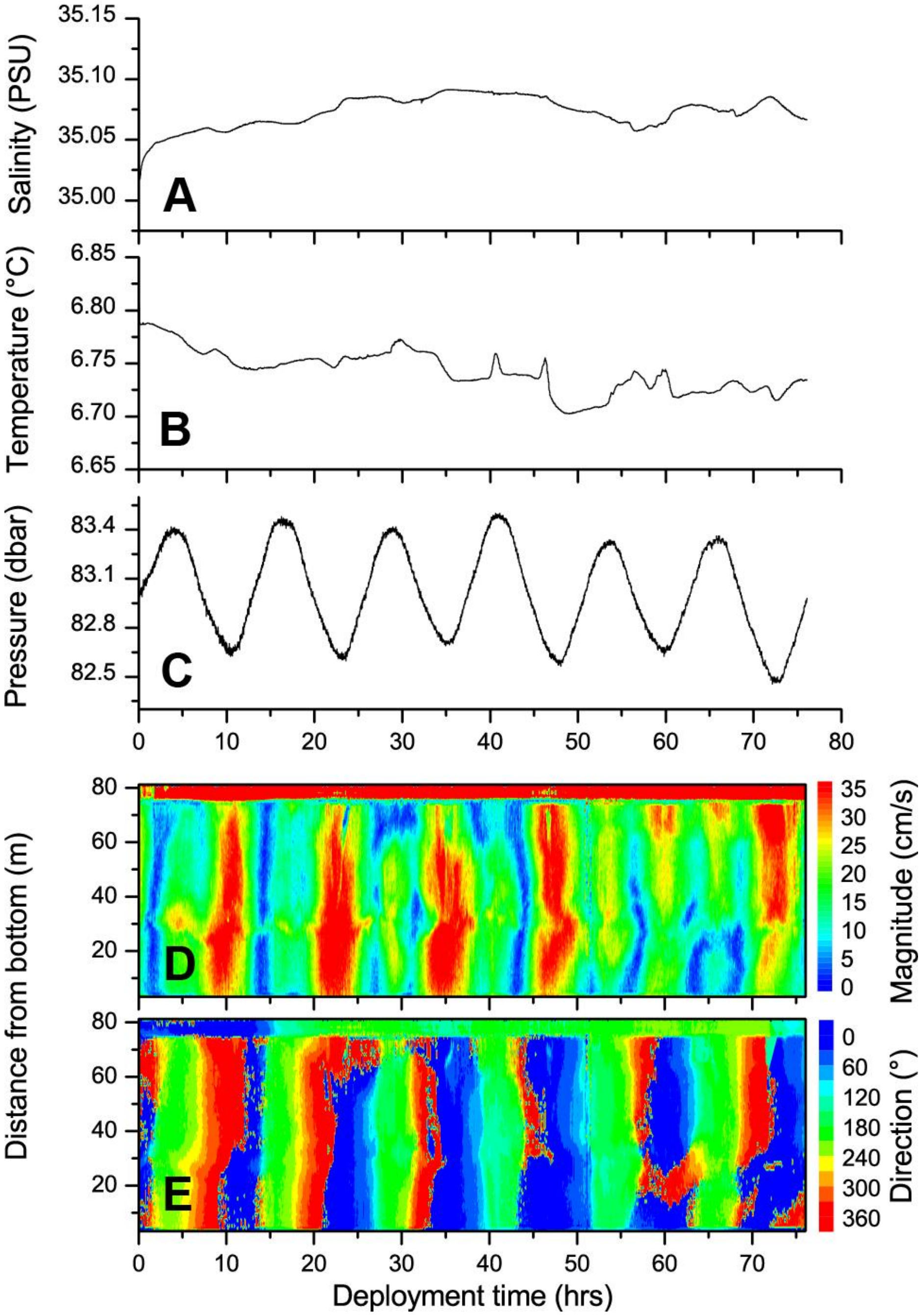


Fig. 47*: Results of the satellite lander deployment at Sleipner: A. Salinity, B. Temperature, and C. Pressure close to the seafloor, D. Current velocities and D. Current directions measured in 1 m bins up to 80 m distance from the seafloor.*

10. ACKNOWLEDGEMENTS

We thank Captain Norbert Hechler and his crew for their excellent support during the cruise and the members of the technology and logistics center at IFM-GEOMAR for their professional support during mobilization and demobilization of the cruise. Charts of the Sleipner area were provided by Statoil.

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ANNEX I: LIST OF STATIONS

Station	Gear	No.	Area	Date	Start	Coordinates		Depth	at depth	Coordinates		Depth	End stat.	Coordinates		Depth
No.				2011	Time	Lat. °N	Long. °E	(m)	Time	Lat. °N	Long. °E	(m)	Time	Lat. °N	Long. °E	(m)
495	VCTD	1	SD Juist	30.05.	04:15	54°1.492'	6°50.212'	30	04:27	54°1.489'	6°50.272'	30,4	06:18	54°1.139'	6°50.137'	30,7
496	OFOS	1	SD Juist	30.05.	07:53	54°2.093'	6°50.293'	31,8	07:58	54°2.096'	6°50.296'	31,3	10:11	54°1.143'	6°50.197	30,4
497	VCTD	2	SD Juist	30.05.	10:22	54°1.109'	6°50.182'	30,8	10:29	54°1.096'	6°50.156'	30,5	10:35	54°1.094'	6°50.101'	30
498	SG	1/1	SD Juist	30.05.	10:52	54°1.090'	6°50.135'	30,2	10:52	54°1.090'	6°50.135'	30,2	10:56	54°1.079'	6°50.140'	30,3
498	SG	1/2	SD Juist	30.05.	10:59	54°1.076'	6°50.138'	30,2	10:59	54°1.076'	6°50.138'	30,2	11:00	54°1.079'	6°50.140'	30,2
498	SG	1/3	SD Juist	30.05.	11:07	54°1.062'	6°50.083'	30,2	11:08	54°1.060'	6°50.082'	30,5	11:08	54°1.055'	6°50.076'	30,5
498	SG	1/4	SD Juist	30.05.	11:15	54°1.062'	6°50.083'	30,3	11:15	54°1.062'	6°50.083'	30,3	11:15	54°1.062'	6°50.083'	30,3
499	MIC	1/1	SD Juist	30.05.	11:30	54°1.032'	6°50.126'	30,1	11:32	54°1.03'	6°50.12'	30,1	11:35	54°1.012'	6°50.157'	30
499	MIC	1/2	SD Juist	30.05.	11:39	54°1.010'	6°50.157'	30	11:41	54°1.01'	6°50.16'	30	11:51	54°0.999'	6°50.212'	30
500	VCTD	3	SD Juist	30.05.	13:15	54°1.144'	6°50.333'	30	13:34	54°1.220'	6°50.336'	30	17:44	54°1.769'	6°50.385'	31
501	MB	1	SD Juist	30.05.	19:30	54°1.188'	6°50.400'	31,1					20:47	54°1.144'	6°50.004'	
502	MB	2	SD Juist	30.05.	22:28	54°0.200'	6°53.000'	29,3					01:41	54°0.305'	6°53.000'	
503	MB	3	SD Juist	30.05.	02:19	54°0.300'	6°50.800'	28,2					06:58	54°0.300'	6°50.415'	
504	FF	1	SD Juist	31.05.	07:00	5°1.59'	6°45.89'	30,6					08:45	54°8.26'	7°7.54'	37,6
505	FF	2	Sleipner	02.06.	06:06	58°22.366'	1°56.013'	79					06:22	58°22.401'	1°56.223'	79
506	VCTD	4	Sleipner	02.06.	06:57	58°22.415'	1°55.593'	80	07:26	58°22.411'	1°55.863'	79	16:06	58°22.372'	1°56.221'	79
507	MIC	2/1	Sleipner	02.06.	16:25	58°22.385'	1°55.984'	80					16:33	58°22.40'	1°55.94'	79,1
507	MIC	2/2	Sleipner	02.06.	16:35	58°22.405'	1°55.919	80					16:41	58°22.41	1°55.93'	80,7
507	MIC	2/3	Sleipner	02.06.	16:48	58°22.404'	1°55.924'	80					16:52	58°22.40'	1°55.93'	79,6
507	MIC	2/4	Sleipner	02.06.	16:54	58°22.406'	1°55.958'	80					17:00	58°22.40'	1°55.95'	79,4
508	SG	2/1	Sleipner	02.06.	17:13	58°22.411'	1°55.928'	79					17:18	58°22.40'	1°55.92'	79,1
508	SG	2/2	Sleipner	02.06.	17:18	58°22.406'	1°55.939'	80					17:22	58°22.41'	1°55.92'	80,3
508	SG	2/3	Sleipner	02.06.	17:25	58°22.407'	1°55.945'	80					17:27	58°22.41'	1°55.94'	78,6
508	SG	2/4	Sleipner	02.06.	17:30	58°22.409'	1°55.954'	80					17:31	58°22.41'	1°55.95'	79,7
509	MB	4	Sleipner	02.06.	19:00	58°21.3'	1°55.5'						23:00	58°21.54'	1°55.5'	
510	MB	5	Sleipner	02.06.	23:22	58°21.5'	1°55.75'						07:15	58°21.5'	1°58.22'	
511	STL	1	Sleipner	03.06.	08:01	58°22.434'	1°56.025'	80	08:35	58°22.446'	1°55.976'	79	08:36	58°22.447'	1°55.977'	79
512	OFOS	2	Sleipner	03.06.	09:20	58°23.216'	1°58.689'	79	09:25	58°23.204'	1°58.603'	79	11:41	58°23.181'	1°56.697	79
513	VCTD	5	Sleipner	03.06.	12:04	58°23.190'	1°58.539'	79	12:28	58°23.187'	1°58.301'	79	15:00	58°23.155'	1°56.230'	80
514	SG	3/1	Sleipner	03.06.	15:10	58°23.193'	1°56.771'	80					15:12	58°23.19'	1°56.77'	79,6
514	SG	3/2	Sleipner	03.06.	15:17	58°23.182'	1°56.748'	79,8					15:19	58°23.18'	1°56.74'	79,4

Station	Gear	No.	Area	Date	Start	Coordinates		Depth	at depth	Coordinates		Depth	End stat.	Coordinates		Depth
514	SG	3/3	Sleipner	03.06.	15:22	58°23.167'	1°56.732'	79,4					15:25	58°23.16'	1°56.76'	79,7
514	SG	3/4	Sleipner	03.06.	15:27	58°23.138'	1°56.778'	79,3					15:27	58°23.15'	1°56.77'	79,7
514	SG	3/5	Sleipner	03.06.	15:30	58°23.126'	1°56.788'	79,4					15:33	58°23.13'	1°56.79'	79,5
515	SG	4/1	Sleipner	03.06.	15:45	58°23.207'	1°56.900'	79,5					15:48	58°23.21'	1°56.89'	79,6
515	SG	4/2	Sleipner	03.06.	15:52	58°23.185'	1°56.933'	79,3					15:56	58°23.21'	1°56.91'	79,4
515	SG	4/3	Sleipner	03.06.	15:58	58°23.222'	1°56.858'	79,2					16:00	58°23.22'	1°56.86'	78,4
515	SG	4/4	Sleipner	03.06.	16:02	58°23.207'	1°56.872'	79,4					16:04	58°23.21'	1°56.87'	79,6
515	SG	4/5	Sleipner	03.06.	16:08	58°23.196'	1°56.918'	78,9					16:09	58°23.20'	1°56.92'	79,4
516	SG	5/1	Sleipner	03.06.	16:18	58°23.197'	1°57.257'	79					16:20	58°23.20'	1°57.26'	79,2
516	SG	5/2	Sleipner	03.06.	16:23	58°23.201'	1°57.216'	78,9					16:26	58°23.20'	1°57.20'	79,4
516	SG	5/3	Sleipner	03.06.	16:28	58°23.179'	1°57.205'	79,1					16:30	58°23.18'	1°57.21'	79
516	SG	5/4	Sleipner	03.06.	16:32	58°23.187'	1°57.245'	78,8					16:34	58°23.19'	1°57.25'	79,2
516	SG	5/5	Sleipner	03.06.	16:37	58°23.197'	1°57.308'	79,3					16:38	58°23.20'	1°57.31'	78,5
517	SG	6/1	Sleipner	03.06.	16:46	58°23.196'	1°57.563'	78,7					16:48	58°23.19'	1°57.56'	79
517	SG	6/2	Sleipner	03.06.	16:52	58°23.203'	1°57.523'	78,9					16:54	58°23.20'	1°57.52'	78,8
517	SG	6/3	Sleipner	03.06.	16:56	58°23.203'	1°57.554'	79					16:58	58°23.20'	1°57.56'	79,2
517	SG	6/4	Sleipner	03.06.	17:00	58°23.211'	1°57.564'	79,2					17:02	58°23.21'	1°57.56'	78,9
517	SG	6/5	Sleipner	03.06.	17:04	58°23.208'	1°57.539'	78,8					17:06	58°23.21'	1°57.53'	78,3
518	SG	7	Sleipner	03.06.	17:21	58°23.203'	1°58.244'	78,3					17:25	58°23.20'	1°58,22'	79
519	MB	6	Sleipner	03.06.	18:42	58°24.0'	1°56.85'						05:11	58°23.6'	1°56.0'	
520	VCTD	6	Sleipner	04.06.	06:02	58°21.506'	1°56.196'	79	06:20	58°21.644'	1°56.288'	79	17:55	58°28.552'	2°1.774'	80
521	MIC	3/1	Sleipner	04.06.	18:56	58°23.189'	1°57.509'	79,1					19:00	58°23.19'	1°57.51'	79,4
521	MIC	3/2	Sleipner	04.06.	19:03	58°23.192'	1°57.519'	79,6					19:04	58°23.19'	1°57.52'	78,4
521	MIC	3/3	Sleipner	04.06.	19:09	58°23.186'	1°57.514'	79,2					19:12	58°23.18'	1°57.52'	78.7
521	MIC	3/4	Sleipner	04.06.	19:15	58°23.198'	1°57.510'	78,9					19:16	58°23.20'	1°57.51'	78.4
521	MIC	3/2	Sleipner	04.06.	19:21	58°23.196'	1°57.508'	78,2					19:23	58°23.20'	1°57.50'	79,3
522	SG	8/1	Sleipner	04.06.	19:50	58°23.205'	1°58.282'	78,2					19:51	58°23.21'	1°58.28'	78,4
522	SG	8/2	Sleipner	04.06.	19:53	58°23.200'	1°58.290'	79,2	19:54	58°23.20'	1°58.28'	79	19:55	58°23.20'	1°58.28'	79
522	SG	8/3	Sleipner	04.06.	19:56	58°23.226'	1°58.261'	78,4	19:56	58°23.22'	1°58.26'	78,3	19:58	58°23.23'	1°58.26'	78,5
522	SG	8/4	Sleipner	04.06.	20:00	58°23.217'	1°58.241'	78,4	20:00	58°23.22'	1°58.25'	78,6	20:02	58°23.21'	1°58.24'	77,8
522	SG	8/5	Sleipner	04.06.	20:03	58°23.209'	1°58.205'	78,4	20:04	58°23.21'	1°58.20'	78,9	20:06	58°23.21'	1°59.19'	78,5
523	MB	7	Sleipner	04.06.	20:55	58°23.8'	1°52.0'						23:54	58°23.8'	1°52.95'	
524	VCTD	7	Sleipner	05.06.	06:42	58°21.952'	1°52.002'	84	07:02	58°22.027'	1°52.113'	84	17:18	58°23.910'	1°57.747'	79
525	MIC	4/1	Sleipner	05.06.	17:42	58°22.555'	1°56.780'	80					17:46	58°22.57'	1°56.77'	79,2

Station	Gear	No.	Area	Date	Start	Coordinates		Depth	at depth	Coordinates		Depth	End stat.	Coordinates		Depth
525	MIC	4/2	Sleipner	05.06.	17:48	58°22.583'	1°56.766'	78,9					17:52	58°22.59'	1°56.78'	78,8
525	MIC	4/3	Sleipner	05.06.	17:54	58°22.572'	1°56.798'	80					17:57	58°22.57'	1°56.80'	79,5
526	SG	9/1	Sleipner	05.06.	18:06	58°22.613'	1°56.729'	79,8					18:08	58°22.61'	1°56.73'	78,5
526	SG	9/2	Sleipner	05.06.	18:10	58°22.640'	1°56.730'	78,8					18:11	58°22.64'	1°56.73'	79,6
526	SG	9/3	Sleipner	05.06.	18:13	58°22.654'	1°56.736'	79,7					18:15	58°22.65'	1°56.74'	79,7
526	SG	9/4	Sleipner	05.06.	18:16	58°22.654'	1°56.729'	79,4					18:18	58°22.65'	1°56.73'	78,9
527	MIC	5/1	Sleipner	06.06.	06:01	58°22.080'	1°52.245'	84,2					06:05	58°22.09'	1°52.21'	83,4
527	MIC	5/2	Sleipner	06.06.	06:10	58°22.113'	1°52.153'	84					06:14	58°22.11'	1°52.14'	84,1
527	MIC	5/3	Sleipner	06.06.	06:17	58°22.104'	1°52.128'	84,1					06:22	58°22.11'	1°52.13'	84
528	SG	10/1	Sleipner	06.06.	06:42	58°22.134'	1°52.113'	84,6					06:45	58°22.13'	1°52.10'	84,4
528	SG	10/2	Sleipner	06.06.	06:47	58°22.130'	1°52.076'	84					06:49	58°22.13'	1°52.08'	84,4
528	SG	10/3	Sleipner	06.06.	06:51	58°22.133'	1°52.068'	84					06:53	58°22.14'	1°52.07'	83,8
528	SG	10/4	Sleipner	06.06.	06:55	58°22.172'	1°52.091'	84,9					06:58	58°22.18'	1°52.10'	84,8
529	BIGO	1	Sleipner	06.06.	09:57	58°22.602'	1°56.872'	80	10:03	58°22.598'	1°56.856'	80	10:08	58°22.597'	1°56.860'	80
530	MIC	6/1	Sleipner	06.06.	11:23	58°22.394'	1°55.955'	80					11:28	58°22.39'	1°55.94'	80
530	MIC	6/2	Sleipner	06.06.	11:29	58°22.390'	1°55.938'	79,7					11:32	58°22.39'	1°55.94'	79,5
530	MIC	6/3	Sleipner	06.06.	11:36	58°22.400'	1°55.940'	79,9					11:39	58°22.40	1°55.93'	80,1
530	MIC	6/4	Sleipner	06.06.	11:53	58°22.384'	1°55.959'	80					11:56	58°22.39'	1°55.97'	80,2
530	MIC	6/5	Sleipner	06.06.	11:58	58°22.391'	1°55.940'	80					11:59	58°22.39'	1°55.94'	79,9
530	MIC	6/6	Sleipner	06.06.	12:01	58°22.392'	1°55.916'	80					12:06	58°22.39'	1°55.93'	79,9
531	STL	2	Sleipner	06.06.	12:00								13:13	58°22.271'	1°56.434'	80
532	MB	8	Blowout	06.06.	17:51	57°55.3'	1°37.0'						01:54	57°55.25'	1°37.7'	
533	MB	9	Blowout	07.06.	06:41	57°54.92'	1°37.47'	93,4					07:22	57°55.49'	1°38.08'	93,3
534	VCTD	8	Blowout	07.06.	07:30	57°55.448'	1°38.052'	94	07:38	57°55.346'	1°37.909'	93	15:53	57°55.135'	1°37.691'	93
535	STL	3	Blowout	07.06.	16:19	57°55.260'	1°77.816'	93		57°55.360'	1°37.862'	104	16:40	57°55.331'	1°37.884'	93
536	BIGO	2	Sleipner	08.06.	06:33	56°22.662'	1°56.820'	80	06:42	58°22.660'	1°56.788'	80	07:00	58°22.714'	1°56.918'	80
537	OFOS	3	Sleipner	08.06.	09:10	58°24.226'	1°52.771'	85	09:16	58°24.223'	1°52.948'	85	13:13	58°22.398'	1°57.789'	80
538	VCTD	9	Sleipner	08.06.	14:17	58°22.576'	1°56.791'	79					17:41	58°22.515'	1°56.743'	80
539	MB	10	Sleipner	08.06.	18:00	58°21.5'	1°58.0'						22:05	58°21.8'	1°51.86'	
540	VCTD	10	Blowout	09.06.	07:00	57°55.380'	1°37.698'	93	07:32	57°55.353'	1°37.766'	93	12:50	57°55.381'	1°37.770'	93
541	MB	11	Blowout	09.06.	15:13	57°55.15'	1°37.5'						18:12	57°55.45'	1°37.5'	
542	VCTD	11/1	Blowout	10.06.	06:30	57°55.125'	1°37.888'	93					09:12	57°55.32'	1°38.03'	93
543	VCTD	11/2	Blowout	10.06.	09:32	57°55.43'	1°37.96'	93					11:50	57°55.347'	1°37.671'	93
544	VCTD	12	Blowout	10.06.	12:27	57°55.479'	1°37.749'	93					17:10	57°55.365'	1°37.874'	93

Station	Gear	No.	Area	Date	Start	Coordinates		Depth	at depth	Coordinates		Depth	End stat.	Coordinates		Depth
545	FF	3	Sleipner	11.06.	05:58	58°21.501'	1°53.299'	84					06:41	58°21.91'	1°52.61'	83,3
546	FF	4	Sleipner	11.06.	06:50	58°22.05'	1°52.58'	83,5					07:00	58°21.49'	1°53.21'	82,2
547	VCTD	13	Sleipner	11.06.	07:41	58°21.122'	1°53.236'	82	08:05	58°21.150'	1°53.199'	82	13:12	58°21.723'	1°53.182'	81

Times in UTC (Local time = summer time – 2 hours)

Gear:

BIGO: Biogeochemical Observatory

FF: Fishfinder

MIC: Mini Corer

MB: Multibeam

OFOS: Ocean Floor Observation System

SG: Sediment Grab

STL: Satellite Lander

VCTD: Video-CTD/Rosette

ANNEX II: LIST OF MULTIBEAM AND ECHOSOUNDER PROFILES

TIME	DATE	LONG	dec'	LAT	dec'	Heading	NOTE / WORKING AREA	FILE-NAME-START	FILE-NAME-END
UTC	**2011**	**E**		**N**			**SALT DOME JUIST**		**SALT DOME JUIST**
	30/05/	6	50,4	54	1,188	270	START of Profile I-A Calibration	002	002
	30/05/	6	49,8	54	1,188	270	END of Profile I-A Calibration	002	002
	30/05/	6	49,8	54	1,188	90	START of Profile I-B Calibration	003	003
19:44	30/05/	6	50,4	54	1,188	90	END of Profile I-B Calibration	003	003
19:57	30/05/	6	50,4	54	1,166	270	START of Profile II-A Calibration	004	004
20:01	30/05/	6	49,8	54	1,166	270	END of Profile II-A Calibration	004	004
20:11	30/05/	6	49,8	54	1,166	90	START of Profile II-B Calibration	005	005
20:16	30/05/	6	50,4	54	1,166	90	END of Profile II-B Calibration	005	005
20:27	30/05/	6	50,4	54	1,144	270	START of Profile III-A Calibration	006	006
20,31	30/05/	6	49,8	54	1,144	270	END of Profile III-A Calibration	006	006
20:43	30/05/	6	49,8	54	1,144	90	START of Profile III-B Calibration	007	007
20:47	30/05/	6	50,4	54	1,144	90	END of Profile III-B Calibration	007	007
22:28	30/05/	6	53	54	0,2	270	START of Profile 001	008	011
23:11	30/05/	6	45	54	0,2	270	END of Profile 001	008	011
23:18	30/05/	6	45	54	0,235	90	START of Profile 002	012	015
00:02	31/05/	6	53	54	0,235	90	END of Profile 002	012	015
00:06	31/05/	6	53	54	0,27	270	START of Profile 003	016	019
0:50	31/05/	6	45	54	0,27	270	END of Profile 003	016	019
0:56	31/05/	6	45	54	0,305	90	START of Profile 004	020	023
01:41	31/05/	6	53	54	0,305	90	END of Profile 004	020	023
02:19	31/05/	6	50,8	54	0,3	360	START of Profile 005	024	025
02:38	31/05/	6	50,8	54	2,4	360	END of Profile 005	024	025
02:46	31/05/	6	50,75	54	2,4	180	START of Profile 006	026	027
03:06	31/05/	6	50,75	54	0,3	180	END of Profile 006	026	027
03:13	31/05/	6	50,69	54	0,3	360	START of Profile 007	028	029
03:33	31/05/	6	50,69	54	2,4	360	END of Profile 007	028	029
03:41	31/05/	6	50,64	54	2,4	180	START of Profile 008	030	031
04:01	31/05/	6	50,64	54	0,3	180	END of Profile 008	030	031
04:08	31/05/	6	50,58	54	0,3	360	START of Profile 009	032	033
04:29	31/05/	6	50,58	54	2,4	360	END of Profile 009	032	033
04:39	31/05/	6	50,53	54	2,4	180	START of Profile 010	034	035
04:59	31/05/	6	50,53	54	0,3	180	END of Profile 010	034	035
05:09	31/05/	6	50,47	54	0,3	360	START of Profile 011	036	037
05:29	31/05/	6	50,47	54	2,4	360	END of Profile 011	036	037
05:39	31/05/	6	50,42	54	2,4	180	START of Profile 012	038	040
06:58	05/31/	6	50,415	54	0,3	180	END of Profile 012	038	040
UTC	**2011**	**E**		**N**			**SLEIPNER PLUME**		**SLEIPNER**
19:05	02/06/	1	55,5	58	21,3	90	START of Profile I-A Calibration	040	FEHLER
	02/06/	1	57,3	58	21,3	90	END of Profile I-A Calibration	040	FEHLER
	02/06/	1	57,3	58	21,3	270	START of Profile I-B Calibration	041	FEHLER
19:39	02/06/	1	55,5	58	21,3	270	END of Profile I-B Calibration	041	FEHLER
~20:40	02/06/	1	55,5	58	21,3	90	START of Profile I-A Calibration	042	042
20:49	02/06/	1	57,3	58	21,3	90	END of Profile I-A Calibration	042	042

TIME	DATE	LONG	dec'	LAT	dec'	Heading	NOTE / WORKING AREA	FILE-NAME-START	FILE-NAME-END
21:02	02/06/	1	57,3	58	21,3	270	START of Profile I-B Calibration	043	043
21:14	02/06/	1	55,5	58	21,3	270	END of Profile I-B Calibration	043	043
	02/06/					90	START of Profile II-A Calibration	044	044
21:47	02/06/					90	END of Profile II-A Calibration	044	044
21:56	02/06/					270	START of Profile II-B Calibration	045	045
22:09	02/06/					270	END of Profile II-B Calibration	045	045
22:28	02/06/					90	START of Profile III-A Calibration	046	
22:41	02/06/					90	END of Profile III-A Calibration	046	
22:50	02/06/					270	START of Profile III-B Calibration	047	
	02/06/					270	END of Profile III-B Calibration	047	
23:22	02/06/	1	55,75	58	21,5	360	START of Profile 001	048	
23:50	02/06/	1	55,75	58	24,2	360	END of Profile 001	048	
23:55	02/06/	1	55,94	58	24,2	180	START of Profile 002	049	
00:23	03/06/	1	55,94	58	21,5	180	END of Profile 002	049	
	03/06/	1	56,13	58	21,5	360	START of Profile 003	050	
00:58	03/06/	1	56,13	58	24,2	360	END of Profile 003	050	
01:03	03/06/	1	56,32	58	24,2	180	START of Profile 004	051	
01:30	03/06/	1	56,32	58	21,5	180	END of Profile 004	051	
01:38	03/06/	1	56,51	58	21,5	360	START of Profile 005	052	
02:05	03/06/	1	56,51	58	24,2	360	END of Profile 005	052	
02:12	03/06/	1	56,7	58	24,2	180	START of Profile 006	053	
02:40	03/06/	1	56,7	58	21,5	180	END of Profile 006	053	
02:48	03/06/	1	56,89	58	21,5	360	START of Profile 007	054	
03:15	03/06/	1	56,89	58	24,2	360	END of Profile 007	054	
03:22	03/06/	1	57,08	58	24,2	180	START of Profile 008	055	
03:50	03/06/	1	57,08	58	21,5	180	END of Profile 008	055	
03:58	03/06/	1	57,27	58	21,5	360	START of Profile 009	056	
04:24	03/06/	1	57,27	58	24,2	360	END of Profile 009	056	
04:33	03/06/	1	57,46	58	24,2	180	START of Profile 010	057	
05:00	03/06/	1	57,46	58	21,5	180	END of Profile 010	057	
05:07	03/06/	1	57,65	58	21,5	360	START of Profile 011	058	
05:35	03/06/	1	57,65	58	24,2	360	END of Profile 011	058	
	03/06/	1	57,84	58	24,2	180	START of Profile 012	059	
06:08	03/06/	1	57,84	58	21,5	180	END of Profile 012	059	
06:14	03/06/	1	58,03	58	21,5	360	START of Profile 013	060	
06:40	03/06/	1	58,03	58	24,2	360	END of Profile 013	060	
06:49	03/06/	1	58,22	58	24,2	180	START of Profile 014	061	
	03/06/	1	58,22	58	21,5	180	END of Profile 014	061	
UTC	**2011**	**E**		**N**			**N-WELL 15/7-02 SLEIPNER**		**SLEIPNER**
18:42	03/06/	1	56,85	58	24	28	START of Profile 015	062	063
19:36	03/06/	2	01,46	58	28,65	28	END of Profile 015	062	063
19:44	03/06/	2	01,66	58	28,65	208	START of Profile 016	064	065
20:39	03/06/	1	57,05	58	24	208	END of Profile 016	064	065
20:47	03/06/	1	57,25	58	24	28	START of Profile 017	066	067
21:43	03/06/	2	01,86	58	28,65	28	END of Profile 017	066	067
21:49	03/06/	2	02,06	58	28,65	208	START of Profile 018	068	069

TIME	DATE	LONG	dec'	LAT	dec'	Heading	NOTE / WORKING AREA	FILE-NAME-START	FILE-NAME-END
22:46	03/06/	1	57,45	58	24	208	END of Profile 018	068	069
22:53	03/06/	1	57,65	58	24	28	START of Profile 019	070	071
23:50	03/06/	2	02,26	58	28,65	28	END of Profile 019	070	071
23:56	03/06/	2	02,46	58	28,65	208	START of Profile 020	072	073
00:52	04/06/	1	57,85	58	24	208	END of Profile 020	072	073
UTC	**2011**	**E**		**N**			**NW-WELL 15/9-11 SLEIPNER**		**SLEIPNER**
01:11	04/06/	01	56	58	24,4	270	START of Profile 021	074	074
01:35	04/06/	01	52	58	24,4	270	END of Profile 021	074	074
01:42	04/06/	01	52	58	24,3	90	START of Profile 022	075	075
02:04	04/06/	01	56	58	24,3	90	END of Profile 022	075	075
02:12	04/06/	01	56	58	24,2	270	START of Profile 023	076	076
02:35	04/06/	01	52	58	24,2	270	END of Profile 023	076	076
02:41	04/06/	01	52	58	24,1	90	START of Profile 024	077	077
3:06	04/06/	01	56	58	24,1	90	END of Profile 024	077	077
03:13	04/06/	01	56	58	24	270	START of Profile 025	078	078
03:37	04/06/	01	52	58	24	270	END of Profile 025	078	078
03:44	04/06/	01	52	58	23,9	90	START of Profile 026	079	079
04:07	04/06/	01	56	58	23,9	90	END of Profile 026	079	079
04:16	04/06/	01	56	58	23,8	270	START of Profile 027	080	080
04:39	04/06/	01	52	58	23,8	270	END of Profile 027	080	080
04:47	04/06/	01	52	58	23,7	90	START of Profile 028	081	081
05:11	04/06/	01	56	58	23,7	90	END of Profile 028	081	081
UTC	**2011**	**E**		**N**			**W-WELL 15/9-16 SLEIPNER**		**SLEIPNER**
20:55	04/06/	01	52	58	23,8	180	START of Profile 029	082	082
21:16	04/06/	01	52	58	21,8	180	END of Profile 029	082	082
21:25	04/06/	01	52,19	58	21,8	360	START of Profile 030	083	083
21:46	04/06/	01	52,19	58	23,8	360	END of Profile 030	083	083
21:53	04/06/	01	52,38	58	23,8	180	START of Profile 031	084	084
22:14	04/06/	01	52,38	58	21,8	180	END of Profile 031	084	084
22:22	04/06/	01	52,57	58	21,8	360	START of Profile 032	085	085
22:45	04/06/	01	52,57	58	23,8	360	END of Profile 032	085	085
22:51	04/06/	01	52,76	58	23,8	180	START of Profile 033	086	086
23:12	04/06/	01	52,76	58	21,8	180	END of Profile 033	086	086
23:21	04/06/	01	52,95	58	21,8	360	START of Profile 034	087	087
23:43	04/06/	01	52,95	58	23,8	360	END of Profile 034	087	087
UTC	**2011**	**E**		**N**			**Well 22/4-b BLOWOUT CRATER**		**BLOWOUT**
17:51	06/06/	1	37	57	55,3	90	START of Profile 001	088	088
18:05	06/06/	1	39	57	55,3	90	END of Profile 001	088	088
18:25	06/06/	1	39	57	56	220	START of Profile 002	089	089
18:47	06/06/	1	37	57	54,8	220	END of Profile 002	089	089
19:00	06/06/	1	38	57	54,8	360	START of Profile 003	090	090
19:15	06/06/	1	38	57	56	360	END of Profile 003	090	090
19:24	06/06/	1	37,85	57	56	180	START of Profile 004	091	091
19:39	06/06/	1	37,85	57	54,8	180	END of Profile 004	091	091
19:50	06/06/	1	37,85	57	56	360	START of Profile 005	092	092
20:04	06/06/	1	37,85	57	54,8	360	END of Profile 005	092	092

TIME	DATE	LONG	dec'	LAT	dec'	Heading	NOTE / WORKING AREA	FILE-NAME-START	FILE-NAME-END
20:16	06/06/	1	37	57	54,8	180	START of Profile 006	093	093
20:31	06/06/	1	37	57	56	180	END of Profile 006	093	093
20:41	06/06/	1	37,2	57	56	360	START of Profile 007	094	094
20:55	06/06/	1	37,2	57	54,8	360	END of Profile 007	094	094
21:04	06/06/	1	37,4	57	54,8	180	START of Profile 008	095	095
21:20	06/06/	1	37,4	57	56	180	END of Profile 008	095	095
21:30	06/06/	1	37,6	57	56	360	START of Profile 009	096	096
21:45	06/06/	1	37,6	57	54,8	360	END of Profile 009	096	096
21:52	06/06/	1	37,8	57	54,8	180	START of Profile 010	097	097
22:09	06/06/	1	37,8	57	56	180	END of Profile 010	097	097
22:15	06/06/	1	38	57	56	360	START of Profile 011	098	098
22:31	06/06/	1	38	57	54,8	360	END of Profile 011	098	098
22:41	06/06/	1	38,2	57	54,8	180	START of Profile 012	099	099
22:57	06/06/	1	38,2	57	56	180	END of Profile 012	099	099
23:05	06/06/	1	38,4	57	56	360	START of Profile 013	100	100
23:20	06/06/	1	38,4	57	54,8	360	END of Profile 013	100	100
23:29	06/06/	1	38,6	57	54,8	180	START of Profile 014	101	101
23:44	06/06/	1	38,6	57	56	180	END of Profile 014	101	101
23:52	06/06/	1	38,8	57	56	360	START of Profile 015	102	102
00:08	07/06/	1	38,8	57	54,8	360	END of Profile 015	102	102
00:15	07/06/	1	39	57	54,8	180	START of Profile 016	103	103
00:30	07/06/	1	39	57	56	180	END of Profile 016	103	103
	07/06/	1	38,2	57	55,2	302	START of Profile 017	104	104
01:08	07/06/	1	37,5	57	55,4	302	END of Profile 017	104	104
01:29	07/06/	1	37,7	57	55,35	302	START of Profile 018	105	105
01:33	07/06/	1	38	57	55,25	302	END of Profile 018	105	105
01:45	07/06/	1	38	57	55,35	302	START of Profile 019	106	106
01:54	07/06/	1	37,7	57	55,25	302	END of Profile 019	106	106
UTC	**2011**	**E**		**N**			**SLEIPNER S**		**SLEIPNER**
18:00	08/06/	1	58	58	21,5	270	START of Profile 001	107	107
18:33	08/06/	1	53	58	22	270	END of Profile 001	107	107
18:43	08/06/	1	52,81	58	21,95	90	START of Profile 002	108	108
19:17	08/06/	1	58	58	21,4	90	END of Profile 002	108	108
~19:26	08/06/	1	58	58	21,3	270	START of Profile 003	109	110
20:00	08/06/	1	52,62	58	21,9	270	END of Profile 003	109	110
20:07	08/06/	1	52,43	58	21,85	90	START of Profile 004	111	112
20:45	08/06/	1	58	58	21,2	90	END of Profile 004	111	112
20:53	08/06/	1	58	58	21,1	270	START of Profile 005	113	114
	08/06/	1	52,24	58	21,8	270	ZIGZAG at the END of	113	114
	08/06/	1	21,8	58	52,05		ZIGZAG at the END of	113	114
	08/06/	1	21,1	58	52,35		ZIGZAG at the END of	113	11
	08/06/	1	21,1	58	52,16		ZIGZAG at the END of	113	114
22:02	08/06/	1	21,8	58	51,86		END of Profile 005	113	114
UTC	**2011**	**E**		**N**			**Well 22/4-b BLOWOUT CRATER**		**BLOWOUT**
15:01	09/06/	1	37,5	57	55,15		SEDIMENT ECHOSOUNDER	115	120
18:12	09/06/	1	37,5	57	55,45			115	120

ANNEX III: DIC AND DISSOLVED GAS SAMPLES

Station No.	CTD Profile	Date	Location	Niskin Btl.	"Tracy" No	DICvial
495	**1-2**	**30.05.2011**	**Salt Dome Juist**	**1**	**AL374_CH4_028**	**1**
				2	**AL374_CH4_030**	**2**
				3	**AL374_CH4_031**	**3**
				4	**AL374_CH4_032**	**4**
				5	**AL374_CH4_033**	**5**
				6	**AL374_CH4_034**	**6**
				7	**AL374_CH4_035**	**7**
				8	**AL374_CH4_036**	**8**
				9	**-**	**9**
				10	**AL374_CH4_037**	**10**
506	**4**	**02.06.2011**	**Sleipner**	**1**	**AL374_CH4_090**	
				2	**AL374_CH4_091**	
				3	**AL374_CH4_092**	
				4	**AL374_CH4_093**	
				5	**AL374_CH4_094**	
				6	**AL374_CH4_095**	
				7	**AL374_CH4_096**	
				8	**AL374_CH4_097**	
				9	**AL374_CH4_098**	
				10	**AL374_CH4_099**	
				11	**AL374_CH4_100**	
				12	**AL374_CH4_101**	
513	**5**	**03.06.2011**	**Sleipner**	**1**	**AL374_CH4_120**	**11**
				2	**AL374_CH4_121**	**12**
				3	**AL374_CH4_122**	**13**
				4	**AL374_CH4_123**	**14**
				5	**AL374_CH4_124**	**15**
				6	**AL374_CH4_125**	**16**
				7	**AL374_CH4_126**	**17**
				8	**AL374_CH4_127**	**18**
				9	**AL374_CH4_128**	**19**
				10	**AL374_CH4_129**	**20**
				11	**AL374_CH4_130**	**21**
				12	**AL374_CH4_131**	**22**
520	**6**	**04.06.2011**	**Sleipner**	**1**	**AL374_CH4_185**	
				2	**AL374_CH4_186**	
				3	**AL374_CH4_187**	
				4	**AL374_CH4_188**	
				5	**AL374_CH4_189**	
				6	**AL374_CH4_190**	
				7	**AL374_CH4_191**	

Station No.	CTD Profile	Date	Location	Niskin Btl.	"Tracy" No	DICvial
				8	**AL374_CH4_192**	
				9	**AL374_CH4_193**	
				10	**AL374_CH4_194**	
				11	**AL374_CH4_195**	
				12	**AL374_CH4_196**	
524	**7**	**05.06.2011**	**Sleipner**	**1**	**AL374_CH4_second_sample_table_067**	**23**
				2	**AL374_CH4_second_sample_table_068**	**24**
				3	**AL374_CH4_second_sample_table_069**	**25**
				4_1	**AL374_CH4_second_sample_table_070**	**26**
				4_2	**AL374_CH4_second_sample_table_071**	
				5	**AL374_CH4_second_sample_table_072**	**27**
				6	**AL374_CH4_second_sample_table_073**	**28**
				7	**AL374_CH4_second_sample_table_074**	**29**
				8	**AL374_CH4_second_sample_table_075**	**30**
				9	**AL374_CH4_second_sample_table_076**	**31**
				10	**AL374_CH4_second_sample_table_077**	**32**
				11	**AL374_CH4_second_sample_table_078**	**33**
				12	**AL374_CH4_second_sample_table_079**	**34**
534	**8**	**07.06.2011**	**Blowout**	**1**	**AL374_CH4_second_sample_table_099**	
				2	**AL374_CH4_second_sample_table_100**	
				3	**AL374_CH4_second_sample_table_101**	
				4	**AL374_CH4_second_sample_table_102**	
				5	**AL374_CH4_second_sample_table_103**	
				6	**AL374_CH4_second_sample_table_104**	
				7	**AL374_CH4_second_sample_table_105**	
				8	**AL374_CH4_second_sample_table_106**	
				9	**AL374_CH4_second_sample_table_107**	
				10	**AL374_CH4_second_sample_table_108**	
				11	**AL374_CH4_second_sample_table_109**	
				12	**AL374_CH4_second_sample_table_110**	
538	**9**	**08.06.2011**	**Sleipner**	**1**	**AL374_CH4_third_sample_table_139**	**35**
				2	**AL374_CH4_third_sample_table_140**	**36**
				3		**37**
				4	**AL374_CH4_third_sample_table_141**	**38**
				5	**AL374_CH4_third_sample_table_142**	**39**
				6	**AL374_CH4_third_sample_table_143**	**40**
				7	**AL374_CH4_third_sample_table_144**	**41**
				8	**AL374_CH4_third_sample_table_145**	**42**
				9	**AL374_CH4_third_sample_table_146**	**42**
				10	**AL374_CH4_third_sample_table_147**	**44**
				11	**AL374_CH4_third_sample_table_148**	**45**
				12	**AL374_CH4_third_sample_table_149**	**46**
540	**10**	**09.06.2011**	**Blowout**	**1**	**AL374_CH4_second_sample_table_144**	
				2	**AL374_CH4_second_sample_table_145**	
				3	**AL374_CH4_second_sample_table_146**	
				4	**AL374_CH4_second_sample_table_147**	

Station No.	CTD Profile	Date	Location	Niskin Btl.	"Tracy" No	DICvial
				5	**AL374_CH4_second_sample_table_148**	
				6_2	**AL374_CH4_third_sample_table_102**	
				7	**AL374_CH4_second_sample_table_151**	
				8	**AL374_CH4_second_sample_table_152**	
				9	**AL374_CH4_second_sample_table_153**	
				10	**AL374_CH4_second_sample_table_154**	
				11	**AL374_CH4_second_sample_table_155**	
				12	**AL374_CH4_second_sample_table_156**	
542	**11**	**10.06.2011**	**Blowout**	**1**	**AL374_CH4_third_sample_table_086**	
				2	**AL374_CH4_third_sample_table_087**	
				3	**AL374_CH4_third_sample_table_088**	
				4	**AL374_CH4_third_sample_table_089**	
				5	**AL374_CH4_third_sample_table_090**	
				6	**AL374_CH4_third_sample_table_091**	
				7	**AL374_CH4_third_sample_table_092**	
				8	**AL374_CH4_third_sample_table_093**	
				9	**AL374_CH4_third_sample_table_096**	
				10	**AL374_CH4_third_sample_table_097**	
				11	**AL374_CH4_third_sample_table_100**	
				12	**AL374_CH4_third_sample_table_101**	
543	**12**	**10.06.2011**	**Blowout**	**1**	**AL374_CH4_third_sample_table_069**	
				2	**AL374_CH4_third_sample_table_070**	
				3	**AL374_CH4_third_sample_table_071**	
				4	**AL374_CH4_third_sample_table_072**	
				5	**AL374_CH4_third_sample_table_073**	
				6	**AL374_CH4_third_sample_table_074**	
				7	**AL374_CH4_third_sample_table_075**	
				8	**AL374_CH4_third_sample_table_076**	
				9	**AL374_CH4_third_sample_table_077**	
				10	**AL374_CH4_third_sample_table_078**	
				11	**AL374_CH4_third_sample_table_079**	
				12	**AL374_CH4_third_sample_table_080**	
543	**12**	**10.06.2011**	**Blowout**	**I**	**AL374_CH4_third_sample_table_081**	
Air samples				**II**	**AL374_CH4_third_sample_table_082**	
				III	**AL374_CH4_third_sample_table_083**	
				IV	**AL374_CH4_third_sample_table_085**	
546	**13**	**11.06.2011**	**Sleipner**	**1**	**AL374_CH4_third_sample_table_060**	**47**
				2	**AL374_CH4_third_sample_table_061**	**48**

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41	FS SONNE Fahrtbericht / Cruise Report SO206, Caldera, Costa Rica – Caldera, Costa Rica, 30.05. – 19.06.2010, Ed.: Christian Hensen, 95 pp, In English
42	FS SONNE Fahrtbericht / Cruise Report SO212, Talcahuano, Chile – Valparaiso, Chile, 22.12. – 26.12.2010, Ed.: Ernst Flüh, 47 pp, in English
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