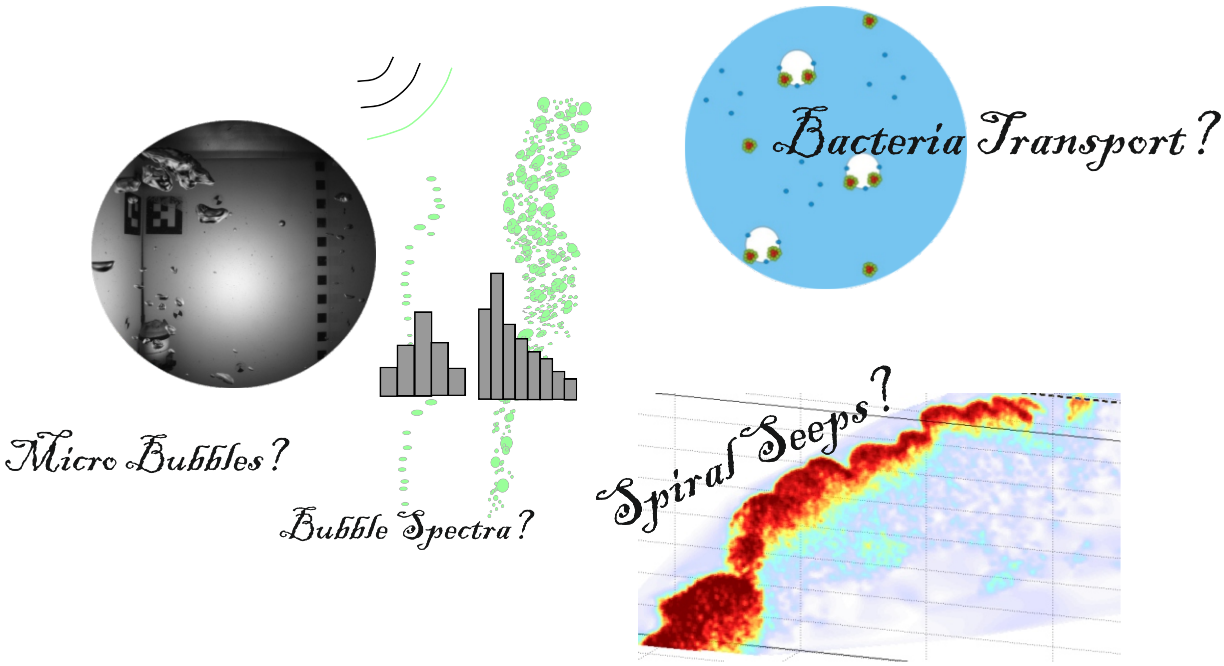
Christian-Albrechts-Universität zu Kiel
Institut für Geowissenschaften

Cruise Report R/V POSEIDON POS504

Seepage process analyses at the abandoned well Blowout site (22/4b, North Sea)

27.08.2016 – 09.09.2016 (Kiel - Kiel)



Port Calls	None
Institutes	University Kiel (CAU), Institute of Baltic Sea Research (IOW), GEOMAR University of Los Angeles
Number of Scientists	6
Related Projects	Future Ocean GQ2 (CP1207), Future Ocean Quabble (CP1331), Bubble Shuttle II (DFG SCHM 2530/7-1)

Compiled by: Jens Schneider von Deimling

Content

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2 Research program

In May 1994, Rehder et al. (1998) identified a pronounced dissolved methane peak in surface waters near 58° 00' N and 01° 40' E, about 200 km east off the Scottish coast, with maximum concentrations more than 700 times atmospheric equilibrium, and attributed this to ongoing leakage from the abandoned well site 22/4b, that blew out in 1990. Direct geochemical and hydroacoustic evidence of ongoing and intense gas bubble release from a 20 m deep crater at 22/4b up to the sea surface was provided during a cruise in 2005 (Schneider von Deimling et al., 2007). This so-called "Blowout site" was subsequently studied in detail (special issue: Leifer and Judd, 2015, references therein).
Research during POS 504 focused on the Blowout site with the aim to study two recently discovered seepage processes in detail that could affect the fate of methane in the water column and thus affecting the emission of this greenhouse gas into the atmosphere. Pilot studies demonstrated that the two seepage processes termed "Spiral Vortex" (Schneider von Deimling et al., 2015) and "Bubble Transport Mechanism" (Schmale et al., 2015) exist. ROV based video and special imaging sonar techniques for water column analyses were applied to further analyse the "Spiral Vortex" process. We hypothesize that this process has strong implications on the methane bubble dissolution and distribution, and may considerably be tide-dependent. Studies regarding the "Bubble Transport Mechanism" process showed that rising gas bubbles from the seabed could serve as a bentho-pelagic transport vehicle for methane oxidizing bacteria. This process may contribute to the pelagic methane sink by continuously inoculating the water column with methane oxidizing microorganisms in addition to the local pelagic population of methanotrophic microorganism (Schmale et al., 2015). To investigate the "Bubble Transport Mechanism" a special device (Bubble Catcher) was developed and applied by the ROV to capture gas bubbles and to later analyse the samples for potential bacteria accumulations and identification.

To succeed we prepared and applied a challenging and interdisciplinary research program with customised hydroacoustic, biogeochemical, microbiological and oceanographic methods. Special devices were developed and adapted for use with the workclass ROV PHOCA: (1) the Bubble Box was initially developed within SUGAR II for both, minor and major gas bubble seepage flux measurements (Jordt et al., 2015). It was further enhanced in the FUTURE OCEAN research projects QUABBLE and GQ2 at Kiel University, and video analyses and electronics were realized by the Deep Sea Monitoring group at GEOMAR; (2) the Bubble Catcher represents a special device from IOW for microbial sampling of particles carried on gas bubbles; (3) an imaging Sonar was provided by the German naval department WTD 71 and adapted for online use with the ROV PHOCA.

The primary research target of POS 504 was the abandoned well site 22/4b, hereafter termed the "Blowout" site in the British sector of the North Sea. Due to the high probability of strong wind and significant swell heights, that would restrict the deployment of the workclass ROV PHOCA, alternate seep areas and research areas were notified in Norwegian and Dutch seas to be able to react in case of bad weather. However, given the prevailing weather situation, we decided to stay near the Blowout site throughout this research cruise.

3 Narrative of the cruise with technical details

Saturday (27.08), the scientific equipment of this cruise was loaded in Kiel (Germany). Shortly before leaving the harbour on **Sunday (28.08)**, in the morning, the vessel faced a technical problem causing a few hours of delay. However, RV POSEIDON could take off after noontime and the delay could be recovered during the upcoming 500 nm of transit towards our study site (Fig. 1). Our target study site is located around the abandoned well site 22/4b at 57° 55’ N and 01° 38’ E, thus we decided to steam through the Skagerrak towards the Central North Sea. With easterly winds and a relatively new ship hull paint the vessel could steam >10 knots. On the evening of **Monday (29.08)**, we reached the British Exclusive Economic Zone and the working area, respectively. First, we targeted the abandoned well site 22/4b to investigate, if it is still active in terms of gas release and found a positive result. Subsequently, the first CTD casts were run to acquire sound velocity profiles for the hydroacoustic surveys during the night. Given the limited man power on RV POSEIDON, both, science and crew, the night program was generally performed with either hydroacoustic surveying or CTD casting. **Tuesday (30.08)**, after midnight, a noise test was performed to evaluate if and how the different sounders interfere on this vessel. Unfortunately, the fix installed 50 kHz multibeam on RV POSEIDON strongly interfered with our mobile parametric subbottom profiler that was installed in the moon pool. Therefore, the 5x10 km wide area had to be surveyed independently with the respective devices to acquire high performance data for bathymetry, water column, and subbottom. At 07 o’clock in the morning, we ran a stationary test site for the imaging box that was supposed to be deployed via ROV later on that day. Given the significant ship movement, a planned ROV dive was postponed and instead CTDs were run. At 13 o’clock, the ROV could be deployed for the first time. We deployed an ADCP mooring 800 m away from the Blowout and subsequently performed the first observation flight towards and into the crater. Only moderate gas release was found during this first dive, however, this was due to overseeing the mega seeps during the first observation dive. Unfortunately, the subpositioning USBL system was encountered not to work properly during the cruise. **Wednesday (31.08)**, the weather worsened again with the critical conditions of ca. >11 m/s wind and 2 m swell and the bad weather alternative research program was conducted with eleven CTDs for chemical, biological and oceanographic sampling and measurements. The acoustic measurements suffered from the bad weather during the night. Nevertheless, the water column data showed good quality and the gas releases could be clearly imaged.

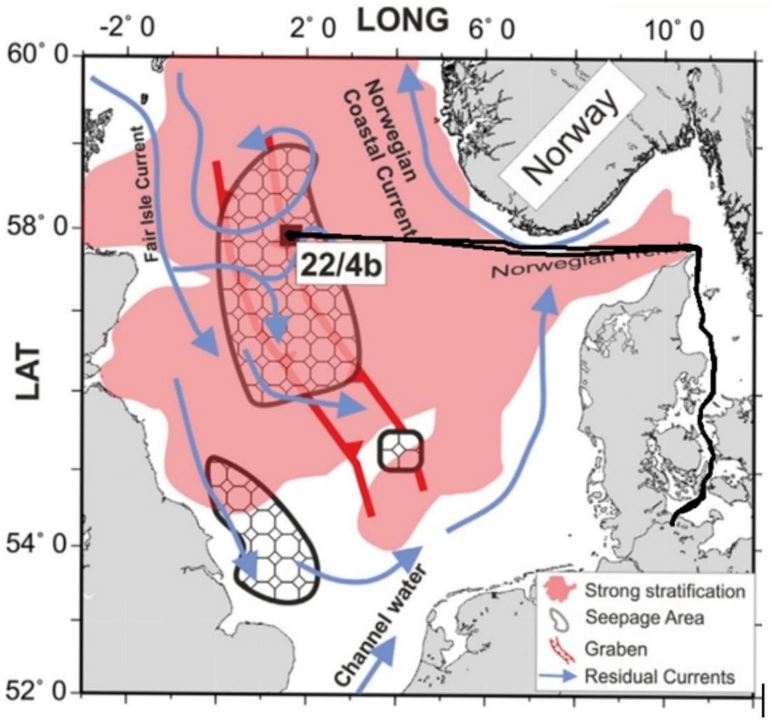

Fig. 1: Cruise track of POS 504, figure adapted after Schneider von Deimling et al. (2015).

Thursday (01.09), our additional bad weather program was to acquire sediment samples from the seabed to ground truth the acoustic surveys by Van-Veen grab and Frahm-Lot coring. **Friday (02.09),** weather conditions were constantly at the limit in terms of ROV deployment, though we managed another dive on Friday for the "Bubble Catcher experiment". A shocking moment was the detection of a leak in the hydraulic system after this dive. **Saturday (03.09) until Monday (05.09)**: fortunately, the hydraulic leak was fixed and the PHOCA was in full operation again. The wind and swell forecast for the upcoming days had worsened until the end of the weather model forecast. Therefore, the decision was drawn to recover the deployed ADCP mooring that had acquired already enough data to fulfil the goal of estimating tidal currents and derive tracer distribution afterwards. The following days were again characterized by conditions close to or beyond save ROV deployments. Nevertheless, we could conduct the main measurements of our campaign with a total of 8 ROV dives, 48 CTDs, 14 grab samples, 5 Frahm-Lot cores, approximately 100 hours of hydroacoustic measurements.

Tuesday (06.09), a possible last dive was cancelled given the critical swell on the last day in the research area and finally, we took off to steam back towards Kiel harbour on the evening. As scheduled, RV POSEIDON reached the final destination on Friday morning at 09 o'clock.

4 Scientific report and first results

4.1 First inspection of the 22/4b Blowout site seep activity

First action of POS 504 was targeting the abandoned well site 22/4b to investigate, if the formerly reported intense gas release, that was thoroughly investigated during several campaigns in the recent years (see special issue Leifer and Judd, 2015), were persistent or not. First findings from the hydroacoustic flare imaging during the night revealed ongoing and strong gas seep release visible via a prolific hydroacoustic plume above the 22/4b well site crater with similar shape as observed in 2005 (Schneider von Deimling et al., 2007). An area centred around 22/4b covering approximately 14 nm² was surveyed during POS 504, and further natural gas seep sites could be identified near 22/4b by acoustic flare imaging. The secondary crater southeast of 22/4b, that was recognized during the PATHFINDER mission in 2011 (Wilson et al., 2015) and sampled by an ROV in 2012 (Linke, 2012), was found to be still active as well.

At daytime and with good visibility the typical surface bubble patch above the 22/4b crater became visible by eye spotting. The patch showed an approximate size of 10 m diameter thus being smaller compared to the first direct observations after the accident from 2005 (Schneider von Deimling et al., 2007) and obviously attracts seagulls for hitherto unknown reasons (Fig. 2).

Fig. 2a: Surface gas bubble patch with seagull as size reference.

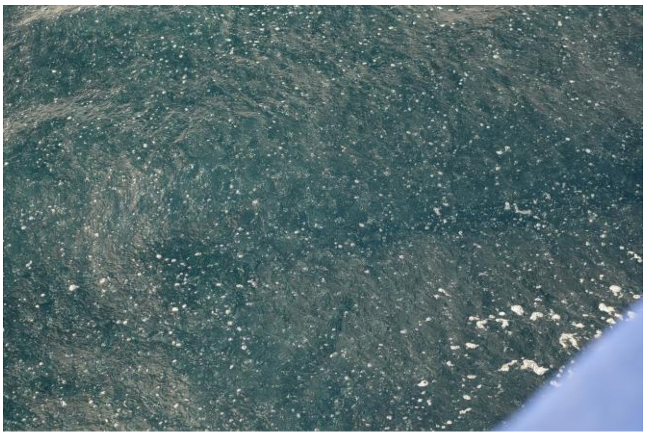

Fig. 2b: Close up of gas bubble surface patch.

A first ROV NE-SW transect was planned with a starting point 800 m away from the crater (Fig. 3a). The flight across the seabed towards the crater served as an inspection flight and we found biological activity on the seabed with increasing abundance of benthic life, fish (mainly Pollack) and mussel debris with proximity to the crater. The dive into the crater was accompanied by a large abundance of fish, and the crater seafloor was found to consist of sandy-silty sediments and mostly covered by mussel debris. A seep field with dozens of minor (ml/min) to major (l/min) gas release sites was identified during this first inspection dive. No mega seeps (10^6 t/day) were found during this first dive, which we attribute to the limited survey time during the first dive (Fig. 3b).

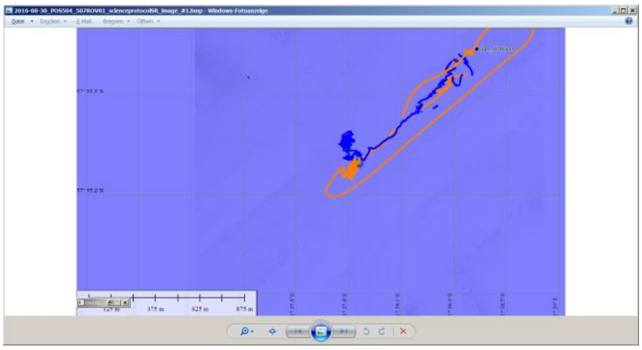

Fig. 3a: ROV inspection survey track with initial ADCP deployment 800 m northeast of 22/4b.

Fig. 3b: First Marker set for later Bubble Catcher deployment within the crater at a seep field consisting of minor to major vent sites.

Subsequent dives with thorough visual inspection and sonar guidance provided unambiguous evidence that three mega seeps are present, which were found to be active during all subsequent dives (Fig. 4). The visual impression of the mega seep intensity is in line with the first in situ observation from 2006 (Pfannkuche, 2006).

Fig. 4: Still picture of one of the three mega seeps.

The three mega seeps were acoustically identified as bright spots with the ROV in the crater (Fig. 5) that are hereafter termed S1, S2, and S3. S3 consists of two individual mega seeps being only 0.1-0.2 m apart thus acoustically appearing as one sonar pattern.

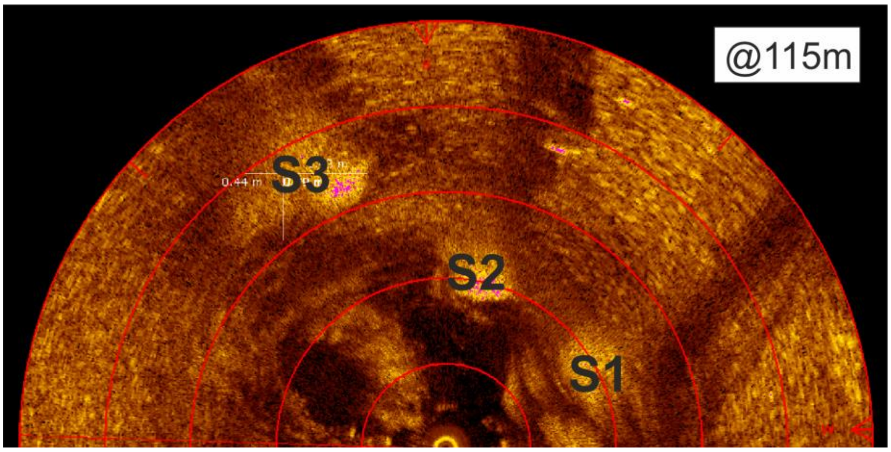

Fig. 5: Sector Scan sonar image recorded while ROV sitting on the bottom of the crater, S1-S3 represent the individual "mega seeps".

The acoustic signals were able to penetrate the bubble plume and its width was measured to approximately 0.5 m diameter (S1 and S2), and 1 m for S3 with an overall mega seep plume extent bounding 1.2 m². A successful deployment of the Bubble Box system adapted for mega seeps flux quantification revealed F_B=1±0.1 L per second within the 0.3x0.3 m (0.09 m²) area (Fig. 6).

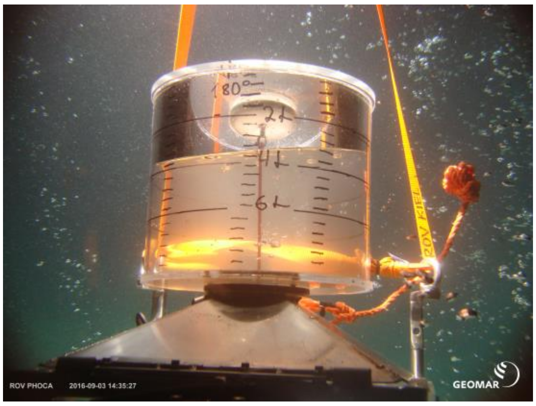

Fig. 6: In situ flux measurement with the Bubble Box measurement tool.

A first order estimate with F_{all}=1.2 m²/0.09 m² x F_B=13 Ls^{-1} provides a flux being similar to the recently published flux by Leifer (2015). Unfortunately, due to bad weather and severe problems with underwater positioning of the ROV, measurements with a duration lasting over a tidal cycle could not be conducted during the cruise.

After the assessment of the benthic gas flux, the ROV ascended approx. 25 m along the crater wall until reaching the crater shoulder around 95 m water depth. By looking towards the centre of the crater, a strong sonar gas pattern could be identified within the 50 m wide crater (Fig. 7).

Discrimination of the individual mega seeps S1-S3 is not possible any longer in the sonar pattern. We conclude that the three mega seeps S1-S3 and the adjacent minor to major gas seeps have merged after ascending 25 m forming one rising gas megaplume (M) with an approximate diameter of 10 m (Fig. 7).

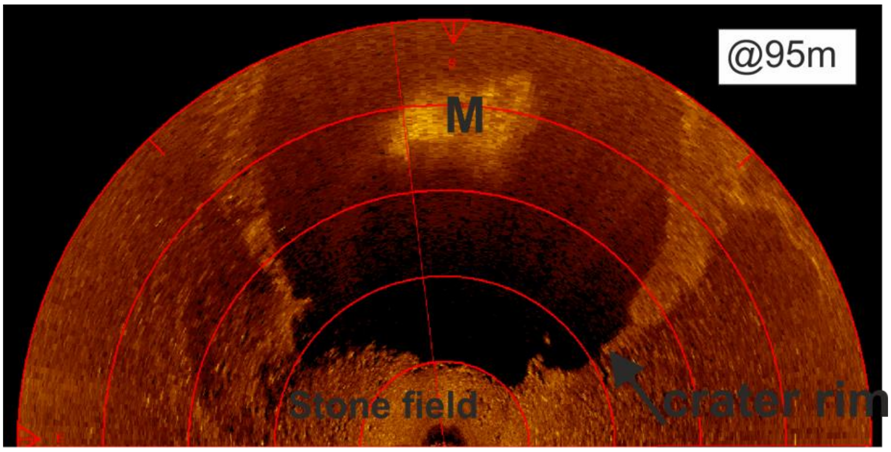

Fig. 7: Sector scan sonar image recorded while ROV sitting next to crater rim observing the 50 m wide crater, M represent the "merged plume" arising from depth.

This 10 m wide plume was imaged with the special 2D imaging sonar, while the ROV was stationary sitting 15 m away from the crater rim on the 95 m deep seafloor to potentially observe spiral motion and other dynamic plume motions (Schneider von Deimling et al, 2015). First data evaluation reveals strongly varying plume shape (Fig. 8), indicating a transition between laminar and turbulent fluid motions on a minute time scale. Further data processing and evaluation is needed to better constrain such complex and transient plume motion dynamics.

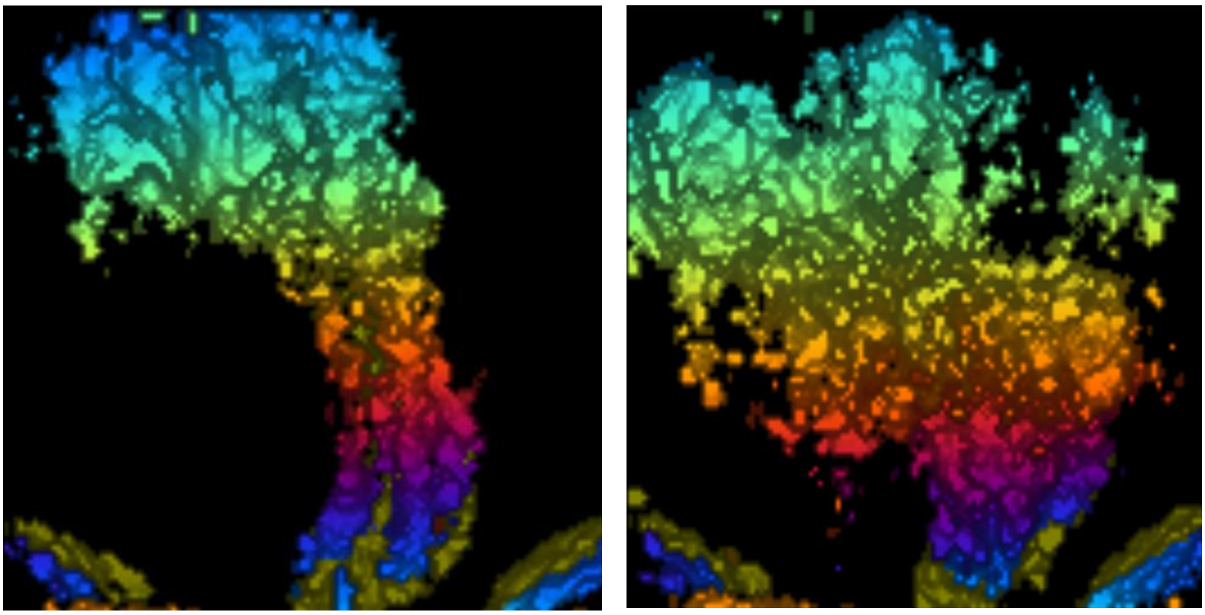

Fig. 8: CODAECHOSCOPE 2D acoustic image of the plume at 2 minutes different times. (a) is showing upwards more laminar flow, (b) is showing turbulent state of the bubble plume.

4.2 Acoustic investigations of the seabed and the water column

We used five acoustic devices with customised settings. The area of interest was first surveyed with multibeam and parametric singlebeam devices in three modes: (1) bathymetric and seabed backscatter, (2) water column backscatter, (3) stationary water column imaging. In addition, two in situ sonars were operated from the ROV to make use of high-resolution/short-range measurements for acoustical particle velocimetry (Schneider von Deimling and Papenberg, 2012). An ADCP was deployed to assess water current profiling data for several days.

4.2.1 Bathymetry and seabed backscatter

Unfortunately, data quality suffered from the bad weather and most likely by bow-bubble wash down effects on RV POSEIDON. First analyses of the bathymetric data indicate that the Blowout crater rim shape and its depth have merely changed since the first bathymetric assessment from 2005 (Schneider von Deimling et al., 2007). Outside the crater, the seafloor morphology appears flat and featureless with a gentle slope increasing from NW to SE (Fig. 9). The positive depth offset on the six most easterly lines are attributed to tidal effects that have not yet been compensated. The snippet backscatter of the multibeam did neither show significant anomalies on the survey area. However, these data need to be considered with care given the unfavourable weather and measurement conditions.

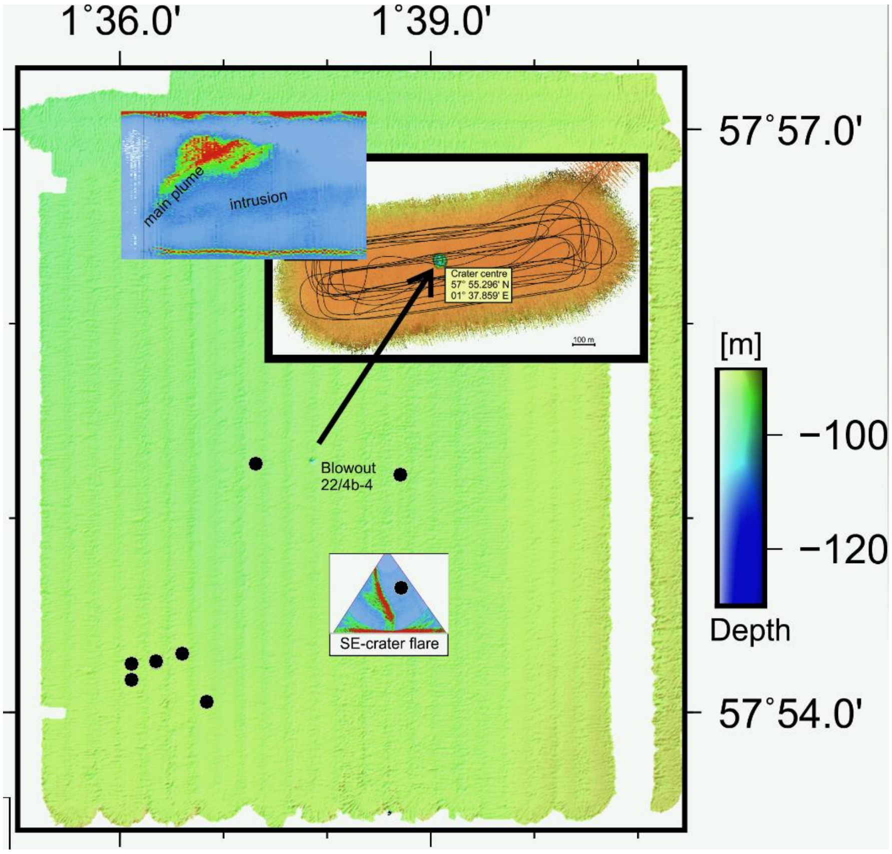

Fig. 9: Overview chart of the bathymetric survey. Fan view showing gas seep activity from the smaller crater 0.8 nm southeast of 22/4b (see Linke et al., 2012), dive 41-ROV10/11 PC25; WCI file 160830_212843_648.gwc). Dots mark flare positions.

4.2.2 Subbottom imaging

SES data were recorded simultaneously with the multibeam data on eight track lines easterly of the Blowout (Fig. 10, red lines) during the first night after arriving the study area. These data were of poor quality and contained several noise-like features (Fig. 11). This was likely caused by air bubbles, sucked under the ship hull at the bow.

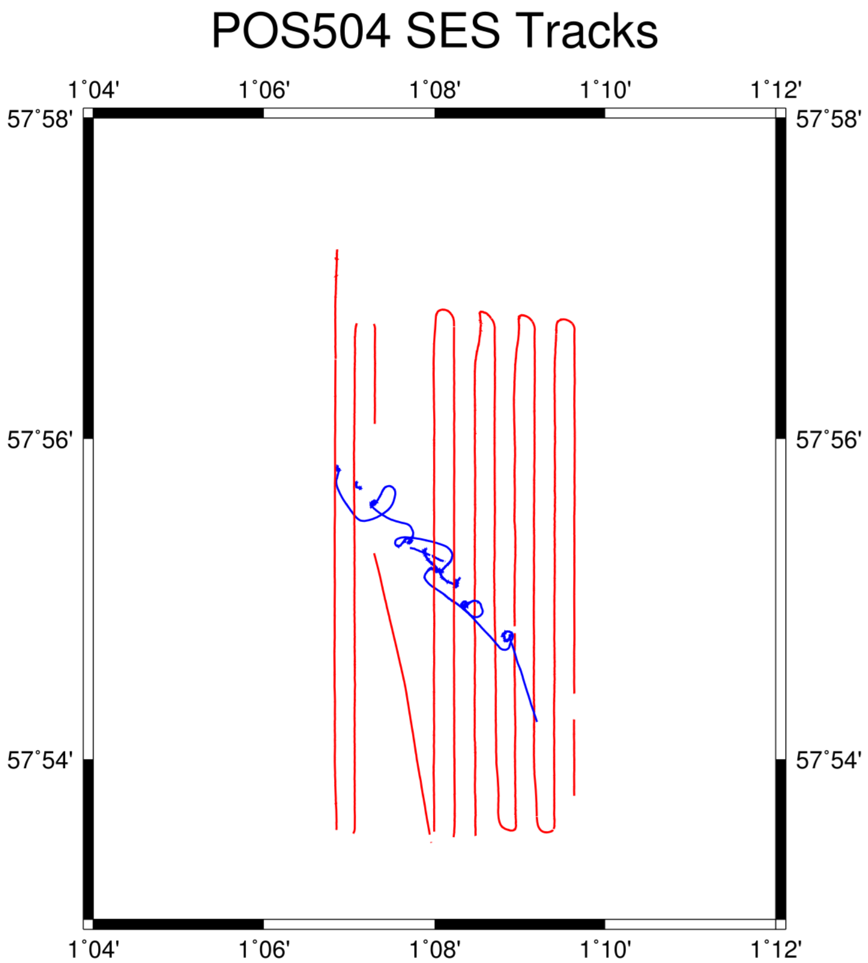

Fig. 10: SES survey lines: subbottom monitoring (red) and water column monitoring (blue).

Two additional SES track lines were recorded on the westerly side of the blow out (Fig. 10, red lines). SES data revealed no sound penetration in the northern part of the survey areas, possibly caused by shallow gas. Sediment layering up to about 5 m depth could be observed in the southern parts. Additionally, the SES was used to record suspended particles in the water column during a drift experiment to support the biological sampling performed at the same time. RV POSEIDON drifted with the water currents during these measurements (Fig. 10, blue lines).

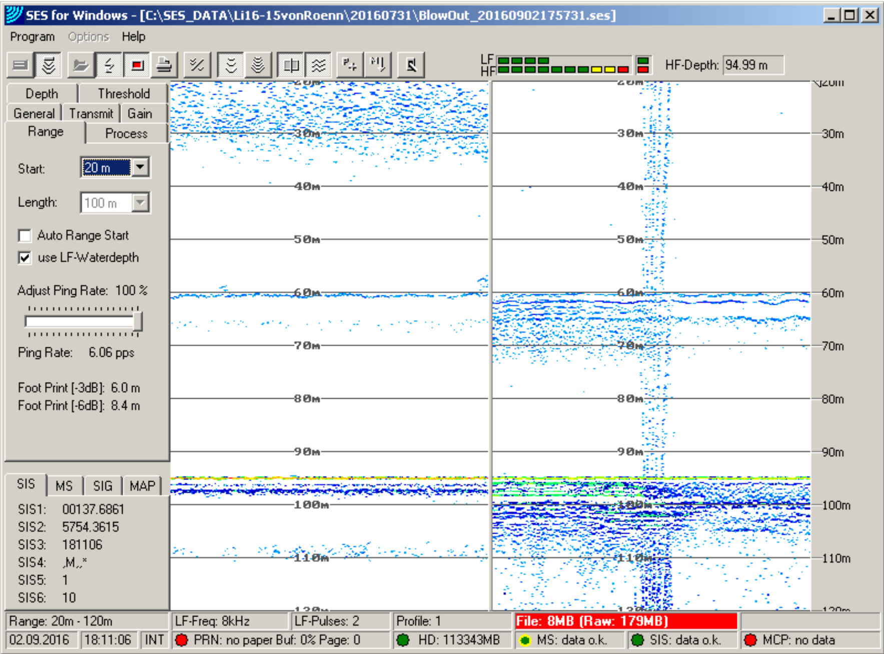

Fig. 11: Screenshot showing SES data together with interferences.

4.2.3 Acoustic water column scatter analyses

Water column imaging and logging was conducted during most surveys with high survey profile line overlap to account for minimum slant range limitation of multibeam WCI, and to allow for spatial coherence analyses of potential rising and current-deflected gas bubbles streams (Schneider von Deimling and Papenberg, 2012). Navigation sounders were switched off to avoid acoustic interference. Single ping mode with 1-2 Hz and 0.4 ms pulse width was chosen for valuable WCI results. The transmission source level and receiver gain were set constant to 0 and 35 dB, respectively, allowing for later comparison of backscattering strengths values.

Next to the identification of ongoing and intense gas releases at 22/4b and the SE crater (Fig. 9), we further identified 8 seep sites (Fig. 12, Tab. 1), which is important for later geochemical-biogeochemical interpretation of water column data. More water column acoustic scatterers like fish, oceanographic layers potentially with particle accumulation, and interfering noise were clearly visible online during surveying.

Table 1: Flares in the survey area surrounding 22/4b, see Fig. 9.

ID	Lat (N)	Long (E)
f1	57° 54' 03.14"	01° 36' 50.65"
f2	57° 55' 16.69"	01° 37' 19.10"
f3	57° 54' 38.33"	01° 38' 43.25"
f4	57° 55' 13.22"	01° 38' 42.51"
f5	57° 54' 15.49"	01° 36' 21.16"
f6	57° 54' 17.90"	01° 36' 36.61"
f7	57° 54' 15.58"	01° 36' 21.17"
f8	57° 54' 15.02"	01° 36' 06.81"
f9	57° 54' 09.93"	01° 36' 07.06"

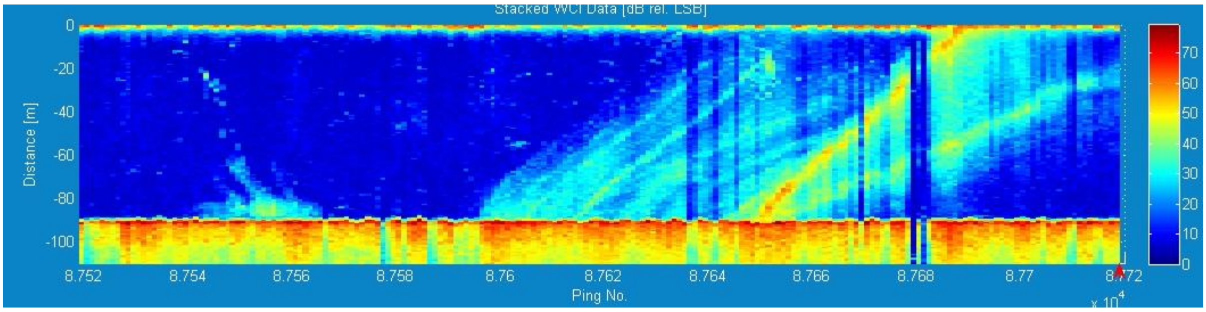

Fig. 12: Beam stack sonar online record showing individual rising gas bubble streams deflected by the currents rising from the 95 mbsl seafloor up to the transducers depth. Near-range data are interrupted by bubble wash down phenomena. Recording time is 02092016 05:44:38 UTC.

4.2.4 Acoustic current profiling and tidal plume estimates

Preliminary ADCP results (Fig. 13) showed that the tidal ellipse at the deployment site next 800 m northeast of 22/4b, explaining 70 to 95 % of the velocity signal, was basically oriented north/south in all three water depth ranges and had a maximum extent of 4.5 km N-S and 2 km E-W. Given the flat bathymetry in this area, we expect these currents to be representative for the entire survey area.

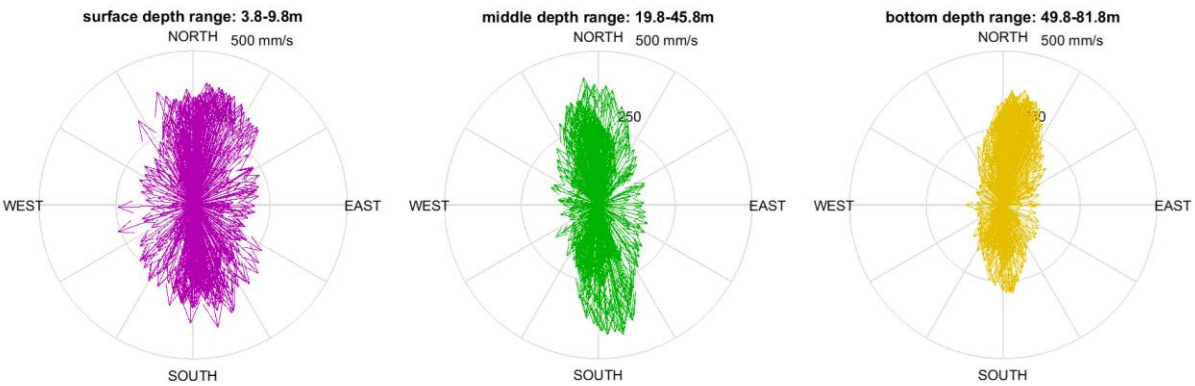

Fig. 13: The arrows indicate measured current orientation summarized in the water depth surface water (3.8-9.8 m, purple), midwater (19.8-45.8 m, green) and bottom water (49.8-81.8 m, yellow).

4.3 Oceanographic and biogeochemical water column studies

4.3.1 Plume mapping in the crater surrounding with physico-chemical, microbial, and particle studies

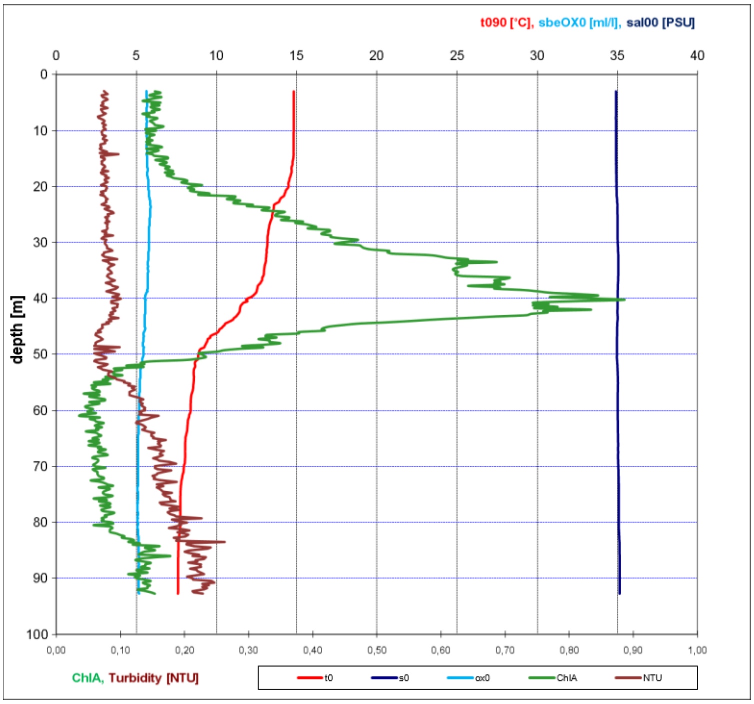

Fig. 14: CTD profile of the water column above the Blowout crater. Parameters depicted are temperature (red), oxygen concentration (light blue), salinity (violet), chlorophyll (green), turbidity (brown).

We performed CTD measurements (Fig. 14) on two crossing transects centred above the Blowout crater and two IN and OUT transects. Parameters analysed were methane concentration, methane oxidation rates, and the abundance of methane oxidizing bacteria (see method description). Further water samples were taken above the Blowout crater (station 553) for DNA extraction. The target of this sampling strategy was to map the extent of the dissolved methane plume, and to assess the strength of the microbial methane sink in the near-field of the Blowout. At three stations, additional samples for particle analyses and particle-associated bacteria were taken (Fig. 15). The stations and parameters analysed are shown in Tab. 2.

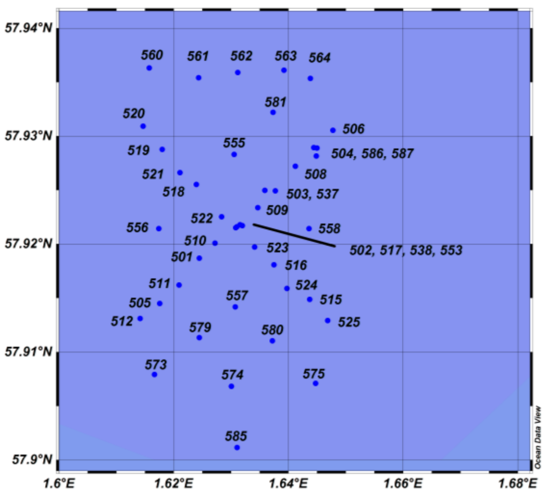

Fig. 15a: This map shows all CTD casts including those conducted only for the collection of oceanographic data.

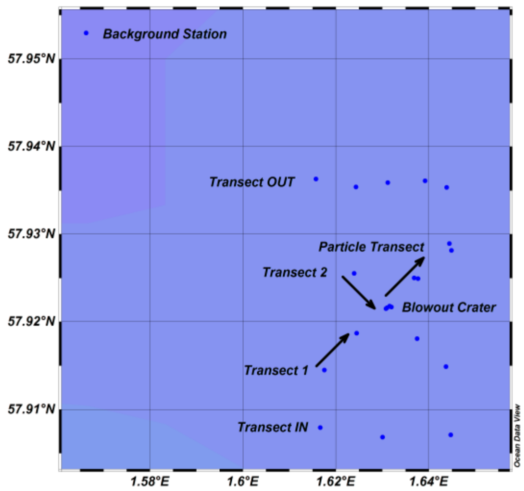

Fig. 15b: Depicted are the transects and the stations included.

Table 2: Station number and position as well as samples taken for water column analysis.

Station	Lat (N)	Long (E)	Methane concentration	Methane oxidation rates	MOB abundance (filter 0.22 µm)	MOB abundance (filter 3.0 µm)	Solved metals	Particle filters	DNA filter	CTD data	Sample
501-1	57.918707	1.624458	x	x	x					x	Transect 1
502-1	57.921617	1.631007	x	x	x					x	Transect 1
503-1	57.924942	1.637683	x	x	x					x	Transect 1
504-1	57.928945	1.644413	x	x	x					x	Transect 1
505-1	57.914498	1.617533	x	x	x					x	Transect 1
515-1	57.914888	1.643705	x	x	x					x	Transect 2
516-1	57.918078	1.637475	x	x	x					x	Transect 2
517-1	57.921793	1.631538	x	x	x					x	Transect 2
518-1	57.925530	1.623925	x	x	x					x	Transect 2
536-1	57.925012	1.636817	x		x	x	x	x		x	Particle Transect
538-1	57.921712	1.631930	x		x	x	x	x		x	Particle Transect
587-1	57.928167	1.644833	x		x	x	x	x		x	Particle Transect
553-1	57.921520	1.630775							x	x	DNA Blowout
560-1	57.936328	1.615725	x	x	x					x	Transect OUT
561-1	57.935420	1.624313	x	x	x					x	Transect OUT
562-1	57.935912	1.631160	x	x	x					x	Transect OUT
563-1	57.936103	1.639205	x	x	x					x	Transect OUT
564-1	57.935365	1.643805	x	x	x					x	Transect OUT
573-1	57.907935	1.616622	x	x	x					x	Transect IN
574-1	57.906842	1.630035	x	x	x					x	Transect IN
575-1	57.907095	1.644712	x	x	x					x	Transect IN
576-1	57.952980	1.566237	x	x	x	x	x	x	x	x	Background

4.3.2 *The box model approach to assess the amount of MOB introduced into the water column by sediment water transport processes in the crater area*

Based on the ADCP measurements the stations for the sampling grid were set (Fig. 16). This grid consists of an "IN" transect (3 stations) to determine the number of MOB cells that enter the bubble flare influenced area, and an "OUT" transect (5 stations) to assert the number of MOB cells that leave the plume influenced crater region (Fig. 16, Tab. 3). Parameters analysed are methane concentration, methane oxidation rates as well as abundance of methane oxidizing bacteria. These data will be fed to a box model, in order to further characterise the influence of the Blowout to the surrounding sea. In addition to these stations, supplementary CTD casts were conducted. During these casts, no water samples were taken. Oceanographic parameters like temperature, salinity, depth, and most notably turbidity were logged to complement the box model.

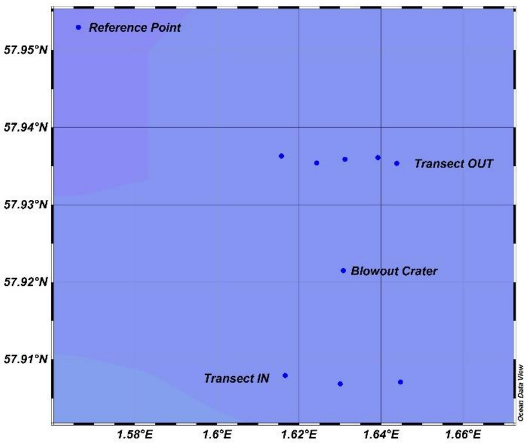

Fig. 16: This map shows the sample coordinates for the IN and OUT transects as well as the reference station and the Blowout crater.

Table 3: Overview of the samples taken at the different stations of the transect IN and OUT.

Station	Lat (N)	Long (E)	Methane concentration	Methane oxidation rates	MOB abundance (filter 0.22 µm)	CTD data	Sample
560-1	57.936328	1.615725	x	x	x	x	Transect OUT
561-1	57.935420	1.624313	x	x	x	x	Transect OUT
562-1	57.935912	1.631160	x	x	x	x	Transect OUT
563-1	57.936103	1.639205	x	x	x	x	Transect OUT
564-1	57.935365	1.643805	x	x	x	x	Transect OUT
573-1	57.907935	1.616622	x	x	x	x	Transect IN
574-1	57.906842	1.630035	x	x	x	x	Transect IN
575-1	57.907095	1.644712	x	x	x	x	Transect IN
576-1	57.952980	1.566237	x	x	x	x	Background

4.4 Sediment studies

Biogeochemical sampling

Sediment samples were gathered during the expedition to study methane concentration, abundance of methanotrophic cells, the microbiological community structure, and sediment properties (Fig. 17). In the close vicinity of gas vents that were sampled by the Bubble Catcher inside the Blowout crater, sediment push cores were taken by the ROV PHOCA (Station 549 and 554). In addition, the crater shoulder (Station 541) was sampled with a Frahm-Lot corer. Along the particle stations (Stations 537 and 587) and the background site (Station 590), sediment samples were taken with a Van-Veen grab sampler, because sediments were too sandy (including clam debris) for coring. Sediment cores (ROV push cores and Frahm-Lot cores) were sliced in 2 cm increments (0-2, 2-4 cm etc.). From each sediment layer, sub-samples were taken to determine methane concentration and sediment properties. The remaining sediment of two consecutive intervals (0-4, 4-8 cm etc.) was then homogenised and sub-sampled for DNA extraction to determine the abundance of methane-oxidising microorganisms. Sediment obtained with the Van-Veen grab sampler was completely homogenised prior to sub-sampling, as the primary structure of the sediment was destroyed during grabbing. An overview of the sediment samples taken is given in Tab. 4.

Table 4: Overview of the samples taken at the different sites.

Station	Sample	Method	Methane concentration	MOM abundance	Sed. Properties	DNA	Comment
541	sediment	Frahm-Lot corer	x	0-4, 4-8	0-2, 2-4, 4-6, 6-8	x	Crater shoulder
549	sediment	PC 47	x	0-4, 4-8, 8-12	0-2, 2-4, 4-6, 6-8, 8-10, 10-12	x	Bubble catcher vent
549	sediment	PC 24	x	0-4, 4-8, 8-12	0-2, 2-4, 4-6, 6-8, 8-10, 10-12	x	Bubble catcher vent
554	sediment	PC 61	x	0-4, 4-8, 8-12	0-2, 2-4, 4-6, 6-8, 8-10, 10-12	x	Bubble catcher vent
567	clam shells	ROV 8		x		x	
588	sediment	Van-Veen	x	0-2	0-2	x	Transect
589	sediment	Van-Veen	x	0-3	0-2	x	Transect
590	sediment	Van-Veen	x	0-4	2-4	x	Background

Fig. 17a: Sediment push core sampling inside the Blowout crater (crater floor) conducted by the ROV.

Fig. 17b: Push core recovered from the crater floor.

Fig. 17c: Clam shells retrieved from a Van-Veen grab.

Fig. 17d: Snail retrieved from a Van-Veen grab.

Geological

Seafloor samples were collected to examine the sediment distribution around the Blowout. An additional question was, if gravel from a gravel layer, exposed at the crater wall, and other coarse material have been distributed to the surroundings by the former explosion. Normally, the seafloor in this region consists of fine-grained sediments. However, previous ROV-flights revealed increasing mussel shell concentration towards the crater.

To examine the distribution pattern, 4 sediment samples were collected along the main tidal flow direction and 3 samples perpendicular to it. Additionally, a Frahm-Lot core was taken inside the crater.

The sediment samples are described in detail in the following:

Station: 527

Lat: 57°55.327‘

Lon: 001°37.910‘

Method: Frahm-Lot corer

Description:
- main component: clay
- contains gas
- few mussel shells

Station: 528

Lat: 57°55.459‘

Lon: 001°38.102‘

Method: Van-Veen

Description:
- main component: fine sand (fS)
- mussel shells
- no layering

Station: 529

Lat: 57°55.606‘

Lon: 001°38.352‘

Method: Van-Veen

Description:
- main component: fine sand (fS)
- few mussel shells
- no layering

Station: 530

Lat: 57°55.732‘

Lon: 001°38.612‘

Method: Van-Veen

Description:
- main component: fine sand and silt (fS + U)
- lots of mussel shells
- 3 stones up to 7 cm
- no layering

Station: 531

Lat: 57°55.849‘

Lon: 001°38.823‘

Method: Van-Veen

Description:
- only little material in the grab
- main component: fine sand (fS)
- broken mussel shells
- 1 worm (alive) and worm tubes
- 1 stone ~ 5 cm
- small quantities of silt (U)
- no layering

Station: 532

Lat: 57°55.444‘

Lon: 001°37.710‘

Method: Van-Veen

Description:
- main component: fine sand (fS)
- little quantities of broken mussel shells
- no layering
- 1 starfish (death)

Station: 533

Lat: 57°55.582‘

Lon: 001°37.503

Method: Van-Veen

Description:
- main components: medium sand and fine sand (mS + fS)
- mussel shells
- worm buildings
- no layering

Station: 534

Lat: 57°55.720‘

Lon: 001°37.293‘

Method: Van-Veen

Description:
- main component: medium sand (mS)
- no mussel shells
- few worm buildings
- no layering

ROV-sediment-sample

During a dive on the 03.09.2016, the ROV touched the crater wall while moving backwards. Sediment from the crater wall got stuck at the rear end of the ROV, due to this contact. The ROV brought this sediment to the surface and subsequently aboard.

The total volume of this sediment sample was about 10 L. The sediment composition was heterogeneous, with fluffy, not consolidated, dark and anoxic silt as main component. There were also some light brown, maybe oxygen-rich parts (Fig. 18a). The main secondary component was broken mussel shells of different size. The broken shells were evenly distributed in the sample, which led to soft grainy consistency (Fig. 18b). Besides the broken shells, there were also several unbroken mussel shells of different sizes and at least two different kind (Fig. 18c).

Another secondary component were consolidated clay lenses. These were sporadic distributed in the sample. Additionally, there were four stones in the samples. Their sizes ranged between 5 to 16 cm (Fig. 18d-g).

Subsamples from the dark anoxic part, from the mussel shells, and from the clay lenses were taken on land for further analysis.

Fig. 18a: Sediment from the crater wall, which got stuck on the ROV, broad on the working deck of RV POSEIDON.

Fig. 18b: Close-up shot of the soft grainy sediment.

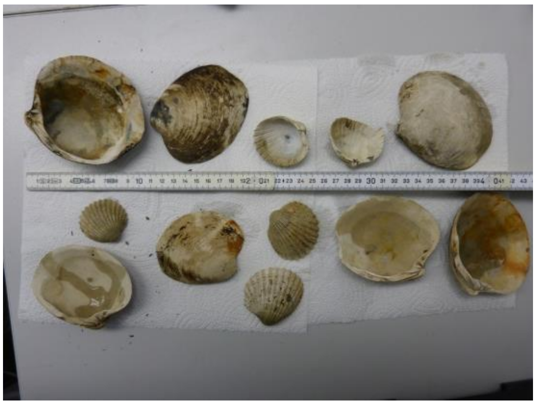

Fig. 18c: Some of the unbroken mussel shells.

Fig. 18d: stone #1.

Fig. 18e: stone #2.

Fig. 18f: stone #3.

Fig. 18g: stone #4.

4.5 Bubble Catcher studies on the bubble mediated transport between sediment and water column

Three bubble catcher deployments (Tab. 5) were successfully carried out in the 22/4b crater in order to allow for quantitative analyses on bacteria transport from the seabed into the water column via gas bubbles.

On board, the water that remained inside the Bubble Catcher was subsampled for the analyses of methane concentration, methane oxidation rates, cell abundance of methane oxidising bacteria, live incubation experiments, DNA, and particles (Tab. 5). For the Bubble Catcher “blank” (= control) experiment, the Bubble Catcher was placed next to a vent hole so that no natural gas bubble could enter the sampling cylinder. During this experiment, artificial nitrogen gas bubbles released from a pressure tank were released above the sediment and trapped with the Bubble Catcher. Subsampling of the "blank" experiment was identically to the "vent" experiment. All treatments of the Bubble Catcher water samples were identical to water column water samples. To study the assimilation of carbon into biomass, live incubation experiments with ^{13}C methane were carried out in 200 mL and 1000 mL vials. These bottles were half filled with water from the Bubble Catcher and closed with rubber stoppers. Subsequently, the headspace was flushed with sterile synthetic air (free of hydrocarbons), followed by an injection of 5 mL of sterile ^{12}C methane into the 200 mL vials and 10 mL into the 1000 mL vials. The vials were incubated at 8 °C until further treatment. In our home laboratory at the IOW, the vials will be flushed with synthetic air and incubated with ^{13}C methane to investigate if benthic microorganisms are capable to survive in the water column.

Table 5: Station number and position as well as samples taken for water column analysis.

Station	Name	Methane concentration	Methane oxidation rates	MOB abundance (filter 0.22 µm)	13-C Incubation	Solved metals	Particle filters	DNA	Comment
546-1	BC vent 1; ROV 2	3*100 mL	6*100 mL	400 mL, 600 mL, 800 mL	4*500 mL	2 * 2 mL	200 mL + 500 mL rw.	2000 mL	Bubble Catcher vent experiment 1
552-1	BC blank; ROV 5	3*100 mL	6*100 mL	400 mL, 600 mL (3,0 µm+0,22 µm), 800 mL	1*500 mL, 4*100 mL	2 * 2 mL	550 mL + 400 mL rw.	2400 mL	Bubble Catcher blank
554-1	BC vent 2; ROV 6	3*100 mL	6*100 mL	400 mL, 600 mL (3,0 µm + 0,22 µm), 800 mL	5*100 mL	2 * 2 mL	600 mL + 400 mL rw.	2400 mL	Bubble Catcher vent experiment 2

Fig. 19a: Bubble Catcher on board.

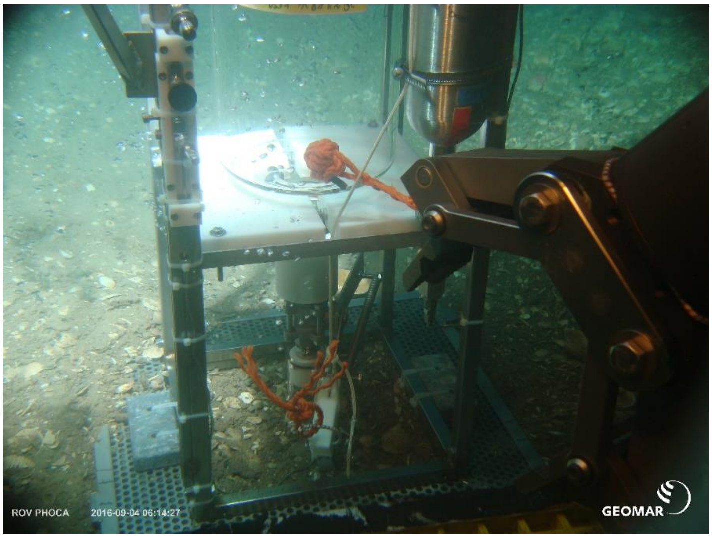

Fig. 19b: Bubble Catcher during a sampling campaign in the crater (blank experiment).

4.6 Video analyses

Bubble Box

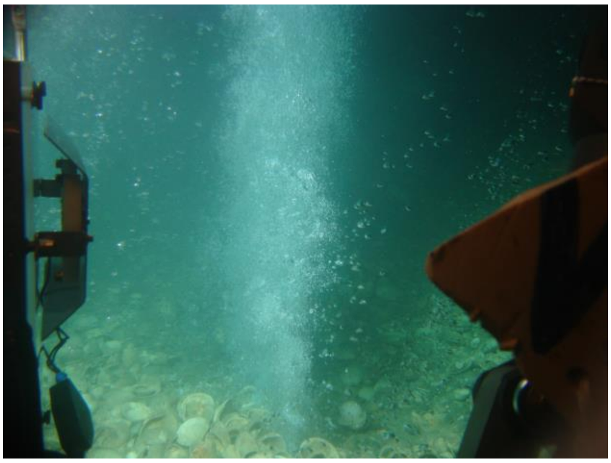

Fig. 20: Mega plume image taken by PHOCA.

The bubble imaging box (Bubble Box, Jordt et al., 2015) for precise evaluation of gas bubble sizes and rising speeds was deployed three times. The first deployment from the winch (30.08.2016, station 500) was a short test deployment to verify the exposure and test the general setup of the box. The test confirmed that the setup was working well and that the images where bright enough using the short exposure time of only one millisecond. However, it was detected that the system dropped frames, which is a potential problem for synchronizing the images. Therefore, the 8-bit LED counter was added for the following dives. The overall setup for the other two dives was

- Framerate: 100 frames per second (fps)
- Exposure: 1 ms
- Aperture: f/11
- Focus distance 11 cm

The second deployment (03.09.2016, station 550) was the only deployment of the Bubble Box using the ROV PHOCA. The Bubble Box was deployed using the 8-litre container lid to measure integrated flow rates of a mega-plume (Fig. 3, 20). One of the main objectives was to investigate bubbles from the same vent that was used in the Bubble Catcher experiment the day before (02.09.2016, station 549). The vent was found using a marker that was left behind. Because of the much larger inlet of the Bubble Box compared to the Bubble Catcher, it was unfortunately not possible to place the Bubble Box in such a way that only bubbles of a single vent were seen by the cameras. This explains why the flow rate measured using the 8-litre gas container lid was higher (ca. 250 ml/min) than the bubble flow into the Bubble Catcher. The images recorded by the Bubble Box show a rather wide spectrum of bubble sizes (Fig. 21, 22). Results that are more detailed will be available in post-processing.

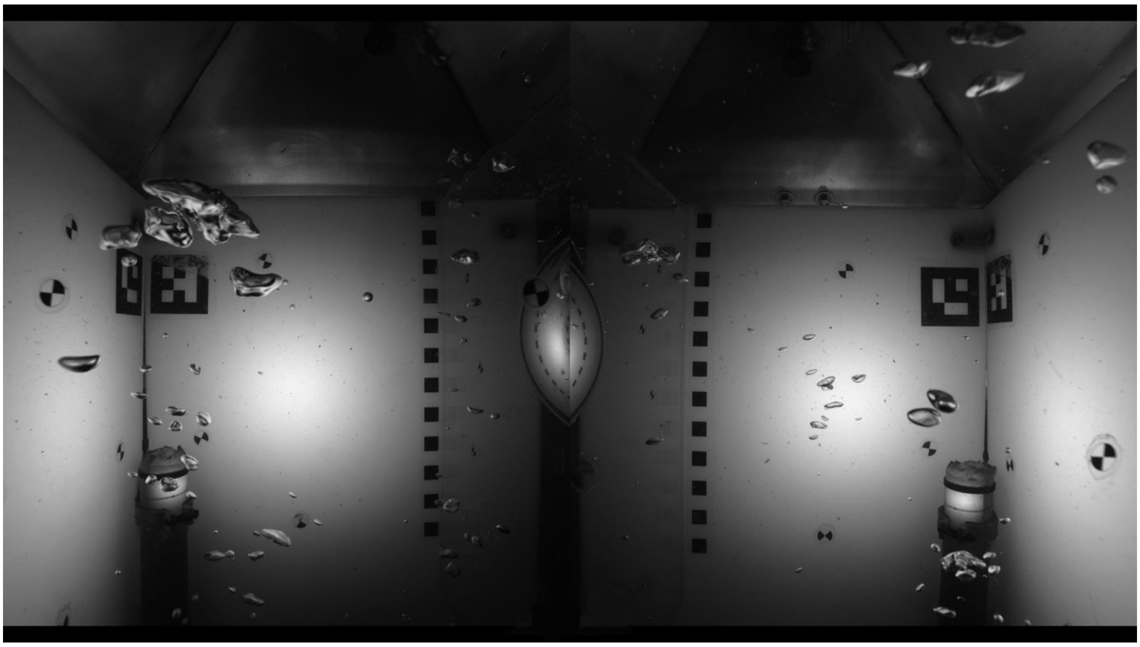

Fig. 21: Bubble Box above Bubble Catcher vent (ca. 250 ml/min). The two images left (‚bubble 1') and right (‚bubble 2') are synchronized and have been taken at exactly the same time.

For the last deployment (06.09.2016, station 583), the Bubble Box was lowered by the winch of RV POSEIDON. This time objective was to get more information about the Blowout related bubbles further up in the water column. Especially an assumed side plume of micro-bubbles that seems to form a stable layer below the thermocline in ca. 50-60 meter water depth as hypothesised in Schneider von Deimling et al. (2015). For this reason a tow-yo track between 40 and 70 m water depth was planned with the aim to catch this intrusion with the Bubble Box. First analyses of the video show that the Bubble Box was inside the main bubble plume multiple times. Also very small bubbles where detected in the depth of ca. 55 m water depth.

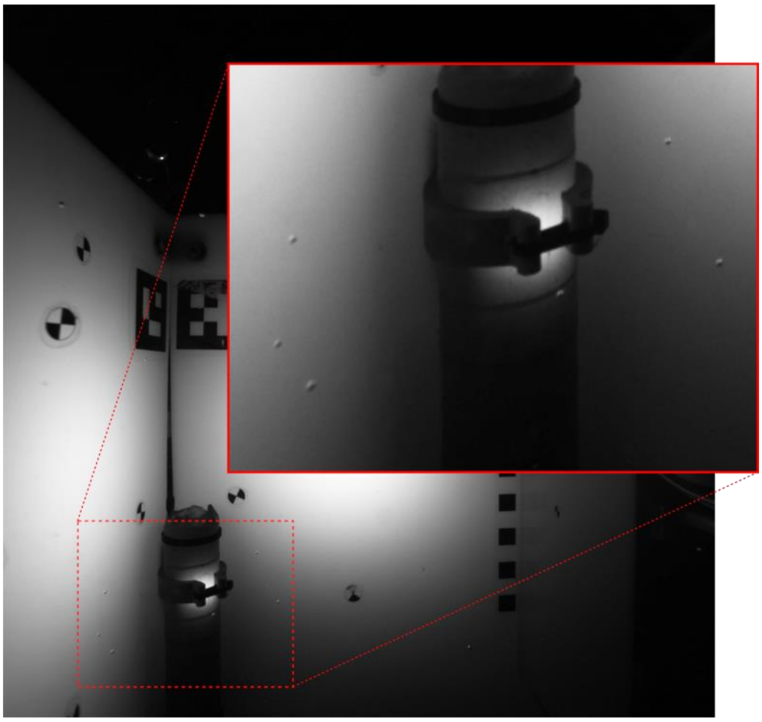

Fig. 22 Micro-bubbles, presumably with r<0.5 mm in ca. 55 m water depth.

5 Scientific equipment: moorings and instruments

5.1 ROV

A 3000 m depth rated PHOCA ROV (manufactured by SubAtlantic FET, Aberdeen, Scotland) was chartered from GEOMAR. It is based on commercially available ROVs, but customised to our demands. ROV PHOCA has previously been operated from the medium sized German research vessels POSEIDON and ALKOR. As an electric workclass ROV of the type Comanche, this is build No. 21. ROV PHOCA and based at GEOMAR, the Helmholtz Centre for Marine Sciences Kiel, Germany. Next to the ROV built-in HD camera, the ROV was equipped with various scientific equipment (see below).

5.2 Hydroacoustics

5.2.1 Hull-mounted multibeam SB3050

A fix installation 50 kHz multibeam SB3050 with a 1.5° x 2° TX/RX aperture manufactured by L-3 ELAC Nautik GmbH was used for bathymetric and water column imaging (WCI) surveying during POS 504. For further description, offsets etc., we refer to the cruise report of POSEIDON 469.

In the beginning of the cruise, we encountered two major issues with the MBES setup on RV POSEIDON. First, the HYPACK survey module constantly crashed for unknown reasons. Therefore, we decided to acquire the data only with Hydrostar. Second, a very strong heave artefact occurred erratically and became well visible at low water depth and short pulse lengths (Fig. 23). Lever arms were controlled to identify possible induced heave issues, but the setup parameters were all correct. The attitude system F180 operated well within specification and respective recorded attitude data for roll, pitch, and heave appear reasonable (Fig. 24). A possible driver for the pronounced heave error can be a latency issue. Therefore, we updated the timeserver, which solved the problem.

Table 6: HSO calibration offsets gathered during POS469. X denotes acrosstrack, Y alongtrack distance (m), Z is vertical offset (m), TD is time delay (s). The respective reference point was defined as the position of the MRU projected on to the water level. GPS position data were output for the MRU position instead of the position of the primary antenna (Nav Sens. Position = Mot. Sensor position).

Nav. Sensor	Mot. Sensor	Hydrophone	Projector
X=0	X=0	X=-1.5	X=-1.41
Y=0	Y=0	Y=6.36	Y=5.20
Z=-5.65	Z=-5.65	Z=4.25	Z=4.25
TD=0		ROLL=1.45	PITCH=-2.40
			YAW=2.00

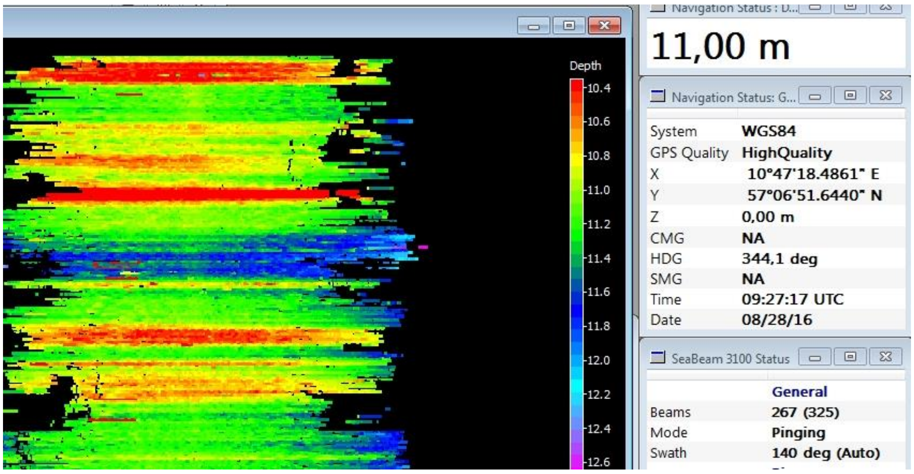

Fig. 23: Plot showing a heave problem that we attribute to a time synchronisation error between the multibeam and the MRU.

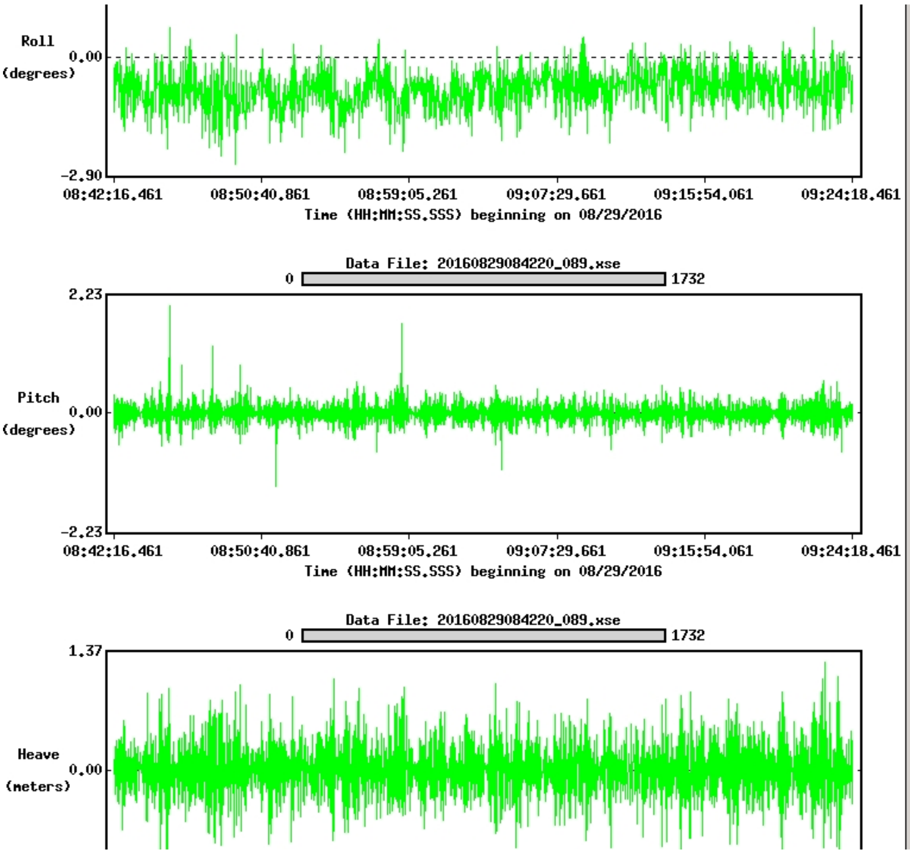

Fig. 24: Time series of the attitude data provided by the F180.

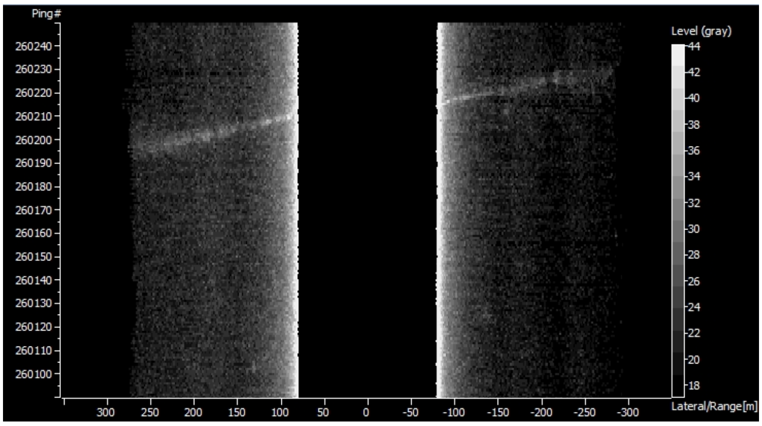

Fig. 25: Sidescan image from the SB3050 MBES showing a pipeline on the seabed

A test survey line was run across a pipeline on the seabed (cross validated by the nautical chart) around 85 m water depth. The sensitivity of the backscatter can be regarded as valuable (Fig. 25) and will be evaluated to map out the surrounding of the crater to investigate possible local habitat evolution around the crater.

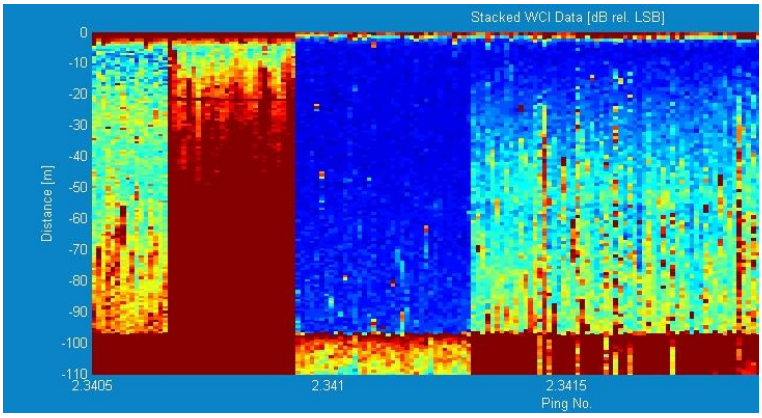

Fig. 26: Noise test to identify interfering sonars on RV POSEIDON.

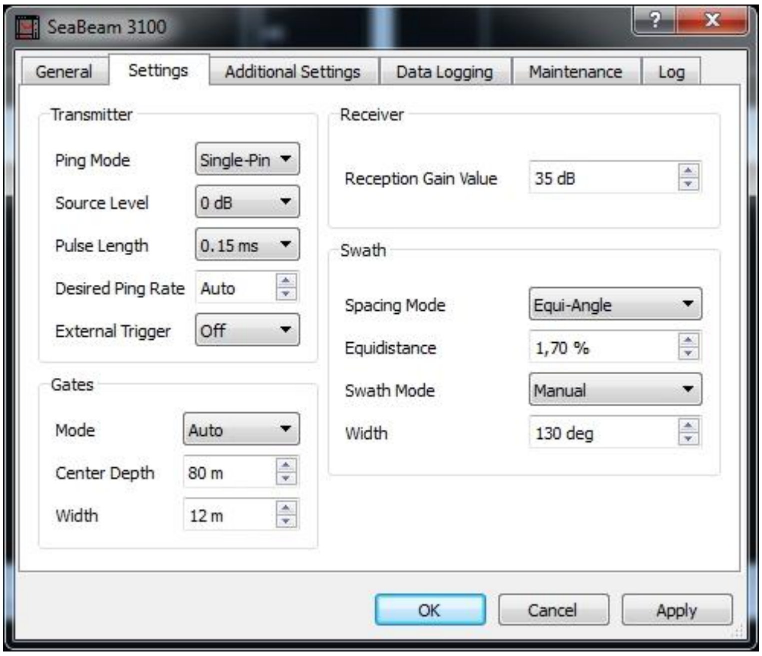

Fig. 27: MBES settings for flare imaging.

5.2.2 Imaging Sonar Codaoctopus Echoscope

The 375 kHz Echoscope® from Coda forms 16,000 soundings for each ping thus providing sounding densities far in excess of those generated by other sonars. Therefore, even when the target and the Echoscope® are moving, the 3D imagery remains clear and accurate, giving the viewer an instant three-dimensional understanding of the underwater environment. The ping geometry of the Echoscope® will allow a target to be visualised many times in a single pass, with each view taken from a different angle. This allows complex subsea phenomena imaging such as bubble movement to be mapped out.

This sonar was adapted to the ROV PHOCA with our self-developed connection box to solve both, high electric power consumption (temporarily >6 Ampere) and RS232-connectivity through the umbilical.

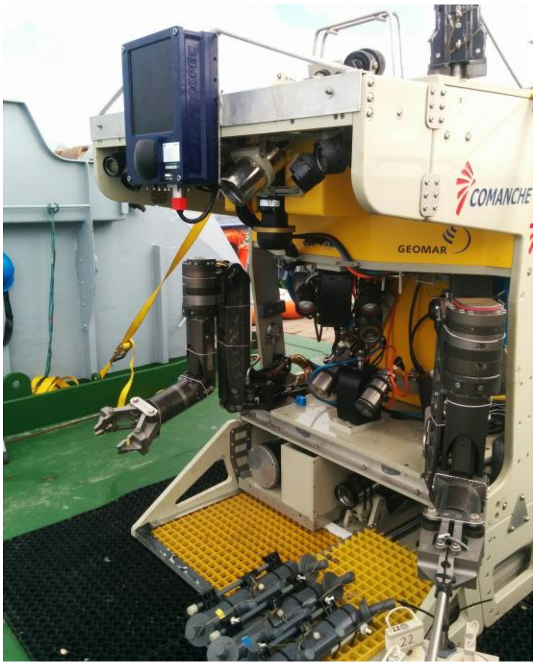

Fig. 28: Picture of the ROV PHOCA equipped with the CODAECHOSCOPE sonar.

5.2.3 Sector Scan KONGSBERG MS 1000

For obstacle avoidance reasons the ROV PHOCA operates a sector-scanning device with 675 kHz. This sonar is additionally extremely useful to identify gas bubbles especially when having a free flight through the water column. Therefore, this sonar data was recorded in addition to the other sonar devices.

5.2.4 Subbottom profiler INNOMAR SES 2000

A parametric sediment echo sounder (SES) of type Innomar SES2000® was used to record subbottom sediment layering. The SES transducer was mounted in the moon pool of RV POSEIDON, at about 4 m depth. The device uses electrical-beamsteering to correct the soundbeam for ship roll. Additionally, the records are heave-compensated for ship movements. The required motion data were supplied by a Seatex® MRU-6 motion sensor, which was mounted directly on the moon pool lid to avoid lever arm effects.

The Innomar SES records one of its primary frequencies, symmetrical placed around 100 kHz, and the selectable secondary frequency. The secondary frequency was chosen to be 8 kHz.

5.2.5 ADCP

On August 30th, the first ROV dive was designated to deploy the Acoustic Doppler Current Profiler (ADCP) about 800 m northeast of the Blowout crater at a depth of 90 m. The 300 kHz RDI Workhorse ADCP tracked the current's direction and magnitude until September 3rd with a measurement ensemble, consisting of 100 subpings, every 10 minutes. In the vertical, there were 43 2-m-high depth bins with midpoints ranging from 85.8 m depth up to 1.8 m below the sea surface. Within each bin, the 4 beams of the ADCP track the water movement in the east-west, north-south and vertical directions by using the Doppler shift of pings backscattered off passive particles in the water column. The raw data was extracted and transferred to the Leibniz-Institute for Baltic Sea Research for processing and analysing. Here the velocities were analysed using the T-TIDE package (Pawlowicz et al, 2002) in MATLAB. Current magnitude and direction were split into a tidal signal and a residual current for 3 depth ranges: bottom, middle and near-surface waters. The first results were sent back to the research vessel POSEIDON in order to plan the further sampling procedure.

5.3 CTD

The key instrument of the physical observational program was the pumped SBE 911plus CTD system (Seabird Electronics, USA) consisting of a SBE 9plus CTD Unit with redundant sensor packs and a SBE 11plus deck unit. Conductivity, temperature, and oxygen were each measured with twin SBE 4 conductivity sensors, SBE 3plus temperature sensors, and SBE 43 oxygen sensors. Each sensor assembly pumped via SBE 5T submersible pumps. Turbidity and fluorescence were observed with a type FLNTURTD sensor from Wetlabs (USA), whereas PAR and SPAR were recorded using the sensor types OSP200L4S and QSR-2200 from Biospherical Instruments (USA). All sensors were embedded in a SBE 32 Carousel Water Sampler with a set of 12 x 5 litre free-flow bottles from Hydrobios (Germany).

5.4 Geochemical and microbial analyses

5.4.1 Water column

Bubble Catcher

Gas bubbles released within the Blowout crater were sampled with the Bubble Catcher. The sampling principle was similar as described in Schmale et al. (2015). For Bubble Catcher "vent" experiments, the device was positioned above a single gas vent within the blowout crater using the ROV PHOCCA. After positioning was finished, the cylinder was opened by the ROV arm via a stopcock, allowing the gas bubbles to enter the glass cylinder. Bubble collection was stopped after a total gas volume of ca. 4 L was collected (i.e., after 10 or 40 min., depending on the gas flux rate). The valve was then closed, and the Bubble Catcher was transported back to the surface. During the ascent, overpressure in the gas chamber was released through a pressure valve.

Dissolved methane concentrations

For the determination of methane concentration, three times the volume of water was filled bubble free into 100 mL or 250 mL crimp vials. The crimp vials were closed bubble free with butyl rubber stoppers and poisoned with 10 µL saturated HgCl solution per mL sample. The rubber stoppers were sealed with silicon and stored upside down at RT until further processing at the IOW (Jakobs et al., 2014).

Methane oxidation rates

For the measurement of methane oxidation rates, seawater was filled bubble free in a 100 mL crimp vials and closed with a non-toxic chlorobutyl rubber stopper (Niemann et al., 2015). The method was carried out as described in Bussmann et al. (2015) and measured with the Triathler LSC (HIDEX) liquid scintillation counter. 10 µL of diluted ^{3}H labelled methane (1:4 with nitrogen) was injected through the rubber stopper. Three killed controls were poisoned with H_2SO_4 (final concentration 0.05 %) resulting in a pH of <1.5 to determine non-biological oxidation of methane and the isotopic exchange of ^{3}H from methane to water. The vials were stored upside down at 8 °C in the dark for 3 days. Following the incubation, the vials were opened, and 2 mL subsamples were transferred to a scintillation vial, to which 5 mL ULTIMA Gold LTT was added, and radioactivity ($^{3}H\text{-}H_2O$ + $^{3}H\text{-}CH_4$) was measured with a liquid scintillation counter (HIDEX). Another 2 mL subsample was transferred to a second scintillation vial, and bubbled with air for 5 minutes to remove $^{3}H\text{-}CH_4$. Thereafter, 5 mL of scintillation cocktail was added, and radioactivity ($^{3}H\text{-}H_2O$) was measured. Methane oxidation rates will be calculated after Bussmann et al. (2015), using the determined rate constant and the total methane concentration.

Abundance of methanotrophic bacteria

The abundance of aerobic methane-oxidising bacteria will be determined at the IOW by the Catalysed Reported Deposition In Situ Hybridization (CARD-FISH) after Pernthaler et al. (2002) and modified after Pernthaler et al. (2004), using the oligonucleotide probes M(γ)84 and M(γ)705 (Eller et al., 2001). CARD-FISH samples were preserved on board, adding 5 mL formaldehyde (37%) to 80 mL of sample (in 100 mL brown glass vials). The samples were incubated for 2-4 hrs at 4 °C. Fixed cells were then filtered on 0.22 µm sterile isopore filters (Millipore), rinsed with sterile phosphate buffer saline (PBS) (1x) and stored at -20 °C after air-drying.

Dissolved metals

Sampling for solved metals was conducted as follows: A 20 mL disposable syringe was rinsed with sampling water prior to filling. A sterile filter was attached to the syringe and 5 mL were used for rinsing the filter. The preconditioned reaction tube was rinsed two times with the filtered sample. Then the reaction tube was filled with 2 mL filtered sample and stored at 4 °C until further processing. As blank the Bubble Catcher and a CTD bottle was rinsed with 2 L ultra-pure water (MilliQ). The background sample was taken at the station 576 at 30 m water depth. Samples will be analyses at the IOW (Dellwig et al., 2007; Kowalski et al., 2009).

Distribution of particles in the near-field of the crater

Particles in the water column were sampled for analysis by filtering 1 L seawater with a 0.44 µm polycarbonate filter. The filters were than air-dried and stored at 4 °C until further procession at the IOW.

Particle-associated methanotrophic bacteria

For particle-associated methane oxidizing bacteria analysis, the water samples were treated as described above. Different to the above method samples were pre-filtered with a 3.0 µm sterile filter. The filtrate was then filtered again with a 0.22 µm sterile filter as described in Grossart et al. (2011). Both filter types will be analysed by CARD-FISH at the IOW.

Microbial community structure

For the collection of water-column DNA samples, at least 1 L of seawater was filtered on 0.22 µm sterile filters. The filters were stored at -80 °C until further processing.

Gas capturing and chemical analyses

Gas bubbles were captured twice with the ROV at 22/4b to fill stainless steel gas cylinders. The gas samples were transferred into 20 ml vials, and will be later analysed for $d^{13}C$-CH_4 isotopes, and N_2, Argon, O_2, and CH_4 concentration.

5.4.2 Sediment

Methane concentration sediment

Two cm³ of sediment were transferred into 10 mL glass vials filled with about 5 mL 2.5 % NaOH. The vials were stored at 4 °C upside down until further processing at the IOW (Schmale et al 2015).

Abundance of methanotrophic bacteria sediment

Half a cm³ of each sediment sample was added to a 15 mL centrifuge vial with 1.5 mL 4% formaldehyde solution (in PBS). The vials were incubated for 2-4 hrs at 4 °C and then centrifuged at 3900 g for 10 min. The supernatant was removed, 1.5 mL PBS was added, the pellet was resuspended, and the vial centrifuged again. This process was repeated once. Finally, 1.5 mL 1xPBS/EtOH (1:1) was added to the pellet, the pellet resuspended and the samples transferred to a 2 mL cryogenic vial. The samples were stored at -20 °C until CARD-FISH analyses at the IOW.

Microbial community structure sediment

For the collection of sediment DNA samples, sediment was filled into a 15 mL plastic vial and stored at -20 °C.

Sediment samples and properties

Sediment samples were collected either with a Van-Veen Grab Sampler or with a Frahm-Lot. A first sample description of sediment types, organic content, additives, and layering was done directly after sample collection on board. For the analysis of sediment properties, at least 10 g sediment was filled with a plastic spoon into a 20 mL plastic vial. The samples were stored at 4 °C until further analysis at the IOW.

5.5 Optics

5.5.1 ROV

ROV PHOCA is a 3000 m rated deep diving platform manufactured by SubAtlantic FET, Aberdeen, Scotland. It is based on commercially available ROVs, but customised to our demands, e.g. being truly mobile. ROV PHOCA has previously been operated from the medium sized German research vessels POSEIDON and ALKOR. As an electric work class ROV of the type Comanche, this is build No. 21. ROV PHOCA, based at GEOMAR, the Helmholtz Centre for Marine Sciences Kiel, Germany. HD and still cameras were used for qualitative assessments during the cruise, while quantitative video data was acquired by our Bubble Box system attached to ROV PHOCA.

5.5.2 Bubble Box

For the assessment of bubble size distribution and bubble rise velocity of CO_2 bubbles, a bubble imaging box (Bubble Box) was designed and constructed at GEOMAR by Jens Schneider von Deimling first in the project SUGAR II, received post processing routines (Jordt et al., 2015) in the project QUABBLE and significant technical improvement by the group of Prof. Greinert.

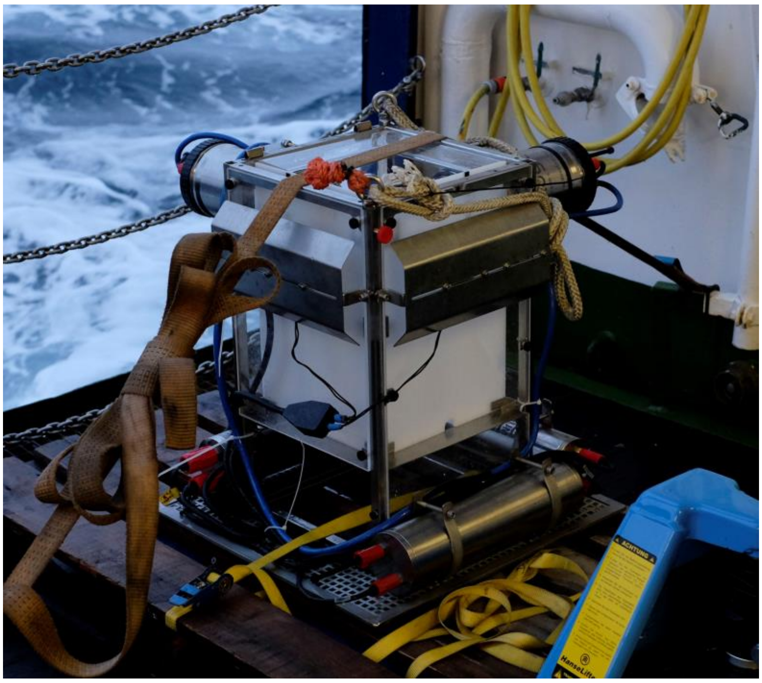

Fig. 29: Bubble Box in flow-through mode (without lid) before tow-yo deployment.

The Bubble Box consists of a metal frame, which holds the camera system, the backlit LED flash and an optional closing lid, which allows either undisturbed vertical flow-through, or precise flux measurements into predefined capture volumes. The gas in the capture volumes can be released using a physical ROV pull-switch to reset the measurement.

The Bubble Box can be used open top or with a closing lid to allow either undisturbed vertical flow-through, or precise flux measurements into predefined capture volumes. The front and sidewalls are made of transparent acrylic glass for ROV video observation, while the back wall is made of a white acryl glass acting as a light diffuser for backlit illumination of the gas bubbles. The LED flash and the cameras are synchronised by a programmable trigger signal which controls the frame rate and the exposure time.

Fig. 30: Checkerboard calibration before deployment.

The time synchronisation between the cameras is archived via a black (not illuminated) frame, which occurs every 5000 frames (50 seconds). To detect frame drops an additional 8 bit LED counter, which can be seen by both cameras have been included into the system.

The camera housings uses a dome port to minimise diffraction at the air/glass/water interface. The cameras where individually calibrated using checkerboards at GEOMAR. Additionally, a calibration checkerboard was recorded in different angles before every deployment. This will allow determining the exact position of the cameras towards each other (Fig. 31).

Fig. 31: Bubble Box with 8-litre volume capture lid mounted on the ROV PHOCA.

The system was powered by two battery containers holding 20x1.5 Volt d-batteries each. To save energy, but also data space, the system could be turned on/off using a physical ROV-switch. Using the LED backlit flash, the system status can be observed by the ROV video cameras:

- 2 second flash: system power on (no bubble computer booted yet)
- 0.5 second flash: the master computer 'bubble 2' booted
- 100 fps: booth computer 'bubble 2' and 'bubble 1' booted and the system is recording data

Thanks to the powerful LED flash, it was possible to record 100 frames per second (fps) at an exposure time of only 1 ms. This allows detailed slow-motion videos without significant motion blur.

5.5.3 CH_4/CO_2 air measurements

The atmospheric CO_2 and CH_4 concentrations were continuously monitored throughout the cruise using cavity ring down spectrometer Picarro G2301-m and GEOMARs 'Atmospheric Intake System' (AIS) that pumps air from different air intakes into integrator volumes, and then towards the Picarro spectrometer. Three air intakes where installed on different elevation levels of RV POSEIDON to allow the calculation of concentration gradients for later sea-air gas flux assessments. Other parameters needed for such flux calculations, i.e. wind speed and water temperature were logged via the WERUM DVS data system throughout the cruise.

The long tubing between the AIS in the wet lab and the air-intakes together with the flow rates of each intake generates time offsets between the air sampling and the actual gas measurement at the Picarro. These delays where measured, by timing the arrival of a CO_2 peak caused by the breath of second person at each air-intake (Tab. 7).

Table 7: Position and delay of air intakes. The elevations of the three different air intakes have been estimated from the Poseidon-General-Plan-Chart.

Air intake no.	Position	Elevation (rough)	Tube delay (seconds)	Flow during delay measurement (l/min)
1	Top deck	10 m	77	2.25
2	Mast	19.5 m	70	2.49
3	Bow	5.5 m	103	2.36

The Picarro measures the different air intakes sequentially one after each other. However, after the initial delay measurement, the flow rates can be tuned to adjust the delay of the different air intakes to make sure that the sequentially measured gas samples of the different air intakes originate from the same time point. Unfortunately, during the first part of the cruise, the calculated flow rates could not be tuned to the desired values, because the pressure at the AIS would get to high (flow rates were to low). Only when the measurement time was changed from one minute to 30 seconds, the flow rates could be adjusted to the ideal values (Tab. 8).

Table 8: Flow rates of different air intakes.

Date / Time (UTC)	Flow Air intake 1 (l/min)	Flow Air intake 2 (l/min)	Flow Air intake 3 (l/min)	Comment
27.08.2016 / Start	2.5	2.44	2.48	Initial state Measurement time was 1 minute
29.08.2016 / 16:30	2	2	2.25	Measurement time was 1 minute
31.08.2016 / 15:10	2.8	1.89	1.99	Measurement time changed to 30 seconds. Times calculated to let gas arrive at the AIS at the same time

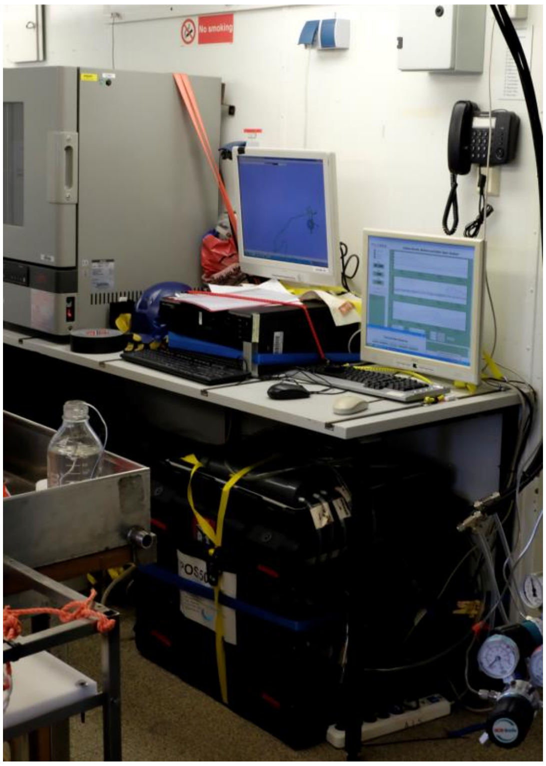

Fig. 32: Atmosphere intake system (AIS) with the Picarro measurement control computer (right computer screen) and the OFOP data logging computer (left computer screen) in the wet-lab.

The Picarro software running on a Picarro control computer was used to examine the gas concentration measurements in real time, and log them for post-processing. Additionally, the OFOP (Ocean Floor Observation Protocol) software, running on a second computer, was used to plot the gas concentrations live onto a georeferenced map in real time (Fig. 33).

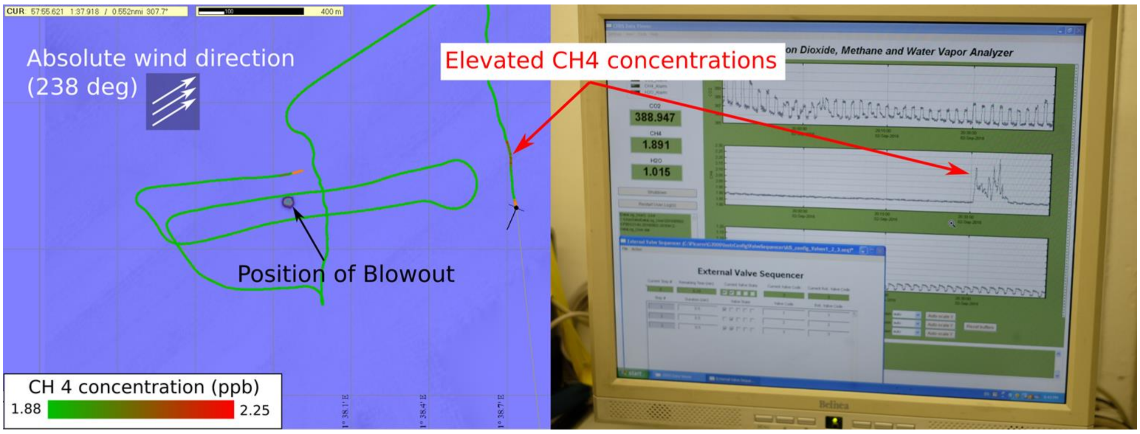

Fig. 33: (left:) OFOP map with plot of elevated CH_4 concentrations on top of a map (in red); (right:) Picarro control computer displaying the elevated concentrations at the same time. The position of the elevated concentrations fit well with position of the Blowout release and the wind direction.

6 Acknowledgements

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We gratefully acknowledge also the friendly and professional work of both, the ship and ROV crew.

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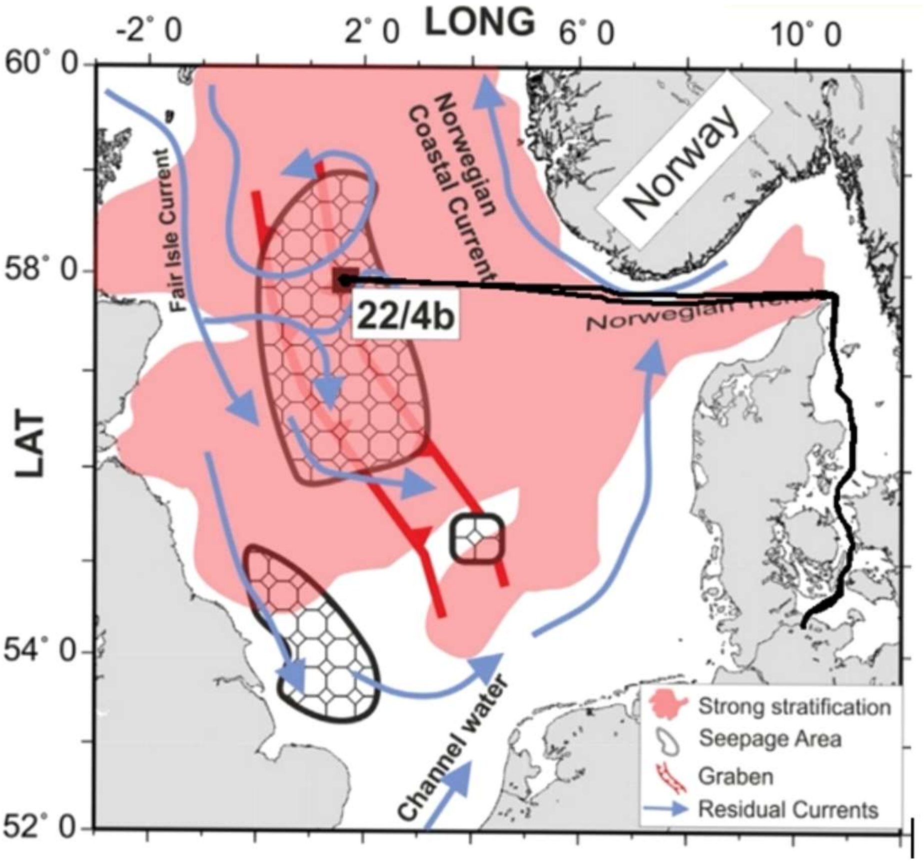
authors formatted in **bold** are directly involved in research related to this ship cruise

Map with cruise track of POS 504

(figure adapted after Schneider von Deimling et al., 2015)



Stationbook

Station No.	Responsible	Place	Gear	Date [UTC]	Time [UTC]	Time end [UTC]	Lat (N)	Lon (E)	Comment
498-1	Schmale		CTD	29.08.16	24:47:00	-	57°55.349	1°37.693	Water sample BC, sound velocity
498-2	Schmale		CTD	29.08.16	22:29:00	-	57°55.320	1°37.638	Water sample BC
499-1	Held	MB01	MBES-WCI	29.08.16	23:35:00	04:42:00	57°56.68	1°36.85	Survey abandoned at Ship 5; MB01: Settings for WCI, bathy very bad; startpunkt: north west
500-1	Urban	Bl	BubbleBox	30.08.16	05:00:00	05:18:00	57°55.313	1°37.906	BubbleBoxTest; see BubbleBox protokoll 01_500_Protokoll_BBox-Test1.odt
501-1	Schmale		CTD	30.08.16	06:25:00	-	57°55.118	1°37.481	CTD 04 Transect 1
502-1	Schmale		CTD	30.08.16	07:30:00	-	57°55.299	1°37.861	CTD 05 Transect 1
503-1	Schmale		CTD	30.08.16	08:00:00	-	57°55.500	1°37.272	CTD 06 Transect 1
504-1	Schmale		CTD	30.08.16	08:32:00		57°55.736	1°38.664	CTD 07 Transect 1
505-1	Schmale		CTD	30.08.16	09:31:00	-	57°55.855	1°37.052	CTD 03 Transect 1
506-1	Schmale		CTD	30.08.16	10:15:00	-	57°55.846	1°38.894	CTD 08 Transect 1
507-1	Schneider	Bl	ROV 1	30.08.16	11:08:00	16:47:00	57°55.55	1°38.38	ca. 800 m northeast of crater ROV Bosi
508-1	Schmale		CTD	30.08.16	17:21:00	-	57°55.629	1°38.476	CTD 09 Transect 1
509-1	Schmale		CTD	30.08.16	17:52:00	-	57°55.403	1°38.063	CTD 10 Transect 1
510-1	Schmale		CTD	30.08.16	18:16:00	-	57°55.209	1°37.630	CTD 11 Transect 1
511-1	Schmale		CTD	30.08.16	18:42:00	-	57°54.990	1°37.257	CTD Transect 1 turbidity
512-1	Schmale		CTD	30.08.16	19:15:00	-	57°54.787	1°36.847	CTD Transect 1 turbidity
513-1	Held	MB01	MBES-WCI	30.08.16	19:45:00	00:46:00	57°54.410	1°38.244	Continuation Multibeam MB01; New soundvelocity profile loaded; Settings for WCI (see screenshot); Bathy very bad
514-1	Held	MB01	SES	31.08.16	01:00:00	05:31:00	57°53.834	1°39.636	MB01 – continuation backwards(start southeast)
515-1	Schmale		CTD	31.08.16	06:09:00	-	57°54.885	1°38.634	CTD 14 Transect 2
516-1	Schmale		CTD	31.08.16	06:51:00	-	57°55.096	1°38.253	CTD 15 Transect 2
517-1	Schmale		CTD	31.08.16	07:35:00	-	57°55.303	1°37.877	CTD 16 Transect 2
518-1	Schmale		CTD	31.08.16	08:19:00	-	57°55.495	1°37.468	CTD 17 Transect 2
519-1	Schmale		CTD	31.08.16	09:11:00	-	57°55.719	1°37.070	CTD 18 Transect turbidity 9:07 WCI particle imaging; Innomar start
520-1	Schmale		CTD	31.08.16	10:00:00	-	57°55.825	1°36.853	CTD 19 Transect 2 turbidity
521-1	Schmale		CTD	31.08.16	10:37:00	-	57°55.595	1°37.254	CTD 20 Transect 2 turbidity
522-1	Schmale		CTD	31.08.16	10:56:00	-	57°55.358	1°37.723	CTD 21 Transect 2 turbidity
523-1	Schmale		CTD	31.08.16	11:26:00	-	57°55.167	1°38.078	CTD 22 Transect 2 turbidity
524-1	Schmale		CTD	31.08.16	11:55:00	-	57°54.970	1°38.386	CTD 23 Transect 2 turbidity, time note wrong (11:26)
525-1	Schmale		CTD	31.08.16	12:29:00	-	57°54.770	1°38.799	CTD 24 Transect 2 turbidity
526-1	Schneider	Bl	MB	31.08.16	13:00:00	14:55 (Log) / 13:54 (ship protocol)	57°53.48	1°39.62	Bathy / Backscatter survey with Auto settings; abandoned, bad weather
527-2	Held	Bl	FL 1	01.09.16	06:11:00	-	57°55.327	1°37.910	gas bubble release from Frahmlot; loamy, greenish, 527-1 repeated
528-1	Held	Bl	V-Grab 1	01.09.16	06:39:00	-	57°55.459	1°38.102	
529-1	Held	Bl	V-Grab 2	01.09.16	07:05:00	-	57°55.606	1°38.352	OFOP: greiferprofile1.txt
530-1	Held	BL	V-Grab	01.09.16	07:25:00	-	57°55.732	1°38.612	FS + U; mussle debris; 3 stones ca. 7cm
531-1	Held	BO	V-Grab	01.09.16	07:44:00	-	57°55.849	1°38.823	FS; Worms/ buildings & 1 alive; mussle debris; stone ~5cm; little mud addition
532-1	Held	BO	V-Grab	01.09.16	08:12:00	-	57°55.444	1°37.710	FS; few mussle debris; no layering; 1 dead seastar
533-2	Held	BO	V-Grab	01.09.16	08:36:00	-	57°55.582	1°37,503	MS + FS; mussle debris; worm buildings; no layering, 533-1 repeated
534-1	Held	BO	V-Grab	01.09.16	08:56:00	-	57°55.720	1°37.293	MS; no mussle debris; some worm buildings; no layering
535-1	Schmale		CTD	01.09.16	11:01:00	-	57°55.695	1°38.634	CTD 25 particle transect
536-1	Schmale		CTD	01.09.16	12:17:00	-	57:55.492	1°38.251	CTD 26 particle transect
537-1	Schmale		CTD	01.09.16	13:12:00	-	57°55.476	1°38.255	CTD 26.2 repeat particle transect
538-1	Schmale		CTD	01.09.16	13:48:00	-	57°55.327	1°37.927	CTD 27 particle transect

Stationbook

Station No.	Responsible	Place	Gear	Date [UTC]	Time [UTC]	Time end [UTC]	Lat (N)	Lon (E)	Comment
539-1	Treude	Crater shoulder	Frahm corer	01.09.16	14:39:00	-	57°55.31	1°37.89	no recovery
540-1	Treude	Crater shoulder	Frahm corer	01.09.16	14:46:00	-	57°55.32	1°37.91	no recovery
541-1	Treude	Crater shoulder	Frahm corer	01.09.16	14:56:00	-	57°55.33	1°37.89	ca. 20 cm core; loamy
542-1	Treude		Frahm corer	01.09.16	15:35:00	-	57°55.52	1°38.24	no recovery, presumably sandy
543-1	Schneider	Bl	Flare imaging	01.09.16	16:15:00	18:33:00	57°55.43	1°38.07	Drift survey BL, 0.3 kn; WCI; 16:37: Fish at transducer 16:41 re-survey; 17:18 Plume tilted, no gas across thermocline
544-1	Schneider	Bl	MBES	01.09.16	18:15:00	01:06:00	57°53.52	1°39.88	MB02; MB östlich MB01; Bathy survey (WCI logging, but not optimized for WCI), survey start ships prot: 19.06
545-1	Held	BO	MBES	02.09.16	02:10:00	10:49:00	57°53.45	1°39.63	MB01, WCI logging, settings like station 544
546-1	Scneider	Bl	ROV 2	02.09.16	11:30:00	-	57°55.30	1°38.01	Bubble Catcher experiment
547-1	Schneider	Bl	Picarro	02.09.16	18:16:00	22:00:00	57°55.39	1°38.28	Combined WCI Picarro Survey over tidal cycle (only until 22 o'clock); details see picarro log
548-1	Held	Bl	MB	02.09.16	22:15:00	07:29:00	57°55.39	1°38.32	WCI – tidal – survey Blowout with wci settings
549-1	Schneider	Bl	ROV 3	03.09.16	09:00:00	12:30:00	57°55.69	1°38.54	ADCP mooring recovery; Gassampling: Sampler Nr. 1, 3; Pushcores: 2x; Bubble Release Exp., start ships prot. 7:55
550-1	Schneider	Bl	ROV 4	03.09.16	13:39:00	17:40:00	57°55.4352	1°37.799	BubbleBox survey; BC-Vent; Mega-Seep; Water Column (mega seeps BubbleBox flux measurement, 8 Liter lid)
551-1		Bl	SES	03.09.16	18:29:00	02:00:00	57°53.50	1°38.22	SES survey completed; 8kHz; LF-Pulses 2, LF-Gain,26 dB; HF-Gain, 24 dB; Tag im SES -1.02 instead of 03.09
552-1	Schmale		ROV 5	04.09.16	05:05:00	08:20:00	57°55.28	1°37.64	
553-1	Schmale		CTD	04.09.16	08:45:00	-	57°55.292	1°37.849	CTD DNA above Blowout
554-1	Schneider	Bl	ROV 6	03.09.16	10:15:00	13:48:00	57°55.28	1°37.78	
555-1	Schmale		CTD	04.09.16	14:23:00	-	57°55.700	1°37.838	turbidity CTD
556-1	Schmale		CTD	04.09.16	14:57:00	-	57°55.289	1°37.046	turbidity CTD
557-1	Schmale		CTD	04.09.16	15:26:00	-	57°54.849	1°37.860	turbidity CTD; 89.7m; Alt Moslernd 6.4m
558-1	Schmale		CTD	04.09.16	15:53:00	-	57°55.288	1°38.615	turbidity CTD
559-1	Held	Bl	MBES	04.09.16	16:45:00	21:45:00	57°56.76	1°36.57	western continuation survey, Bathy, WCI logging
560-1	Schmale		CTD	04.09.16	22:12:00	-	57°56.167	1°36.915	CTD Out Transect
561-1	Schmale		CTD	04.09.16	22:42:00	-	57°56.129	1°37.438	CTD Out Transect
562-1	Schmale		CTD	04.09.16	23:12:00	-	57°56.167	1°37.920	Out Transect
563-1	Schmale		CTD	04.09.16	23:56:00	-	57°56.140	1°38.331	
564-1	Schmale		CTD	05.09.16	00:19:00	-	57°56.105	1°38.665	Out Transect
565-1	Held	Bl	MBES-WCI	05.09.16	01:08:00	05:11:00	57°55.22	1°37.91	Flare imaging, Wiederholtes Treibern über den Hauptflare; WCI-Einstellungen
566-1	Schneider	Bl	ROV 7	05.09.16	07:00:00	10:00:00	57°55.476	1°37.74	Transect towards Bl; Echoscope; 3x Niskin; HD Flight Megaseep; HD Flight Intrusion ~55m water depth
567-1	Schmale	Bl	ROV 8	05.09.16	11:40:00	13:33:00	57°55.314	1°37.866	WCI-pitch-steer modus; BC vent 2
568-1	Held		V-Grab	05.09.16	14:14:00	-	57°55.684	1°38.824	no recovery
569-1	Held		V-Grab	05.09.16	14:22:00	-	57°55.675	1°38.822	
570-1	Held		V-Grab	05.09.16	14:46:00	-	57°56.005	1°39.454	
571-1	Held		V-Grab	05.09.16	15:12:00	-	57°56.321	1°40.126	
572-1	Held	E-Bl	MBES-WCI	05.09.16	16:00:00	21:10:00	57°56.80	1°39.86	Bathy-Survey, WCI logging, first two lines repeated, MBES/MRU Sync problem
573-1	Schmale		CTD	05.09.16	22:08:00	-	57°54.470	1°37.019	IN Transect
574-1	Schmale		CTD	05.09.16	22:57:00	-	57°54.444	1°37.834	IN Transect

Stationbook

Station No.	Responsible	Place	Gear	Date [UTC]	Time [UTC]	Time end [UTC]	Lat (N)	Lon (E)	Comment
575-1	Schmale		CTD	05.09.16	23:30:00	-	57°54.454	1°38.692	IN Transect. Ships prot 1°38.64/65
576-1	Schmale		CTD	06.09.16	00:34:00	-	57°57.178	1°33.972	background CTD, ships prot. 57°57.19 / 1°33.98
577-1	Held	NW-Bl	MBES	06.09.16	01:20:00	03:25:00	57°56.105	1°33.74	Multibeam Pitch & Yaw – Calibration; (old svp); new svp: st576-ctd41.tsc; loaded during transit to ROLL Calib
578-1	Held	SE-crater	MBES-WCI	06.09.16	03:57:00	05:00:00	57°55.01	1°38.98	Flare-Imaging; WCI-Settings; SE-crater surveyed in MB01; now no flare visible
579-1	Schmale		CTD	06.09.16	06:03:00	-	57°54.668	1°37.471	turbidity CTD 42
580-1	Schmale		CTD	06.09.16	06:37:00	-	57°54.663	1°38.230	turbidity CTD 43
581-1	Schmale		CTD	06.09.16	07:25:00	-	57°55.935	1°38.222	turbidity CTD 44
582-1	Schmale		CTD	06.09.16	07:48:00	-	57°55.940	1°37.417	turbidity CTD 45; CTD 91.4m; + Altimeter depth 4.4
583-1	Urban	Bl	BubbleBox	06.09.16	08:32:00	09:40:00	57°55.305	1°37.870	B-Box Tow-yo; 8:35 start WCI-Pitch steer; 9:40: stop (normal WCI); Tow-yo, see BubbleBox protocoll
584-1	Schneider	Bl	MBES-WCI	06.09.16	10:20:00	10:45:00	57°55.79	1°38.72	WCI transect across Bl, (one profile for B-Box)
585-1	Schmale		CTD	06.09.16	11:01:00	-	57°56.582	1°37.885	CTD 46 turbidity; depth CTD 92.2 m; Alt +4.4 m
586-1	Schmale		CTD	06.09.16	12:02:00	-	57°54.060	1°37.847	CTD 47 turbidity. Ships prot. 1°37.87
587-1	Schmale		CTD	06.09.16	13:03:00	-	57°55.685	1°38.690	CTD 48
588-2	Treude		V-Grab	06.09.16	13:26:00	-	57°55.68	1°38.66	particle Transect; (588-1 abandoned)
589-1	Treude		V-Grab	06.09.16	13:43:00	-	57°55.51	1°38.33	particle Transect
590-1	Treude		V-Grab	06.09.16	14:35:00	-	57°57.17	1°33.99	Background
591-1	Held	N-Bl	MBES	06.09.16	15:00:00	19:20:00	57°56.91	1°34.99	Bathy-Survey; WCI logging; End of research programe