MARIA S. MERIAN – Berichte

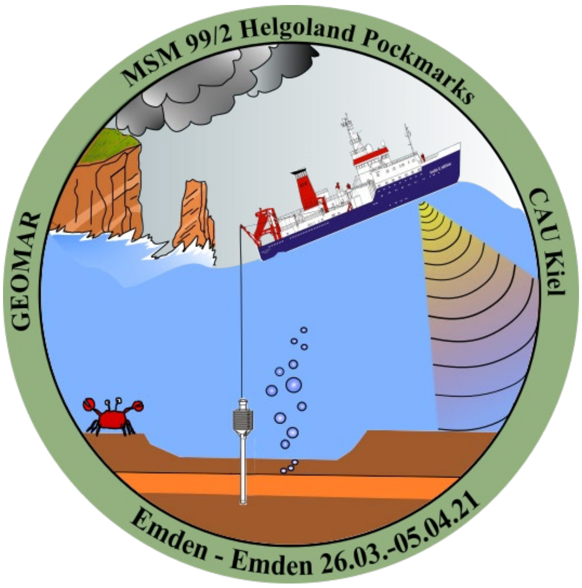
WAVE INDUCED POCKMARK FORMATION IN THE NORTH SEA

Cruise No. MSM 99/2 (GPF 21-1_013)

26.03.2021 – 05.04.2021

Emden (Germany) – Emden (Germany)

HELGOLAND POCKMARKS



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2021

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1 Cruise Summary

1.1 Summary in English

The aim of RV MARIA S. MERIAN cruise MSM99/2 (GPF 21-1_013) was to investigate the occurrence of pockmarks north of Helgoland in the German Bight. It is proposed that the pockmarks in this area emerge during large storms. The assumed mechanism is based on the fact that wave movements lead to pressure changes in the sediment which can lead to spontaneous degassing and accumulation of free gas in the subsurface. This process is highly dependent on the permeability and saturation of dissolved gases in the pore fluid. To test this hypothesis, we planned a work program including hydroacoustic mapping of the seafloor and geological sampling for sediment properties and pore water analysis. We decided for two working areas, the first one north of Helgoland where mainly high permeable sands are deposited and the second south of Helgoland in the Helgoland Mud area where low permeable clays are deposited. During the cruise, we mapped about 1100 NM of the seafloor and took at 35 stations sediment samples. We were able to identify numerous pockmarks in all parts of the northern working area. No pockmarks could be found in the Helgoland Mud Area. With the sediment samples collected during MSM99/2 and the planned on-shore investigations, we will be able to constrain and further understand the process of wave induced pockmark formation in the North Sea.

1.2 Zusammenfassung

Ziel der RV MARIA S. MERIAN Fahrt MSM99/2 (GPF 21-1_013) war es, das Auftreten von Pockmarks nördlich von Helgoland in der Deutschen Bucht zu untersuchen. Es wird allgemein angenommen, dass die Pockmarks in diesem Gebiet während großer Stürme entstehen. Der vorgeschlagene Mechanismus beruht darauf, dass Wellenbewegungen zu Druckänderungen im Sediment führen, die eine spontane Entgasung und Akkumulation von freiem Gas im Untergrund zur Folge haben können. Dieser Prozess ist stark von der Permeabilität und der Sättigung der gelösten Gase im Porenwasser abhängig. Um diese Hypothese zu testen, planten wir ein Arbeitsprogramm, das eine hydroakustische Kartierung des Meeresbodens und geologische Probenahmen für Sedimenteigenschaften und Porenwasseranalysen beinhaltet. Dazu entschieden wir uns für zwei Arbeitsgebiete, nördlich von Helgoland, wo hochpermeable Sande abgelagert sind und das Helgoländer Schlickgebiet südlich von Helgoland indem Tone mit einer geringen Permeabilität abgelagert werden. Während der Fahrt kartierten wir etwa 1100 NM des Meeresbodens und nahmen an 35 Stationen Sedimentproben. Im gesamten nördlichen Arbeitsgebiet konnten wir zahlreiche Pockmarks identifizieren. Im Helgoländer Schlickgebiet konnten hingegen keine Pockmarks gefunden werden. Mit den gesammelten Sedimentproben von MSM99/2 und den an Land durchgeführten Untersuchungen werden wir in der Lage sein, den Prozess der welleninduzierten Pockmarkbildung in der Nordsee weiter einzugrenzen.

2 Participants

2.1 Principal Investigators

Name	Institution
Schmidt, Christopher, Dr.	GEOMAR
Böttner, Christoph, Dr.	CAU

2.2 Scientific Party

Name	Discipline	Institution
Schmidt, Christopher, Dr.	Chief Scientist	GEOMAR
Böttner, Christoph, Dr.	Co- Chief Scientist/Hydroacustics	CAU
Wünsche, Anna	Sedimentology	CAU/BAW
Willems, Tim	Sedimentology	CAU
Schmidt, Mark, PD Dr.	Geochemistry	GEOMAR
Müller, Thomas Harald, Dr.	Geochemistry	GEOMAR
Spiegel, Timo	Geochemistry	GEOMAR
Lindner, Marie	Hydroacustics	CAU
Müller, Frieda	Hydroacustics	CAU
Hunkemöller, Annette	Hydroacustics	CAU

Figure 2.1 Scientific Crew on board R/V Maria S. Merian during MSM99/2 (GPF 21-1_013)

2.3 Participating Institutions

GEOMAR	Helmholtz-Zentrum für Ozeanforschung Kiel
CAU	Christian-Albrechts-Universität zu Kiel
BAW	Bundesamt für Wasserbau Hamburg

3 Research Program

3.1 Description of the Work Area

Two main working areas (WA) for cruise MSM99/2 were defined in the German Bight, North Sea (Figure 3.1). WA1 was located on the Helgoland Reef, north of Helgoland. WA 2 comprised the Helgoland Mud area south of Helgoland. Krämer et al. (2017) showed the existence of abundant very densely spaced pockmarks on the seafloor in WA1. The authors described a mechanism that these pockmarks appear to form episodically in the southeastern North Sea during major storms. The described pockmarks are elliptical depressions of 10 to 20 m in horizontal extend with a depth of 20 cm (Krämer et al., 2017). Bathymetric maps show a large spatial heterogeneity in pockmark density: There are areas with pockmark densities of up to 1200 pockmarks per km² and areas with nearly no pockmark occurrence. Furthermore, pockmarks vanish in calm weather conditions due to the residual sediment transport as a result of the strong tidal forcing. The time of emergence can be confined to 3 months in autumn 2015 (Krämer et al., 2017), during expedition AL512 in 2018 no traces of the pockmark field could be found (Karstens et al., 2018).

Sediment composition of the North Sea consist mainly reworked glacial and fluvial sands and some fine-grained sediments (de Haas et al., 2002). The fine-grained sediments are deposited at local depocenters with low bottom current velocities. In the German Bight the main depocenter for clay sediments is the Helgoland mud area south Helgoland and the Elbe and Eider paleo river valleys (Hebbeln et al., 2003). In general, sediments of both WAs differ considerably with respect to their main grain size composition and saturation of dissolved fluids (Zhang et al., 2019). WA1 is thereby composed of sandy sediments with a lower organic matter input and hence presumably lower dissolved methane concentration. Permeabilities can be expected here rather high. In contrast, WA2 is mainly buildup of clayey sediments with a high organic matter fraction. In general, saturation of dissolved gases are rather high and permeability is rather low here.

3.2 Aims of the Cruise

The major goal of this cruise was to test our hypothesis on formation of pockmarks during major storms. The episodic nature of pockmark formation in the southeastern North Sea suggests there is an ongoing geologic process that remains enigmatic in terms of fluid source and character. Krämer et al. (2017) suggested that pressure changes due to large scale storm waves during the winter season (> 8 m significant wave height) mobilize shallow gas in sediments (< 5 m sediment depth). The gas present in the subsurface is likely formed by the decomposition of organic carbon buried in the postglacial paleo river valley. In this scenario, the wave-induced pressure changes are the final trigger that mobilizes gas present in the subsurface.

In own preliminary work using numerical modeling, we came to an alternative hypothesis for the gas source of the pockmarks. The proposed mechanism is based on the fact that wave movements lead to pressure changes in the sediment which can lead to spontaneous degassing and accumulation of free gas in the subsurface. This process is possible because the solubility of gas in pore water is pressure and temperature dependent. In particular, wave-induced degassing and subsequent pockmark formation is dependent on a sufficiently high initial dissolved gas saturation in the pore water, and a high permeability. These parameters can vary considerably and on different spatial scales in the investigated area, which can influence the local occurrence of pockmarks. Specific project objectives were

- What are the local variations of the TOC content of areas with pockmarks compared to areas without pockmarks on the Helgoland Reef?
- What are the concentrations of dissolved gasses e.g. CO_2 or CH_4 in the pore fluids and can we observe a regional heterogeneity of areas with pockmarks compared to areas without pockmarks?
- What are the hydraulic properties (e.g. permeability) of the sediments? Can we determine the efficiency of leakage pathways for fluid (water, methane) transfer?
- Do pockmarks correlate with paleo-channels (tunnel valleys) or local depocenters?
- How do these pockmarks evolve over time?

3.3 Agenda of the Cruise

After departure from Emden, RV MARIA S. MERIAN we planned sail first into our WA1. The typical planned station work in both working areas included a high-resolution mapping of the study area as well as a targeted geochemical sampling of sediments and pore water. For the sediment sampling, we planned to use the gravity core (GC), Mini Multi Corer (Mini-MUC) and Van-Veen Grab (VGRAB). For hydroacoustic mapping, we planned to carry out regional overview mappings and detailed surveys of specific areas. The regional mappings were planned in order to get an overview about pockmark distribution in the working area. Combined with Parasound profiles these mappings help to identify whether pockmarks are connected to subsurface features e.g. paleo channels. The repeated detailed surveys were planned to investigate how pockmarks evolve over time. The deployment of the sediment sampling devices was planned on a daily basis after reviewing previously acquired multibeam and parasound data. Gravity coring is challenging in sandy sediments. Hence, the deployment of the GC in WA1 is only useful in paleo channels as sediments here can be expected to be of finer material. If gravity coring was not successful, we used the Mini-MUC and VGRAB to sample sediments from the seafloor.

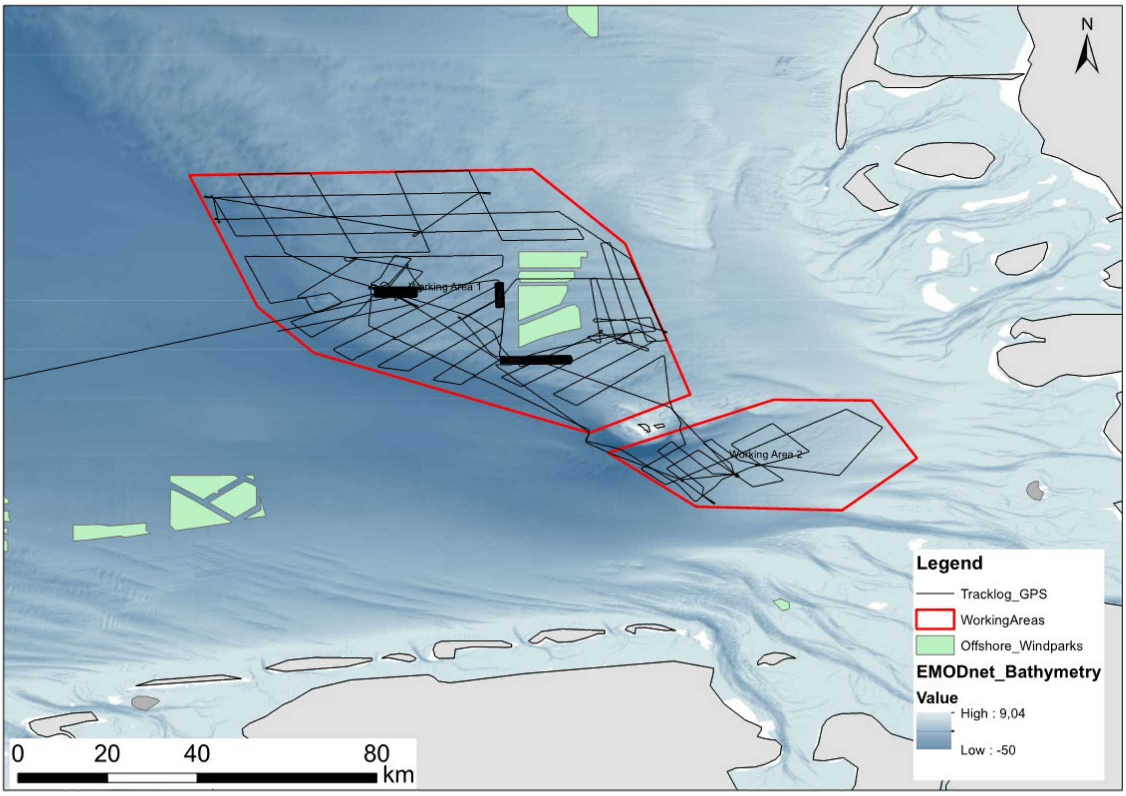

Figure 3.1 Track chart of R/V MARIA S. MERIAN Cruise MSM99/2 (GPF 21-1_013) Bathymetry from Smith and Sandwell (1997). Two main working areas (Working Area 1: Helgoland Reef; Working Area 2: Hegoland Mud Area)

4 Narrative of the Cruise

After a 10-day quarantine for the scientific crew in a hotel in Varel and three negative COVID-19 tests, we were allowed to embark the RV MARIA S. MERIAN on Thursday 25.03.2021 in Emden. In the afternoon, we immediately started setting up the laboratories. On Friday 26th March, RV MARIA S. MERIAN left at 08:30 the port of Emden and we reached after an 8-hour long transit our first working area (WA1) in the German Bight, North Sea, north of Helgoland. Immediately upon reaching the work area, the recording of the hydroacoustic data started. On the first station a CTD-Rosette was deployed to generate a sound velocity profile (SVP) and test CH4, CO2 and N2 sensors. We then conducted a calibration survey over a ship wreck for hydroacoustic systems. On the following night a regional hydroacoustic survey was planned to get an overview about the working area, to find pockmarks to identify possible sediment sampling locations for the next days.

Due to sediment properties gravity coring is a challenging task in the area. During the night we identified 5 coring stations were the deployment of the GC and a Van- Veen grab was planned for Saturday 27th March. However, gravity coring was unfortunately not that successful but we could take the first sediment samples from the seafloor surface with the Van-Veen grab. In the afternoon another CTD rosette was deployed in an area were many pockmarks are present. During the night a detailed hydroacoustic survey of a region where many pockmarks were found the night before was planned. Following on the next morning (Sunday, 28th March), we planned 6 sediment coring stations. Additional to the GC deployments we also used the MIC. We received successfully sediment samples from four MICs and four Van-Veen grab samples, from different pockmarks. After the sediment sampling campaign finished, we started in the following night with mapping of the south western part of our WA 1.

The next morning, we started with another CTD-Rosette cast above a pockmark. For sediment sampling, we planned for the day a transect from an area with thousands of pockmarks to an area with no pockmarks to an area again with thousands of pockmarks. The goal was to understand the differences of the areas with to areas without pockmarks. The deployment of 8 successful MICs was followed in the afternoon by four CTD-Rosette casts in the southern part of WA1.

We then began the short transit from WA1 to WA2. The following night was used for a hydroacoustic survey in WA2. In WA2 no pockmarks could be found, as expected. The next morning started with CTD-Rosette cast in order to get a new sound velocity profile as this area is influenced by the fresh water inflow from the river Elbe. This was followed by two MIC and two GC deployments in the western and eastern part of the WA. Dissolved gas concentrations are higher in WA2 compared to WA1 indicated by a high total alkalinity. Also, sediment properties are different here. Sediments are composed of clayey material rather than sandy sediments in the north. Afterwards, mapping of WA2 continued starting the transit late evening back to WA1. North of Helgoland we identified again an area were gravity coring could be possible in WA1. On Wednesday 31st March we successfully deployed four GCs followed always by MIC deployments over a paleo valley north of Helgoland. This success allows us to better understand whether pockmarks are tied to the paleo valleys. In the afternoon we started our transit to the northern part of WA1 passing by the R/V HEINCKE on their way back to Bremerhaven. The northern part of WA1 overlaps with partly with the Natura 2000 marine protection area "Sylter Außenriff". Here we had to switch off the multibeam system. We could only continue mapping then with the Parasound system. The Paraosund survey took about 18 hours. In the afternoon of Thursday 1st April, we deployed several Mini-MUCs in the northern part of WA 1 area. In the most north western part we also tried to deploy a GC. But sediments did not allow a successful recovery.

Over the next night, we continued Parasound mapping in the most eastern part of WA1, east of the wind farms Amrumbank West, Nordsee Ost and Meerwind Süd/Ost and still in the marine protection area. The next day started with a successful deployed of the gravity core in a paleo valley. After a short transit through the windfarms we deployed the MIC gain three times in an area were the seafloor were covered by thousands of pockmarks south of the wind farm Meerwind Süd/Ost. During the following night, we did a high-resolution mapping with Multibeam system which was allowed to be used again. On next morning of 03rd April we started at 6 am a transit to WA2. Here we deployed successfully the gravity core and MIC again. The goal of the additional deployments here was to understand why no pockmarks occur in the area were high dissolved gas are present. After 4 hours we left WA2 again for a short transit to WA1. We wanted to take more sediment samples from the inside of pockmarks which where mapped the night before. In the afternoon, we reached our first station and deployed three MICs. With this we have finished our sedimentological and geochemical work program. Afterwards packing of the first equipment started immediately. Scientific work continued with a hydroacoustic survey for the next 30 hours but had to stop on Sunday morning, 4th April at 10 am due to bad weather conditions. Therefore, we had to start our transit back to Emden were the cruise ended at 8 pm on Sunday night.

5 Preliminary Results

5.1 Underway Hydroacoustics

(C. Böttner, M. Lindner, F. Müller and A. Hunkemöller)

5.1.1 Multibeam - Equipment and method

RV MARIA S. MERIAN is equipped with two Kongsberg Maritime multibeam echosounder. The EM122 system operates at 12 kHz and covers water depths from 20 meters below the transducers up to full ocean depth; while the EM712 system offers three different frequency ranges (40-100 kHz, 50-100 kHz, 70-100 kHz) of signals for water depths ranging from 3 m below transducers to roughly 3500 m. Two different transmit pulses can be selected: a CW (Continuous Wave) or FM (Frequency Modulated) chirp. In case of the EM712, the latter is part of the full performance version that is installed on RV MARIA S. MERIAN. The sounding mode can be either equidistant or equiangular, depending on operation preferences and requirements. Both systems can be operated in single-ping or dual-ping mode, where one beam is slightly tilted forward and the second ping slightly tilted towards the aft of the vessel. The whole beam can also be inclined towards the front of the back and the pitch of the vessel can be compensated dynamically. The EM122 system produces 432 beams covering a swath angle of up to 150° while the EM712 system produces 512 beams for a maximum swath angle of 144°. The latter offers a high-density beam-processing mode with up to 800 soundings per swath. The swath angle, however, can be reduced, if required.

The transducers of both multibeam echosounder systems of RV MARIA S. MERIAN are mounted in a so-called Mills cross array, where the transmit array is mounted along the length of the ship and the receive array is mounted across the ship. The system on RV MARIA S. MERIAN is of a 1° x 1° design. The EM712 system installed on RV MARIA S. MERIAN is of a 0.5° x 0.5° design, but transducers are much smaller.

The echo signals detected from the seafloor go through a transceiver unit (Kongsberg Seapath) into the data acquisition computer or operator station. In turn, the software that handles the whole data acquisition procedure is called Seafloor Information System (SIS). In order to determine the point on the seafloor, where the acoustic echo is coming from, information about the ship's position, movement and heading, as well as the sound velocity profile in the water column are required. Positioning is implemented onboard RV MARIA S. MERIAN with conventional GPS/GLONASS plus differential GPS (DGPS) by using either DGPS satellites or DGPS land stations resulting in quasi-permanent DGPS positioning of the vessel. These signals also go through the transceiver unit (Seapath) to the operator station. Ship's motion and heading are compensated within the Seapath and SIS by using a Kongsberg MRU 5+ motion sensor. Beamforming also requires sound speed data at the transducer head, which is available from a sound velocity probe at the keel (C-Keel SVP). This signal goes directly into the SIS operator station. Finally, a sound velocity profile for the entire water column can be obtained either from a sound velocity probe or from a CTD (conductivity, temperature and density) probe. The temperature (T), salinity (S) and pressure (p) data acquired by any CTD can be converted into sound speed by using a sound speed function C(S,T,p). During cruise MSM99/2, we used direct sound velocity measurements with a special profiler probe (SVP01, SVP02, SVP04 at 1 m depth intervals) and converted sound velocity from CTD casts (CTD03, CTD08, CTD10, CTD11) as these offered higher sampling rates of the water column (0.2 m depth intervals).

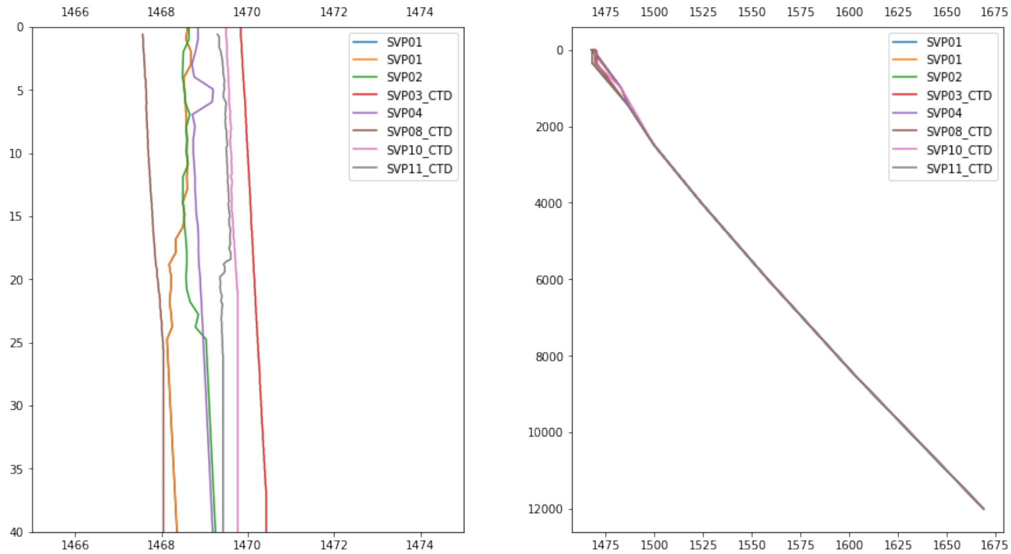

Figure 5.1.1. Comparison of all sound velocity profiles (SVPs) collected during MSM99/2. There are no significant changes in the temperature, salinity or velocity in the water column throughout the whole cruise**.**

In addition to bathymetric information, both the EM122 and the EM712 system register the amplitude of each beam reflection as well as a sidescan signal for each beam (so-called snippets). Both systems also allow recording the entire water column. The amplitude signals correspond to the intensity of the echo received at each beam. It is registered as the logarithm of the ratio between the intensity of the received signal and the intensity of the output signal, which results in negative decibel values. For each ping, EM122 records 432 backscatter intensity values while the EM712 records 800 backscatter values. The water column data correspond to the intensity of the echoes recorded from the instant the output signal is produced. All echoes coming from the water column, the seabed and even below the seabed are recorded for each beam. When the water column data of one ping is divided into a starboard and port subset, one can produce two traces, one for each subset. Each trace is built up as a time series in which for each time the highest amplitude is selected from all beams. Then the starboard and the port traces are joint together.

5.1.1.1 Multibeam - Acquisition parameters

During cruise MSM99/2, the Kongsberg EM122 system was not used, due to the low water depth in the German Bight of the North Sea. Acquisition parameters for the EM712 system were set the following. The pulse was FM, ping mode was set to high-resolution equidistant, dual ping mode was set to fixed, and depth mode was set to automatic. The beam angle was reduced to 140° during most of the survey, except for the surveys, where the maximum coverage was desired. Survey speed varied between 5 and 8 knots. Data were acquired continuously during pre-designed surveys and in between sediment sampling stations. Water column imaging was enabled during the specific survey. The multibeam systems had to be completely switched off during surveys within the protected area “Östliche Deutsche Bucht” due to regulations enforced by the "Bundesamt für Naturschutz" (BFN). A trigger box to organize the soundings of different systems is now fully functional on RV MARIA S. MERIAN. Therefore, we could acquire data with the PARASOUND P70 and the EM712 without any interferences.

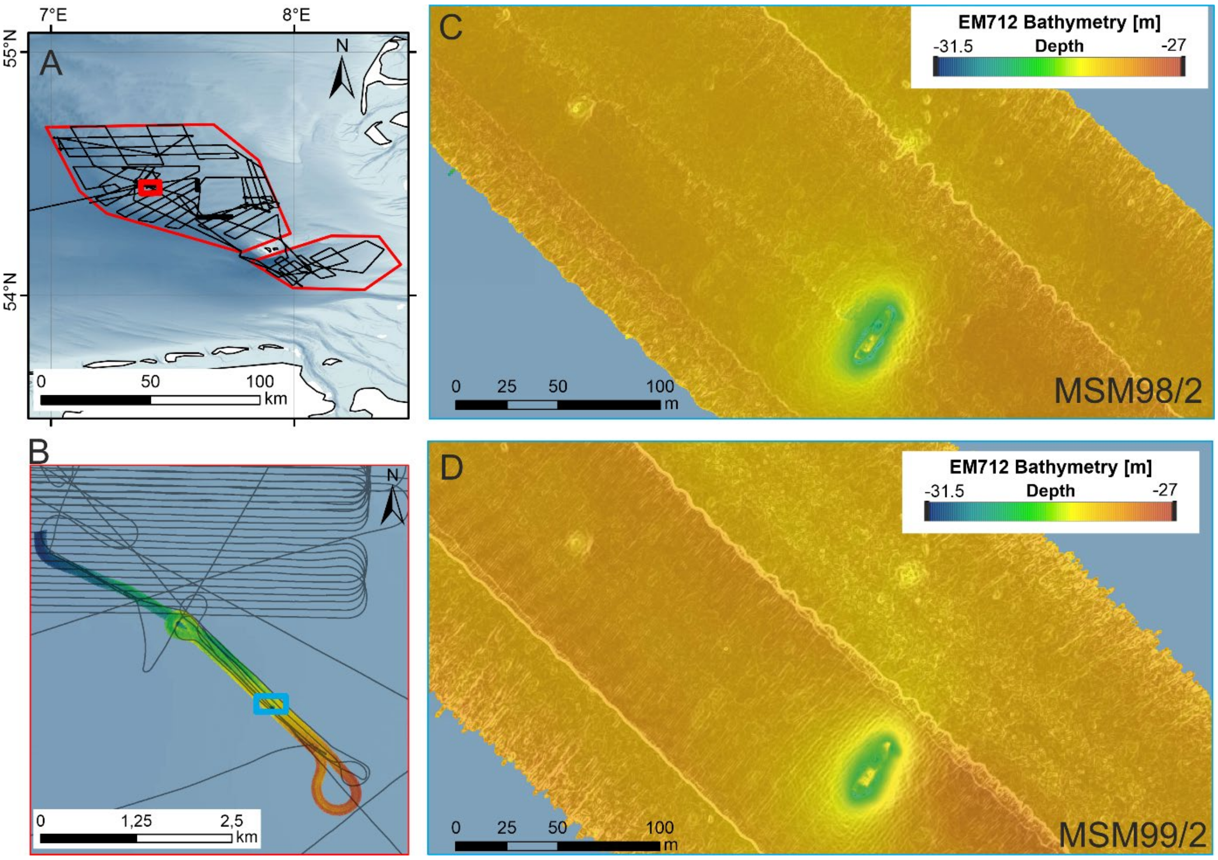

Figure 5.1.2. (A) Bathymetric map of both survey areas with draped cruise track. (B) Bathymetric map of both survey areas with draped cruise track and EM712 bathymetric data of the patch test conducted during MSM98/2. (C) Detailed bathymetric map of the patch test data acquired during MSM98/2 with 0.5 m spatial resolution. (D) Detailed bathymetric map of the patch test data acquired during MSM99/2 with 0.5 m spatial resolution. Both (C) and (D) show a prominent ship wreck and surrounding pockmarks.

5.1.1.2 Multibeam – Processing and expected results

In general, the multibeam data typically suffer from strong interferences with the other seismo-acoustic devices operated in parallel. Therefore, trigger box to organize the soundings of different systems was employed. The soundings were well organized and interference of different sounding systems was not observed during MSM99/2. Despite the organization of different systems, which results in a lower sampling/pinging rate, both systems (EM712 / PARASOUND P70) were pining at very high ping rates (>3 Hz) due to the very low water depth (about 25-40 m).

During the beginning of MSM99/2, a dedicated calibration survey across the location of a shipwreck at the seafloor was conducted to estimate offsets in heave, roll and pitch (i.e. "patchtest"). All three values show very low deviations from the anticipated 0° offset.

Data post-processing was carried out using different software packages (QPS Fledermaus Mid Water & Qimera). The produced bathymetry was post-processed with QPS Qimera. Tidal correction charts were requested from the BSH (i.e. opmod@bsh.de) and applied to the bathymetric data. Subsequently, the resulting bathymetric grid will be further investigated and compared with previous bathymetric maps by means of state-of-the-art GIS software (i.e. ArcGIS, Figure 5.1.2).

The backscatter (amplitude) signal is stored and preprocessed automatically by the Kongsberg software Seafloor Information System (SIS), including altitude processing, time varying gain (TVG) and angle varying gain (AVG). The backscatter will be processed using QPS FMGeocoder, where radiometric corrections, filtering, angle-varying gain and anti-aliasing filters and topographic corrections can be applied to the backscatter data before outputting a georeferenced mosaic. Evidence of backscatter anomalies, which could be indicative of gas seepage from the seafloor, can thus be observed.

The EM712 multibeam echosounder produces a second type of raw data files with extension *.wcd, which stores water column data. These files will be imported into QPS FMMidWater and QPS Qimera. The raw multibeam echosounder data (.all format) and associated water column data (.wcd) will be placed into a single folder and imported. Each line will be subsequently downsampled, opened in fan view (across track), and displayed as a curtain image (along track, range-stack view). The data will also be filtered by intensity.

5.1.1.3 Preliminary results

The working areas are located north (WA1) and south (WA2) of Helgoland and water depths are ranging predominantly between 25-35 m. The very shallow water depth allowed very high ping rates resulting in very high-quality imaging of the seafloor despite the simultaneous acquisition of PARASOUND PS70 organized through the perfectly working trigger box. In general, some data still show distinct patterns of noise and unmatched boundaries of adjacent swaths (< 10 cm difference) likely related remaining tidal signal or heave related to the direction of steaming (i.e. squat effect: against water surface current vs. with current).

The seafloor in the northern working area (WA1) is characterized by a homogeneous distribution of sandy sediments at the seafloor, which are intercalated by numerous pockmarks throughout the whole survey area. Pockmarks occur in different shapes and sizes but can be assigned to distinct morphological classes. Regardless of the class, the depth of 20-40 cm is fairly shallow. South of the windfarms (i.e. 'Meerwind Süd/Ost') pockmarks of different morphological classes occur in the same area and sediments (Fig. 5.1.3). There, the untypically shaped pockmarks (cauliflower) described by Kraemer et al. (2017) occur alongside (semi-) circular unit pockmarks. In addition, this area is also highly affected by local bottom currents documented by the very prominent sorted bedform structures of the sea floor.

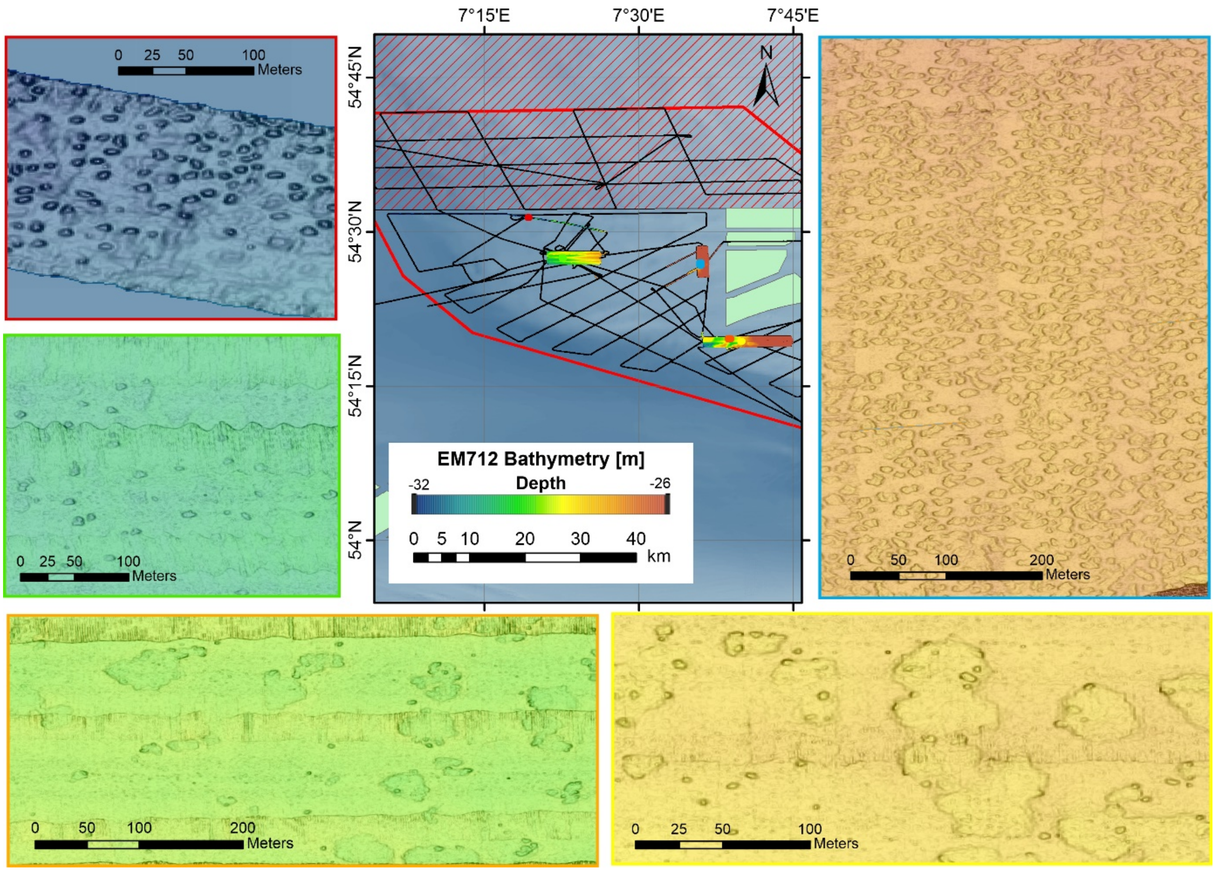

Figure 5.1.3. EM712 bathymetry acquired during MSM99/2 draped onto EMODnet bathymetry (2020). The EM712 bathymetry has a spatial resolution of 0.5 m and vertical resolution of few centimeters. Central map shows the overall working area and sail lines of the survey. Colors of the frames indicate location of zoom-ins in the central map. The red dashed area shows the location of the NSG 'Östliche Deutsche Bucht', where multibeam surveys have been prohibited with the onboard multibeam systems.

The seafloor of the southern working area (WA2) shows a very homogeneous seafloor with no distinct morphological features. This area comprises no pockmarks and shows no indications for fluid release from the seafloor.

5.1.2 Sediment echosounder - Equipment and method

The hull-mounted parametric sub-bottom profiler PARASOUND P70 (Atlas Hydrographic) was operated on a 24-hour schedule for flare imaging and to provide high-resolution (less than 15cm for sediment layers) information on the uppermost 50-100 m of sediment. The system has a depth range of 10 m to > 11000 m (full ocean depth) and a maximum penetration of 200 m. This high sediment penetration is acquired through the high pulse transmission power of 70 kW.

The RV MARIA S. MERIAN is equipped with a PARASOUND P70 system since the start in 2007. PARASOUND P70 works as a narrow beam sediment echo sounder, providing primary frequencies of 18 (PHF) and adjustable 18.5 – 28 kHz, thus generating parametric secondary frequencies in the range of 0.5 – 6 kHz (SLF) and 36.5 – 48 kHz (SHF) respectively. The secondary frequencies develop through nonlinear acoustic interaction of the primary waves at high signal amplitudes. This interaction occurs in the emission cone of the high-frequency primary signals, which is limited to a beam width of 4.5° x 5° for the PARASOUND P70. The system consists of four identical transducer modules, each about 0.3 m x 1.0 m. The P70 version includes 384 acoustic elements combined to form 128 stave channels. Therefore, the footprint size is approx. 4% of the water depth and vertical and lateral resolution is significantly improved compared to conventional 3.5 kHz echo sounder systems. The system provides features like recording of the 18 kHz primary signal and both secondary frequencies, continuous recording of the whole water column, beam steering, different types of source signals (continuous wave, chirp, barker coded) and signal shaping. Digitization takes place at 98 kHz to provide sufficient sampling rates for the high secondary frequency. A down-mixing algorithm in the frequency domain is used to reduce the amount of data and allow data distribution over ethernet.

5.1.2.1 Sediment echosounder - Acquisition parameters

For the standard operation, a parametric frequency of 4 kHz (SLF) and a sinusoidal source wavelet of 1 period were chosen to provide a good balance between signal penetration and vertical resolution. The 18 kHz signal (PHF) was also recorded permanently.

At the survey area, the system was mainly used for analysis of sedimentary processes, such as identification of different phases of glacial deposition or erosion. Due to low water depth (< 50 m) at the survey area the PARASOUND system was operated in a triggered single pulse mode.

The system worked reliable and produced high-quality data throughout the whole time. A trigger box to organize the signals of the EM712 and PARASOUND P70 during acquisition, reducing the ping rate but enabling simultaneous acquisition without major induced artifacts due to interference of both systems. The triggered signals worked well.

All raw data were stored in the ASD data format (Atlas Hydrographic), which contains the data of the full water column of each ping as well as the full set of system parameters. Additionally, a 200 m-long reception window centered on the seafloor was recorded in the compressed PS3 and SEGY data format after mixing the signal back to a final sampling rate of 12.1 kHz. This format is in wide usage in the PARASOUND user community and the limited reception window provides a detailed view on sub-bottom structures.

5.1.2.2 Sediment echosounder - Data processing

All data were converted to SEG-Y format during the cruise using the software package ps32sgy (Hanno Keil, Uni Bremen). The software allows generation of one SEG-Y file for longer time periods, frequency filtering (low cut 2 kHz, high cut 6 kHz, 1 iteration), subtraction of mean and envelope calculation. We used the frequency filtering and loaded all data to the seismic interpretation software IHS Kingdom. The envelope was subsequently calculated within the IHS Kingdom software. One SEG-Y file was created for the length of each profile. This approach allowed us to obtain a first impression of sea floor morphology variations, sediment coverage, sedimentation patterns along the ship’s track and evaluation of subsurface information regarding promising sediment sampling locations.

5.1.2.3 Sediment echosounder data – Preliminary results

We used the PARASOUND P70 to analyze and interpret the uppermost sedimentary succession in the survey area, located in the southeastern North Sea (Figure 3.1). Despite the expected coarse-grained material at the seafloor of this part of the German North Sea sector, the system showed very good penetration rates, in some cases exceeding 30 m below the seafloor.

The overall penetration in the Helgoland Reef was very good and, in many parts, up to 20 m into the subsurface. We used the very high-resolution PARASOUND P70 profiles in addition to existing legacy data (2D seismic reflection & sub-bottom profiler data), to characterize the subsurface and identify possible governing patterns of the local geology that may explain the spatial distribution of pockmarks in the overall area. Furthermore, we used the PARASOUND P70 system to identify and verify any fluid conduits reaching to the surface and characterize the overall sedimentation patterns in the area (e.g. Figure 5.1.4). Due to the high-frequency signal, the system is highly sensitive to fluids or gases within the sedimentary succession and above the seafloor. However, only few indications for free gas in the pore space could be identified.

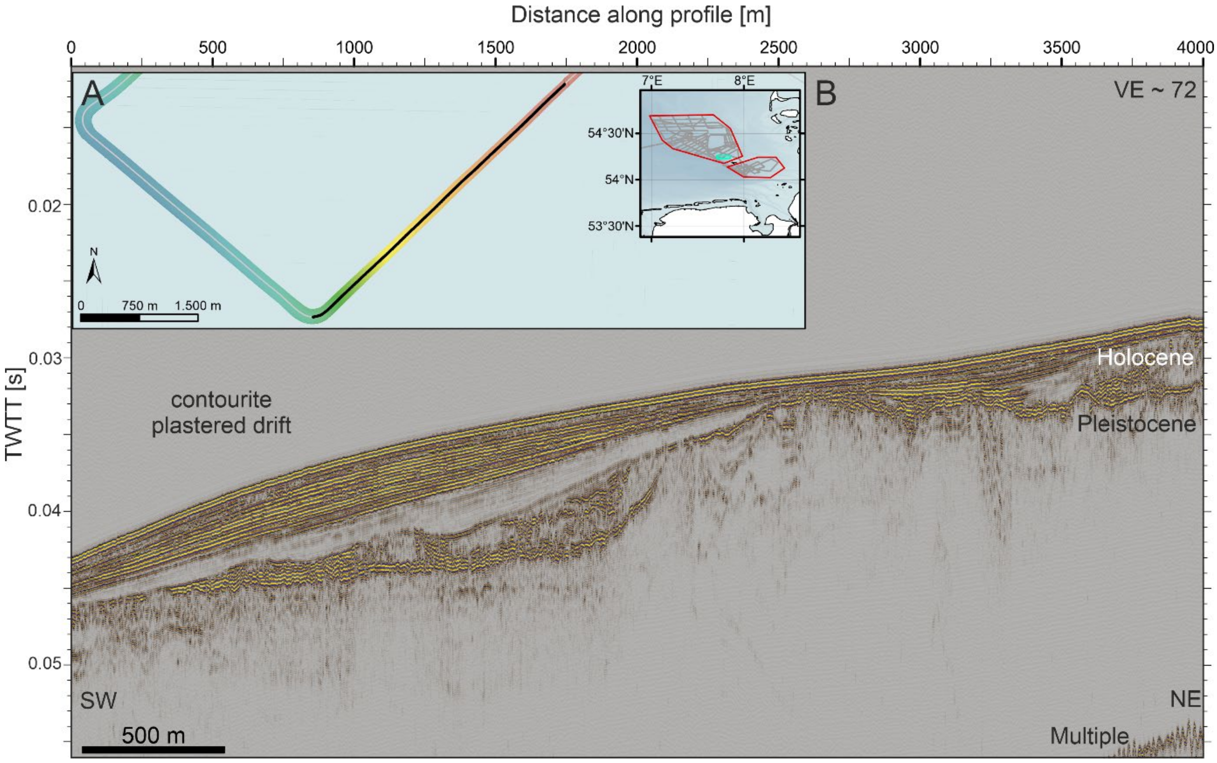

Figure 5.1.4. A combination of both hydroacoustic systems EM712 and PARSOUND P70 showing the seafloor and corresponding sedimentary succession of working area 1 (WA1), north of Helgoland. (A) Location of profile with simultaneously acquired EM712 bathymetric data. The cruise track is shown in grey, the profile extent in black. The inset shows the location of (A) with a turquoise rectangle. (B) ~ 4 km-long PARSOUND P70 profile P608 (here amplitude data) acquired in the northern part of working area 1 showing a contourite. In particular, the profile shows a plastered drift indicating strong bottom currents reworking the sediments in the working area. The topmost Holocene sediment show very finely laminated layering. The Holocene sediments are clearly separated from the chaotic to transparent Pleistocene sediments by a boundary layer which is associated with high amplitudes that likely indicate free gas in pore space. The profile shows two-way travel time (TWTT) in seconds on the y-axis and distance along profile in meters on the x-axis. The vertical exaggeration is approximately 72.

In general, the top sediments (Holocene) can be characterized by a very fine lamination of seismic reflections or completely transparent facies comprising almost no impedance contrasts (Figure 5.1.4). The Holocene sedimentation is clearly separated by a strong reflection (partly related to polarity inversions indicating free gas) possibly representing the top of Pleistocene sediments. In many cases this stratigraphic unit is cropping out at the surface, creating a distinct morphological pattern (5.1.4). This highly corrugated surface is intersected by a number of paleo-valleys. The seismic facies of these Pleistocene deposits are transparent to chaotic and give insights on the poor sorting due to glacial processes. Steeply dipping reflections within these units indicate the presence of paleo-valleys. This unit also represents the acoustic basement of our data. If any of these geological features influence the occurrence of pockmarks remains uncertain until further and more detailed analyses of the subsurface and a detailed mapping of the sediments with respect to the location of observed pockmarks.

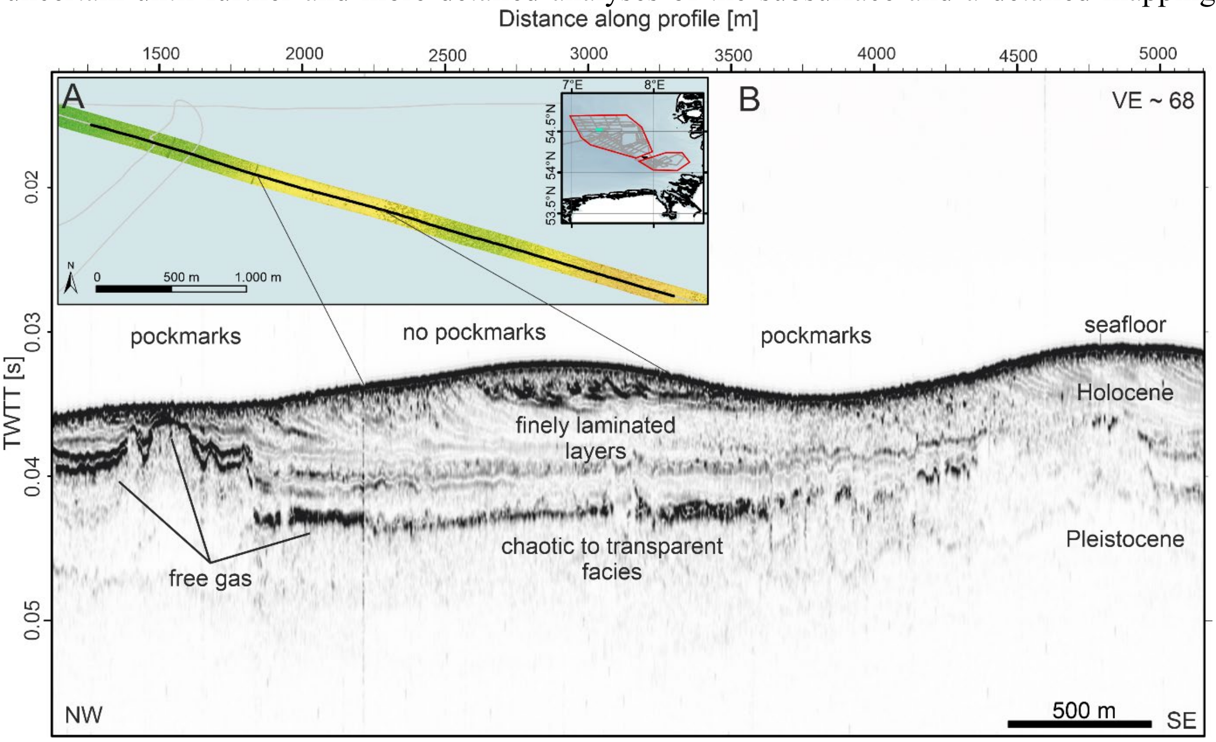

Figure 5.1.5. A combination of both hydroacoustic systems EM712 and PARSOUND P70 showing exemplary the seafloor and corresponding sedimentary succession of working area 1 (WA1), north of Helgoland. (A) Location of profile with simultaneously acquired EM712 bathymetric data. The cruise track is shown in grey, the profile extent in black. The inset shows the location of (A) with a turquoise rectangle. (B) ~ 4 km-long PARSOUND P70 profile P216 (here envelope data) acquired in the northern part of working area 1 showing exemplary the stratigraphy of the area. The topmost Holocene sediment show very finely laminated layering with pockmarks occurring at the seafloor where acoustic turbidity is increased. The Holocene sediments are clearly separated from the chaotic to transparent Pleistocene sediments by a boundary layer which is associated with high amplitudes that likely indicate free gas in pore space. The profile shows two-way travel time (TWTT) in seconds on the y-axis and distance along profile in meters on the x-axis. The vertical exaggeration is approximately 68.

Regional profiles across the Helgoland Reef (Figure 5.1.2) will help advance our understanding of recently dominant sedimentary processes (Figure 5.1.4). These profiles cross over a number of sediment sample stations that will help tie our results into a local and regional stratigraphic framework. In addition, these profiles show indications for bottom currents are documented by abundant sorted bedforms or contouritic deposits (Figure 5.1.4) and the influence of abundant salt domes/walls deforming the above lying sediments by local uplift (Figure 5.1.6).

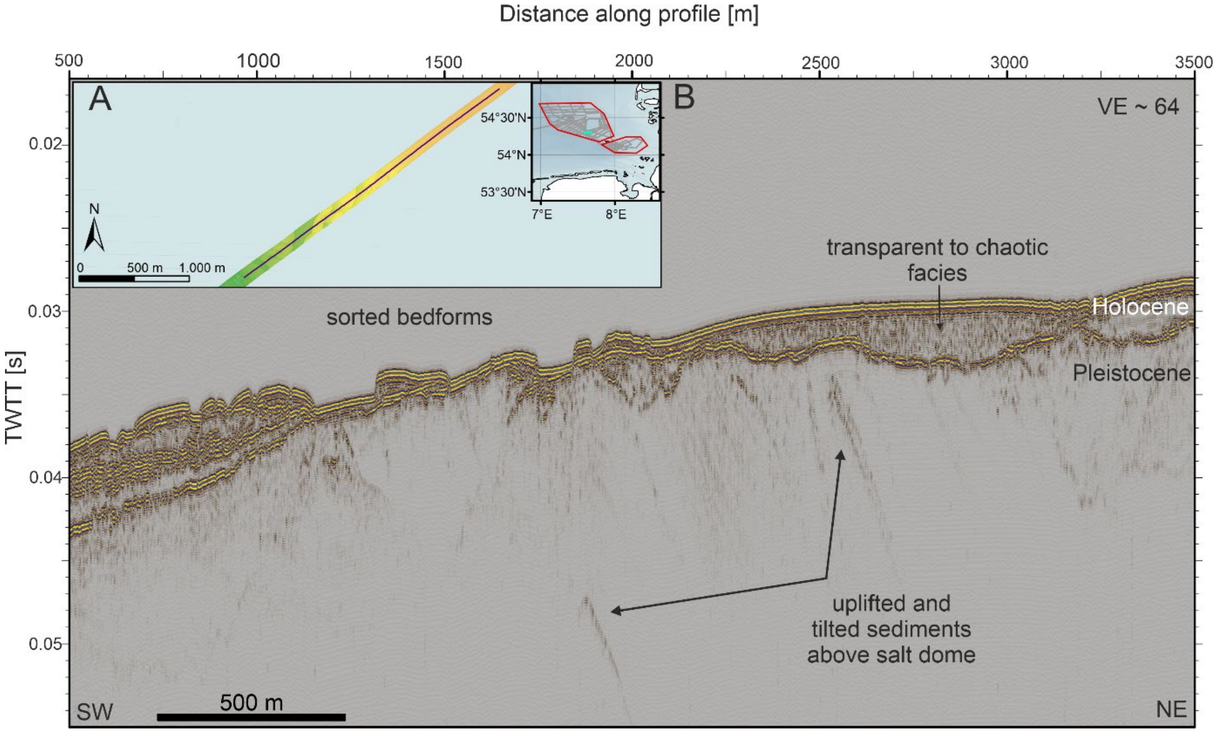

Figure 5.1.6. A combination of both hydroacoustic systems EM712 and PARSOUND P70 showing the seafloor and corresponding sedimentary succession of working area 1 (WA1), north of Helgoland. (A) Location of profile with simultaneously acquired EM712 bathymetric data. The cruise track is shown in grey, the profile extent in black. The inset shows the location of (A) with a turquoise rectangle. (B) ~ 3 km-long PARSOUND P70 profile P608 (here amplitude data) acquired in the northern part of working area 1 showing sorted bedforms at the seafloor as well as uplifted and tilted sediments above a salt dome in the deeper subsurface. The Holocene sediments are clearly separated from the chaotic to transparent Pleistocene sediments by a boundary layer which is likely associated with high amplitudes that likely indicate free gas in pore space. The profile shows two-way travel time (TWTT) in seconds on the y-axis and distance along profile in meters on the x-axis. The vertical exaggeration is approximately 64.

WA 2 (south of Helgoland) is characterized by a very fine laminated sedimentary succession with clear indications of free gas in pore space (i.e. blanking of amplitudes at ~ 75 cm depth). Neither the surface nor the subsurface shows indications for fluid release (e.g. pockmarks, gas chimneys, or similar). This area is used as reference site for working area 1, as here the free gas is clearly visible in the subsurface but no pockmarks have been documented for the seafloor.

5.2 Water and Plankton Sampling with CTD/Rosette

5.2.1 CTD Measurements

(Mark Schmidt, Thomas Harald Müller, Timo Spiegel)

5.2.1.1 Methods

The onboard Water Sampler Rosette/CTD system (Figure 5.2.1) was used to study oceanographic characteristics of the water column and to detect possible gas anomalies (i.e. CO_2, CH_4). The CTD (Sea-Bird Electronics Inc.; SBE9plus underwater unit) was a real-time data acquisition system transmitting data via coaxial cable to the deck unit. The Water Sampler frame was equipped with Niskin bottles (21x10 L) to take water samples at interesting spots. The SBE9plus underwater unit was equipped with 2 pressure sensors, 2 temperature sensors, 2 oxygen sensors and 2 conductivity sensors.

The rosette frame was equipped with additional sensors for dissolved gases, i.e. CO_2 and CH_4, and to measure nitrate concentrations in the water column. A turbidity sensor (Wet Labs) measuring suspended particulates and colloids and photosynthetically active radiation sensor (PAR) were also attached to the rosette frame.

Veering (lowering) and heaving of the CTD-rosette during station work was done with a rope speed of ~0.1 m s^{-1}. CTD data recording and triggering Niskin bottles were controlled with SEASAVE software (SBE7.22). CTD data were recorded with 24 Hz. The ship's GPS position data was logged parallel to the CTD from NMEA-string of RV MARIA S. MERIAN.

Hydro-casts and hydrographic data from towed SBE-CTD were processed by using SBE software SBE7.22.0. Usually data files of 1 second bins and 0.2-meter bins were created from raw data files and exported to ASCII. CTD data was combined with data sets from external sensors (CO2, CH4, NO3) by correlating their individual UTC time stamps.

HydroC^{TM}-CH4 sensors

The membrane inlet methane sensor (CH4P-1019-001, 4H-Jena Contros) had been mounted to the rosette frame replacing one Niskin bottle. The highly sensitive methane sensor was able to detect even smallest increases of dissolved CH_4 above an average background level of 1-2 nM (Schmidt et al., 2013). The methane sensor was powered by NiMH-rechargeable battery pack (24 V, 9 Ah, 6000 m rated), which was mounted to the rosette frame.

HydroC^{TM}-CO_2 sensors

The HydroC-CO_2 (CO_2-0412-005, 4H-Jena Contros) sensors, equipped with pumped (Seabird SBE-5T) sensor heads, were integrated into the Video-CTD device (Schmidt et al., 2015). Measured pCO_2-data is stored internally on SD card, however, the sensors reading is also monitored onboard by using one analogue 0-5 V channel of the SBE9plus. When running in CTD-mode the HydroC-CO_2 is powered by an external NiMH-power unit (>10h at ~16°C).

Submersible Ultraviolet Nitrate Analyzer SUNA V2 (2k)

The SUNA nitrate sensor (SBE) is a chemical-free sensor which can be used in in fresh, brackish and salt water (Johnson and Coletti, 2002). It measures nitrate by ultra-violet absorption spectrometry. Measurements are in units of micromoles per litre (µM). Internal data storage provides calibrated nitrate concentrations after sensor recovery. External power supply was provided by NiMH-power packs mounted to the rosette frame.

Turbidity sensor

A turbidity meter (ECO-NTU, Wet Labs) powered by and connected to the SBE9+ underwater unit was attached in the central department of the rosette frame. The sensor signal was used to detect turbidity distribution in the water column with units given in NTU.

Photosynthetically active radiation (PAR)

The PAR sensor (Chelsea) measures available light intensity at depth in upward looking mode (Photons m^{-2} s^{-1}). The sensor is mounted at the top of the rosette frame. Power supply and sensor reading/storage is provided by connection to SBE underwater unit.

Niskin bottle water sampling

Bottom water samples were taken by Niskin bottles 10 and 11 during hydro-cast CTD09 (Tab. 1). Alkalinity was determined onboard according to Grasshoff et al. (2009). Radon-222 activity concentrations of water samples were measured by liquid-scintillation-counting (LSC) analyses on a mobile and sea-going device (Purkl and Eisenhauer, 2004).

Figure 5.2.1 Deploying the CTD-device of RV M.S. Merian. Water sampler (21x10 L Niskin) rosette includes SBE9plus-CTD, O_2, turbidity (Wet Labs), methane (Contros), CO_2 (Contros), nitrate (SBE) and PAR sensors.

5.2.1.2 CTD stations

Eleven hydro-casts (CTD measurements) were performed in two different working areas located north and south-east of Helgoland, North Sea (Figure 5.2.2). Details about CTDs and water sampling locations etc. are summarized in table 5.2.1.

Table 5.2.1: CTD stations conducted during MSM99_2.

Station ID	Gear ID	Start recording /UTC date+time	Latitude °N	Longitude °E
1_1	1	26.03.2021 16:29:56	54,4331	7,42716
7_3	2	27.03.2021 13:22:41	54,5134	7,4162
11_4	3	28.03.2021 12:34:55	54,44582	7,20544
14_1	4	29.03.2021 06:22:18	54,46316	7,37666
19_1	5	29.03.2021 13:47:35	54,3675	7,3915
20_1	6	29.03.2021 14:48:48	54,33116	7,469
21_1	7	29.03.2021 15:57:48	54,2915	7,5535
23_1	8	30.03.2021 06:07:34	54,05132	8,01
29_1	9	31.03.2021 08:48:02	54,36432	7,83616
31_1	10	01.04.2021 10:15:17	54,6575	7,56132
44_1	11	02.04.2021 12:18:26	54,45032	7,608

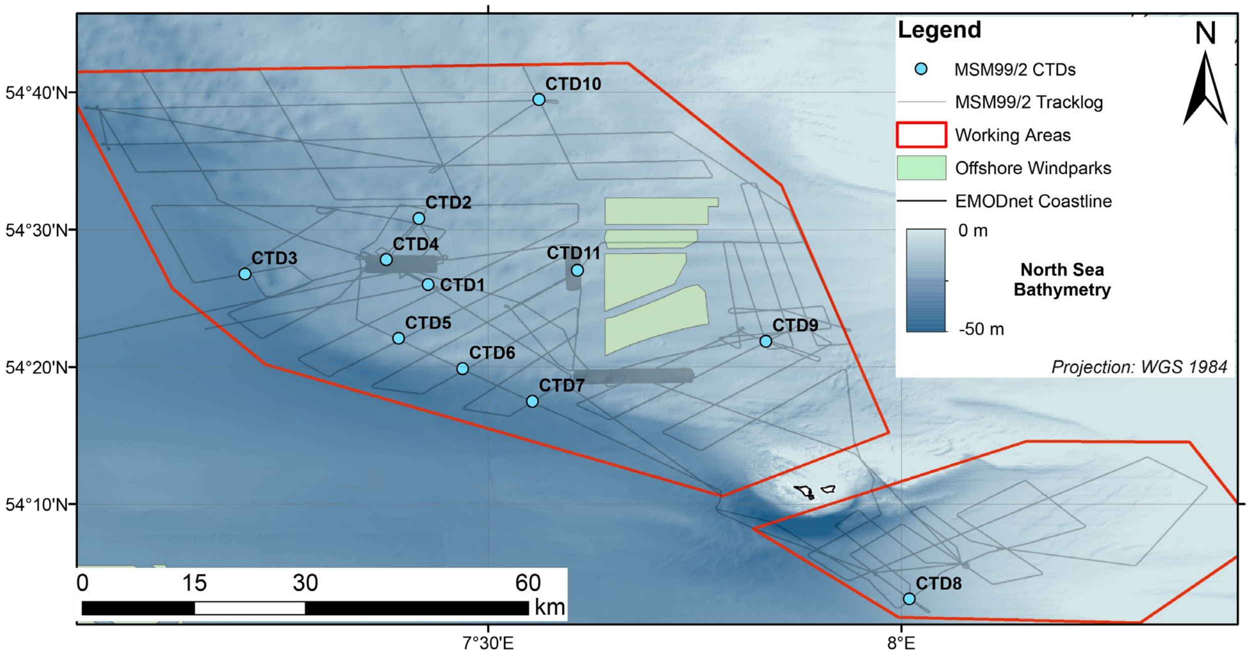

Figure 5.2.2. Locations of CTD stations in working area 1 and 2.

5.2.1.3 Recorded data sets – First results

For each CTD station the following sensor data were recorded and were provided to shipboard scientific party after station end as xlsx-files which contain the following information: Time (UTC), water depth (m), conductivity (S m^{-1}), temperature (°C), density (kg m^{-3}), sound velocity (Chen-Millero, m s^{-1}), oxygen (µmol L^{-1}), salinity, latitude (°N), longitude (°W), pressure (db), turbidity (FTU), light intensity (PAR).

Dissolved concentrations of methane (µatm), carbon dioxide (µatm), nitrate (µM) are additionally added in 1 min intervals.

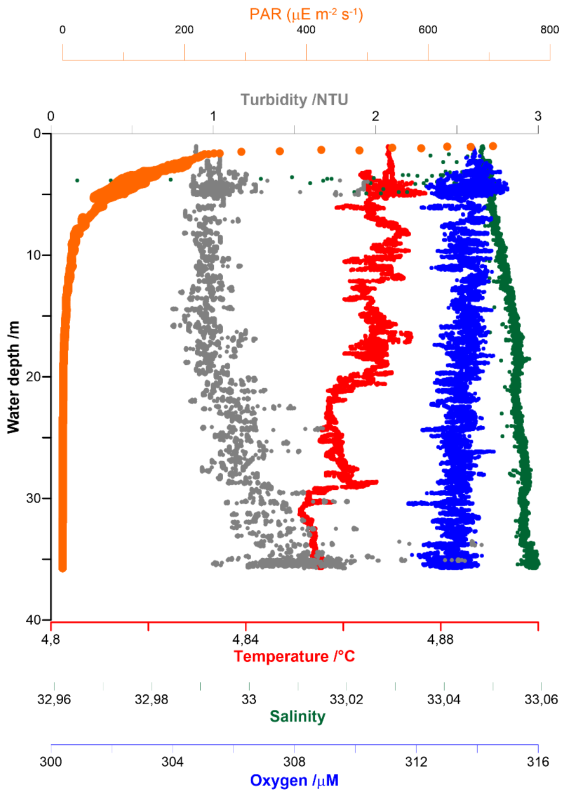

Figure 5.2.3: Dissolved gas concentrations measured by HydroC-sensors during CTD10-cast.

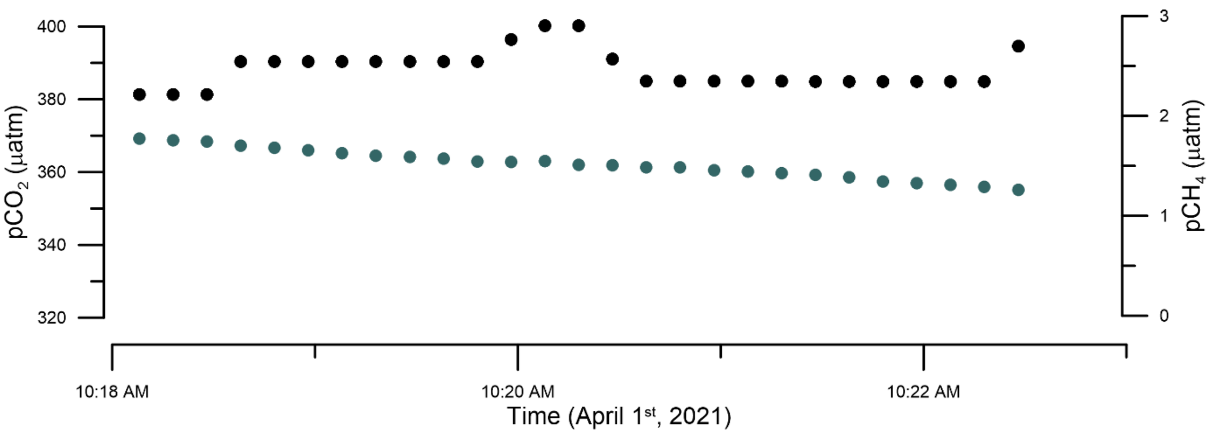

Figure 5.2.4. Water column data of areas of interest recorded during MSM99-2. A well-mixed water column from water surface to bottom is indicated (i.e. CTD07). Air temperatures of 5-6°C equal water temperatures during the cruise.

Dissolved carbon dioxide measurements indicate a well-mixed water column and pCO_2 concentrations are about 40 µatm below atmospheric CO_2 partial pressures. This is in accordance to observations for the Dutch and German North Sea from latitudes below 55.5°N and is mainly assigned to mixing and increasing biological activity in March/April (e.g. Omar et al., 2010). CH_4 is only slightly enriched compared to atmospheric concentration of ~2 µatm.

5.3 Sediment sampling and pore water geochemistry

(Timo Spiegel, Thomas Müller, Mark Schmidt)

5.3.1 Methodology

Gravity coring

A gravity corer with either 3 or 5 m stainless steel tube, inner plastic liner, and 1.25 tons head-weight was deployed for sediment sampling (Figure 5.3.1). The speed of penetration at the seafloor was adapted to the seabed substrate and ranged from 0.1 to 1 m per second. Between 45 and 420 cm of sediment were recovered during deployments. The recovered sediment cores were cut in segments of 1 m length and divided in archive and working halves aboard, which were subsequently processed at laboratory conditions (22°C).

Figure 5.3.1. Deployment of gravity corer (left), Mini Multi corer (middle) and Van-Veen Grab (right)

Mini-Multi Corer

Sediment samples were also retrieved with a Mini-Multi Corer (MIC) equipped with 4 liners (Figure 5.3.1). This sampling device is similar to a multicorer as undisturbed surface sediments and the overlying bottom water are retrieved, but with fewer liners and a smaller head weight. Between 10 and 24 cm of surface sediments were recovered during each deployment. Upon recovery on deck one liner for sediment sampling and another liner for pore water recovery and another liner for hydrocarbon sampling were selected and processed at laboratory conditions (22°C). The bottom water overlying the sediment in the MIC liners was siphoned with a plastic tube.

Grab sampler

At locations were coring with the GC and MIC were not successful due to quite stiff sediments, the grab sampler was used to collect undisturbed surface sediments (Figure 5.3.1). The grab sampler consists of a stainless-steel box that sinks into the sediment recovering a sediment volume of approximately 50 cm x 50 cm x 60 cm. Sediment sampling was performed on deck directly after recovery.

Sediment coring stations

Sediment coring stations off Helgoland are all located within the northwestern or southeastern working areas with water depth between 20 and 50 meters. In total, 28 attempts were made with the gravity corer (Figure 5.3.2). Of these 28 attempts, 7 were successful in terms of sediment recovery, reflecting the difficulty in sampling in the northwestern working area, which consists of mainly sandy sediments. In the case of the Mini-MIC, 26 out of 35 attempts successfully contained sediments (Figure 5.3.3). The grab sampler was used 10 times, containing sediment samples each time (Figure 5.3.4). Selection criteria for sediment sampling locations were based on preliminary investigations or were adapted to the current state of knowledge during the expedition. These are, for example, the results from hydroacoustic and seismic data indicating subsurface sediment structure and composition and thus possible pockmark locations.

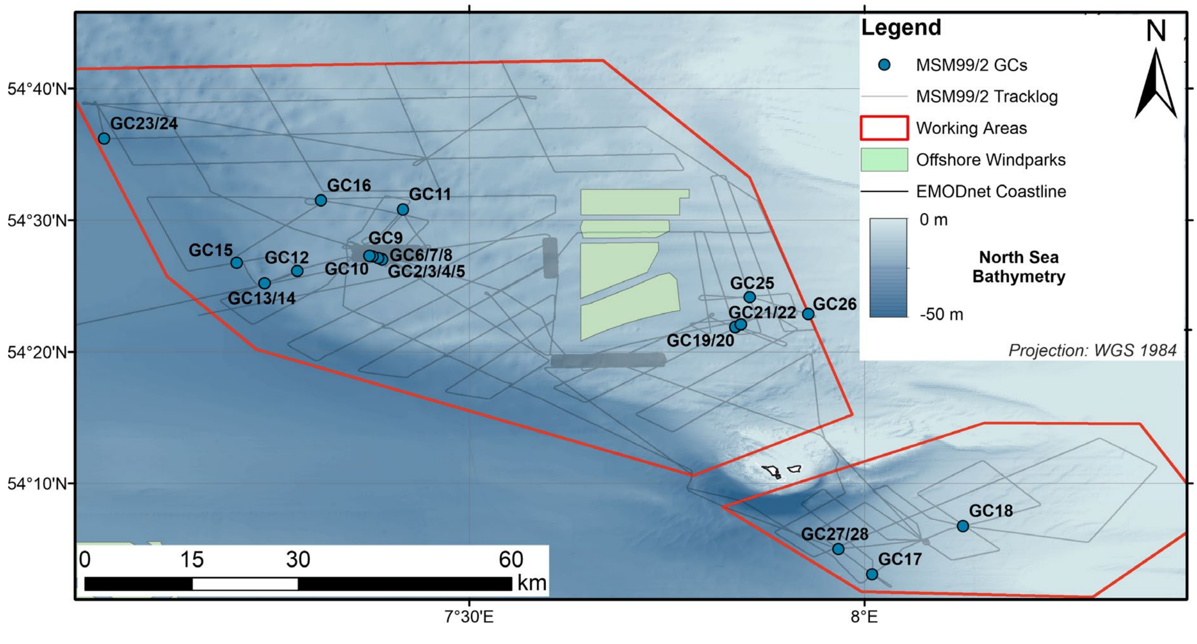

Figure 5.3.2 Sediment coring stations with gravity core

Sediment sampling

Sediment sampling was done in approximately 2 cm intervals for MIC sampling and 10 cm intervals for gravity core sampling. Surface sediment samples from the grab sampler were taken at approximately 1 cm and 5 cm depth. A defined volume of sediment was sampled into pre-weighed plastic cups for the determination of water content and porosity and TCNS analyses in home-based laboratories. About 15 g of wet sediment were collected in whirlpack plastic bags for laboratory analyses, e.g. ICP-MS, ICP-OES, XRF scanning, isotopic composition and grain size determination Three milliliters of sediment were added to 20 ml headspace vials filled with 1.5 g NaCl and 9 ml of saturated NaCl solution, then crimped with silicone rubber stoppers and aluminum caps and stored after mixing for gas chromatographic measurements at GEOMAR (Sommer et al., 2009). At selected stations, additional sediment samples were collected in whirlpack plastic bags to analyze organic carbon-iron compounds in collaboration with Uni Leeds. All sediment samples and working and archive liners were stored at 4°C until transfer to GEOMAR.

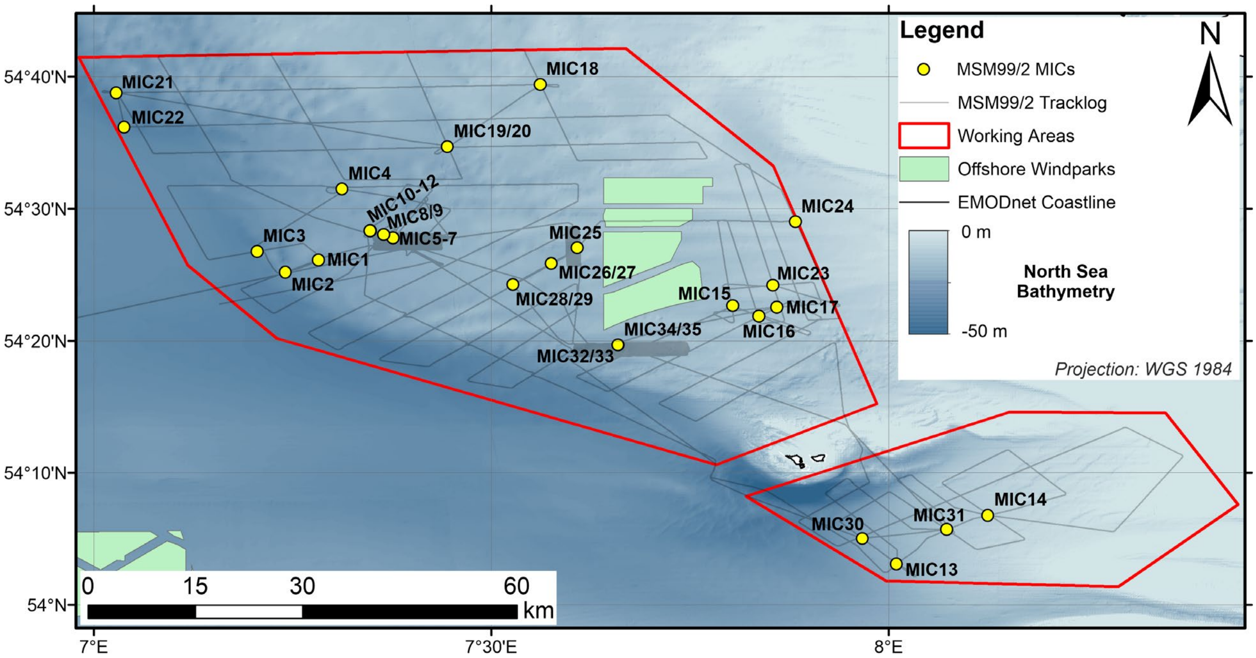

Figure 5.3.3 Sediment coring stations with Mini-MUC

Pore water sampling

Pore water samples were taken by Rhizon-extraction according to the method of (Seeberg-Elverfeldt et al., 2005) at the same intervals as sediment samples. Aliquots of the extracted pore water were sub-sampled for onboard total alkalinity measurement and further home-based laboratory analyses. Subsamples for ICP-OES analysis were acidified with 10 µl of conc. suprapure HNO3 per 1 ml of pore water sample (i.e., pH < 1) to inhibit further microbial degradation. All samples for home-based analyses were stored refrigerated and gas-tight. Chemical titrations for alkalinity of pore water aliquots (1 ml) were immediately determined aboard according to Grasshoff et al. (2009).

Total alkalinity titration

Samples for total alkalinity (TA) were analyzed by titration of 1 ml pore water according to Grasshoff et al. (2009). Titration was ended when a stable pink color appeared. During titration, the sample was degassed by continuously bubbling nitrogen to remove any generated CO2 and H2S. The results were calibrated relative to IAPSO seawater solution.

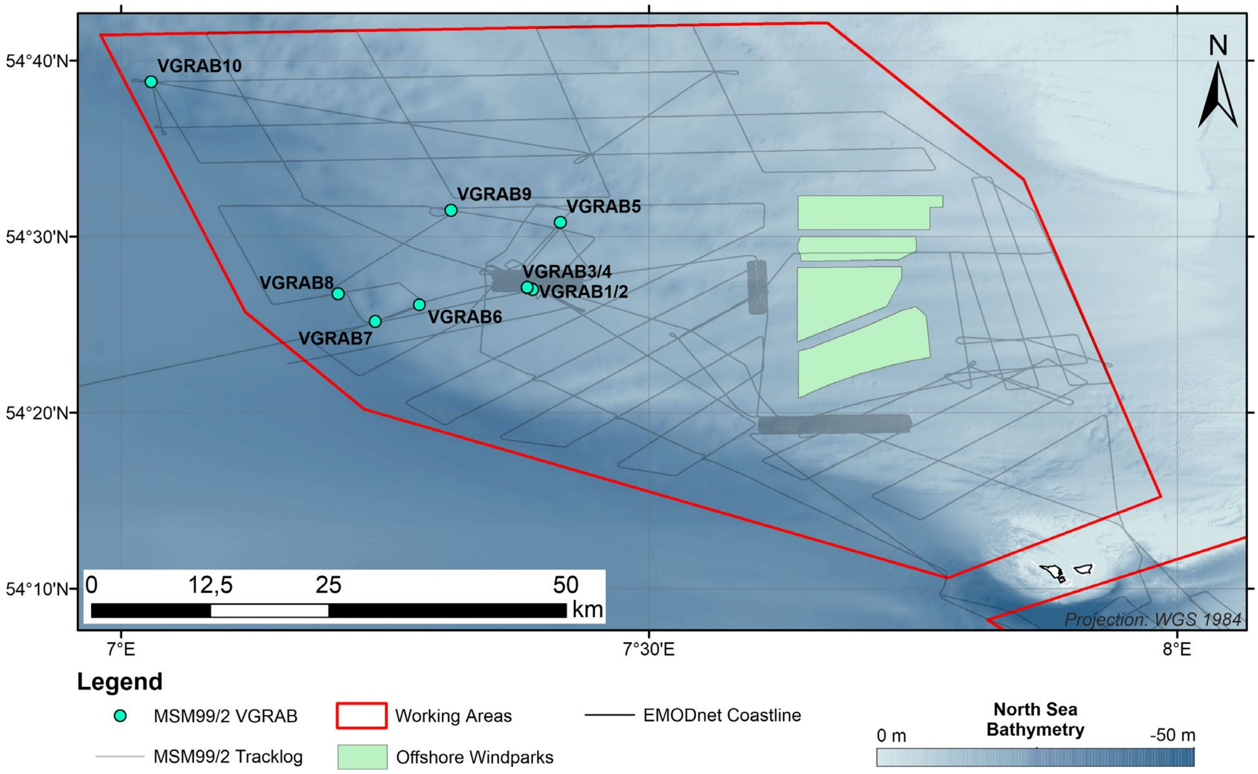

Figure 5.3.4. Sediment coring stations with Van Veen Grab

5.3.2 Preliminary Results

Total alkalinity concentrations range between 0.5 and 65 mmol/l and are characterized by either relatively stable or increasing concentrations with sediment depth (Figure5.3.5). A spatial distribution pattern can be observed between sediment cores from the northern (MIC18, GC22) and southern (MIC30, GC17) working areas. Total alkalinity in the northern part show gently increasing or even stable concentration profiles with maximum concentrations up to 9 mmol/l. The observed concentration range and the absence of H2S smell in these sediment cores indicate that the horizon of sulfate reduction is not reached at depth up to one meter, however, further pore water and solid phase measurements are needed to constrain these preliminary thoughts. Stations in the mud area south of Helgoland are characterized by comparably steep increasing total alkalinity gradients up to a maximum 65 mmol/l (Figure 5.3.5). The working area south of Helgoland is dominated by silt and clay sediments in addition to high sedimentation rates compared to the northwestern working area. Fine-grained sediments are generally enriched in organic matter probably leading to increased organic matter degradation, which is reflected by higher total alkalinities in the pore water. Additionally, a H2S smell was present in these samples indicating sulfate reduction in these sediments.

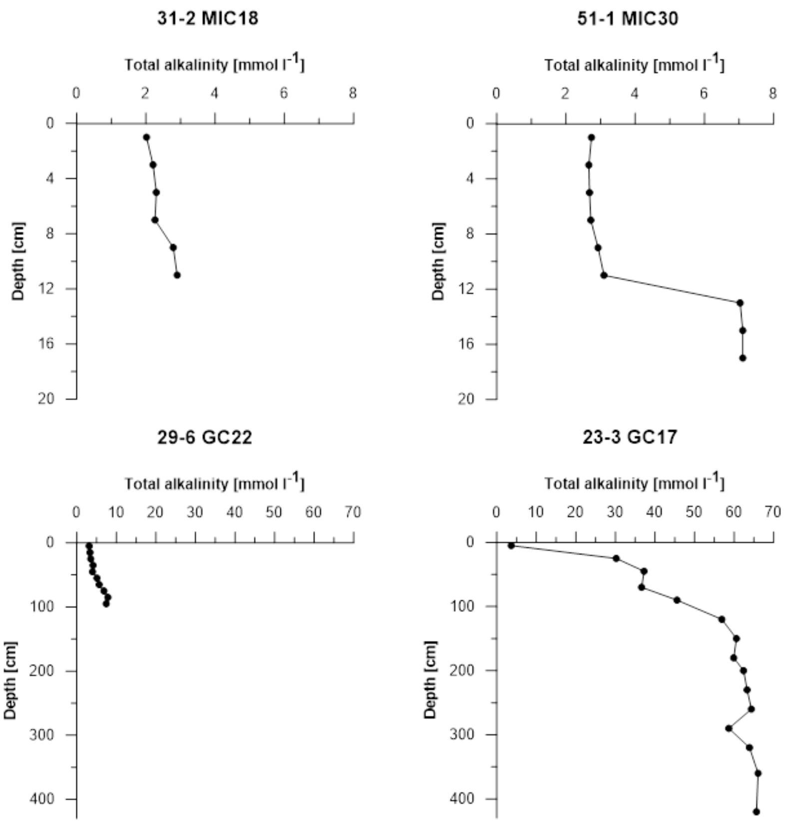

Figure 5.3.5. Total alkalinity concentration plotted against sediment depth for stations 31-2 MIC18 and 29-6 GC22 (WA1) and 51-1 MIC30 and 23-3 GC17 (WA2).

5.4 Sedimentology

(Tim Willems, Anna Wünsche)

5.4.1 Methods

For ground truthing of the seafloor surface grab samples were collected with a Van-Veen Grab Sampler. Alternatively, a MIC was used to describe and sample the undisturbed seafloor surface, and the upper 10- 20 cm of the underlying material.

The GC was deployed to study deeper sedimentary layers. After the recovery of a core, it was divided into sections of a meter each and split lengthwise into a working half and an archive half. Sediment samples were taken from the working half, only. The visual description was performed in each case immediately after the recovery of the core. All cores were described visually and one log for each gravity core was produced.

Additionally, the Munsell color description was registered for each sediment probe and part of the cores. Benthic organisms were documented as well. Van-Veen Grab samples, MIC samples and sediment cores were photographed before further examination. Photographs of the cores are found in the appendix.

Sampling for grain size analyses was performed following the description and first facies analysis. Each facies was sampled at least once. Sieve samples were taken (80- 120 g) as well as samples for examination with the Backmann Coultier Laser (1 – 2 g). Samples with median grain sizes higher than fine sand will be sieved. Samples with grain sizes smaller than fine sand will be lasered. In total 47 sieve samples-, and 155 laser samples were taken.

5.4.2 Results

The study area can be clearly divided into two distinct sedimentation areas. On the one hand, the WA1, which is mainly characterized by thick sand layers with isolated silty layers and surface vegetation by Lanice Conchilega. On the other hand, the WA2, which is dominated by thick, cohesive and organic-rich sediments with few, thin fine sand layers.

WA1

The seafloor surface and the upper 20 cm of the subsurface is composed of massive brown and grey fine and medium sand. It shows little change over the entire northern area. Fine-, and medium sand Shells and shell fragments are rare (approximately 1% surface coverage). Most grab samples contain the polychaete *Lanice conchilega,* often covered by 2 – 4 cm of sand. *Lanice conchilegais* a tube building worm using sand grains and shell fragments as construction element. Due to its habitat structuring effect it is referred as bioengineer (Jones et al., 1994). Normally, those worms use middle to fine sand for their tubes (Van Hoey et al., 2008). Most of the probes also contain individuals of Echinocardium flavescens in around 5 – 10 cm depth and serpent stars (*Ophiura ophiura*) on the surface. The redox horizon is weak and varies between 3 and 10 cm in depth.

Gravity core penetration depth was very limited because of the compact, massive sand. Therefore, seismic data was searched for suitable locations, resulting in a particularly successful 140 cm borehole. Figure 3 shows the photo of the sediment core and the log of the lowest meter of the core as an example. This sediment sequence represents the backfill of a shallow depression, with grey fine sand-silt alternation and coarse sand to gravel with shell fragments at the base. The remaining core sections can be found in the form of photographs in

Figure 5.4.1. Left: seafloor surface of grab sample 5-4 G4 that contains brown, massive fine sand Lanice conchilega tube worm and single bivale shells of Laevicardium crass, Scrobicularia plana and Donax vittatus (in the upper right of the picture); Right: Profile of grab sample 10-1 G7 with Lanice conchilega and a Astropecten jonstoni. Weak redox horizon in the lower part**.**

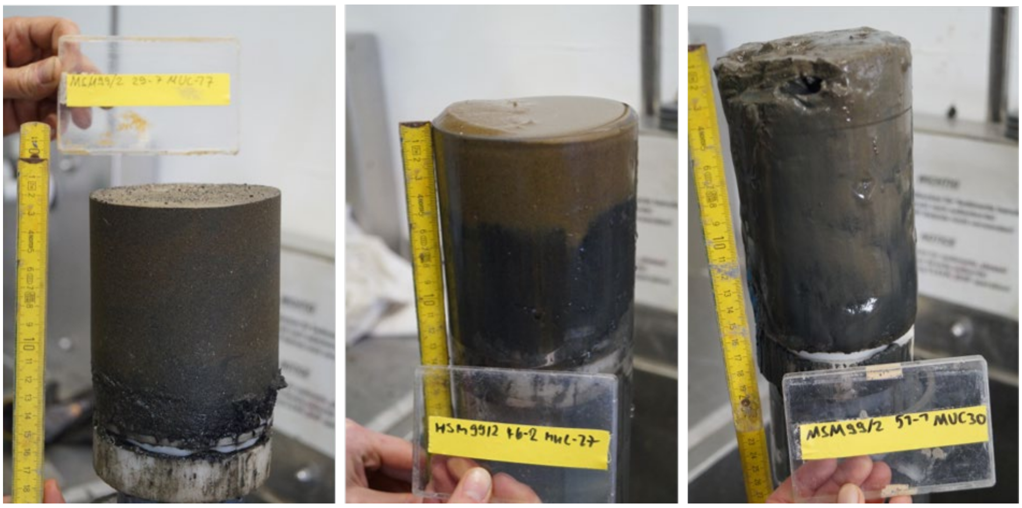

Figure 5.4.2. St. 29-7 MIC 17, St. 46-2 MIC-27 and St. 51-1 MIC-30 with varying depths of the redox horizon and increasing silt fraction from left to right.

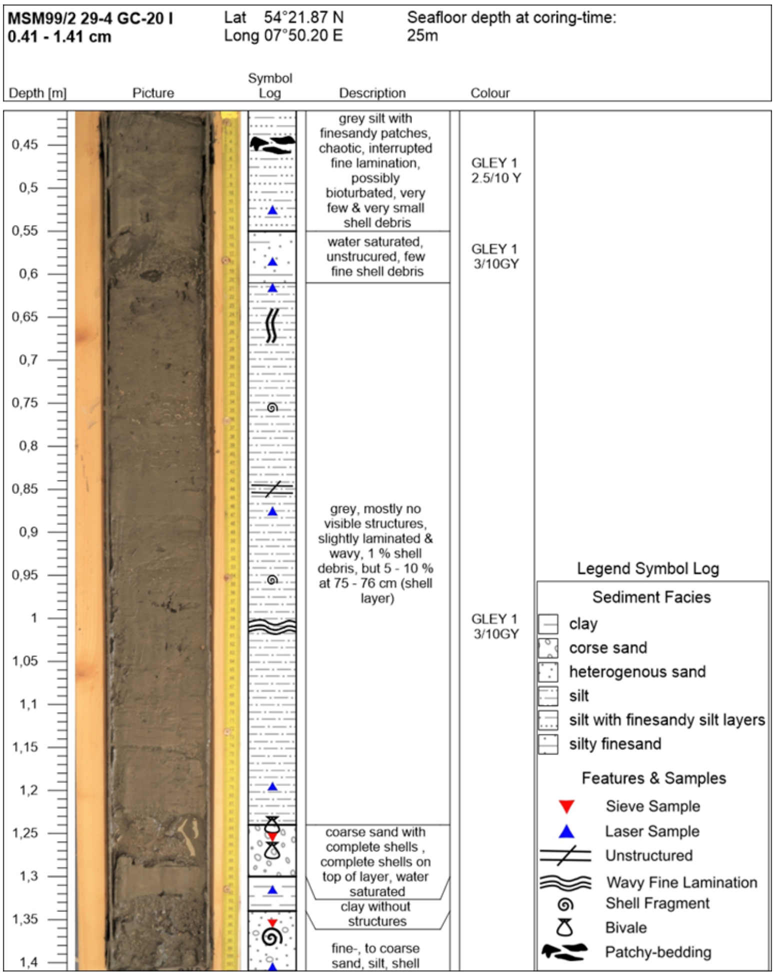

Figure 5.4.3. Deepest core section of the core MSM99/2 29-4 GC-20 at 40 - 140 m, containing grey, slightly laminated silts and two distinct mixed coarser layers with shells and shell fragments

WA2

The seafloor surface of the southern area differs from the northern part by significantly higher shell-, and shell fragment cover, darker color (dark grey) and finer, cohesive sediment. *Lanice conchilega* tubes are rare, but live *Ensis Ensis* are found. H_2S smell is very present and the upper decimeters are strongly bioturbated.

Gravity coring penetration depth was high because of soft sediment. Deeper areas are often poorly textured but show faint horizontal layers of lighter, brownish gray sediments with fine sand content. Rarely, thin layers of shingle are found. No clear sedimentary layers can be discerned and there is little vertical alteration. Figure 5 shows the example of the deepest section drilled.

Thus, the sediments in the northern study area consist of shallow-marine, fine- to medium-grained, shelly sands, and in places silty or clayey sediments. This is a typical composition in the southern North Sea (Streif, 2004; Zeiler et al., 2000). In the southern study area, finer, cohesive sediments with a higher proportion of mussels are primarily found at the surface. This corresponds to the typical sediments in the Helgoland Mud Area (Hebbeln et al., 2003). No clear differences in sediment composition between pockmarks and the surrounding seafloor were noted. However, any characteristics can be investigated in more detail using the grain size analyses, which could then contribute to resolve open questions about the origin of these structures.

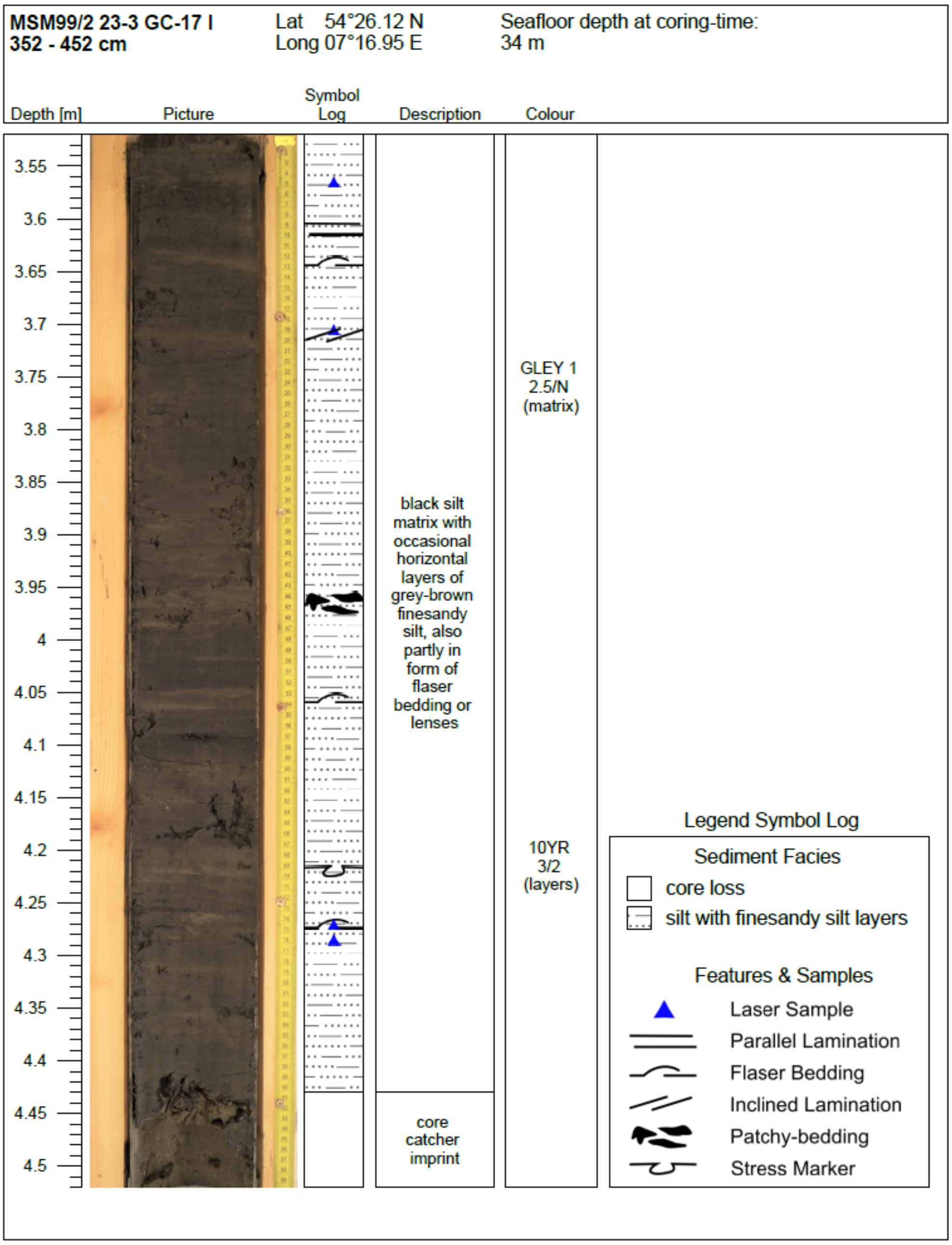

Figure 5.4.4. Deepest core section of the core MSM99/2 23-3 GC-17 at 352 - 452 m, containing dark grey silts and interbedded brown fine sandy silt layers

6 Data and Sample Storage and Availability

On board data and Meta-data of measurements and samples collected during cruise MSM99/2 will be made available through the web-based database PANGAEA. All data will be made available after 1 year past the cruise. Free access to all data will be made available 3 years after cruise. The hydroacoustic (multibeam bathymetry, parasound) data of the working area will be placed at CAU. The sediment samples are hosted at GEOMAR. A brief overview of types of data/samples, responsible scientists are given below and in Table 6.1.

Table 6.1 Overview of data availability

Type	Database	Available	Free access	Contact
Hydroacoustics	PANGAEA	April 2022	April 2024	christoph.boettner@ifg.uni-kiel.de
CTD	PANGAEA	April 2022	April 2024	mschmidt@geomar.de
Pore water data	PANGAEA	April 2022	April 2024	cschmidt@geomar.de
Sediment composition	PANGAEA	April 2022	April 2024	tim.willems@ifg.uni-kiel.de

7 Station List MSM99/2 (GPF 21-1_013)

Station No.	Date	Gear	Time	Latitude	Longitude	Water Depth	Remarks/Recovery
MERIAN	2021		[UTC]	[°N]	[°W]	[m]	
MSM99/2_1-1	26.03.2021	CTD	16:27	54° 25,990' N	007° 25,644' E	28,3	in the water
MSM99/2_1-1	26.03.2021	CTD	16:41	54° 25,986' N	007° 25,627' E	28,4	max depth/on ground
MSM99/2_1-1	26.03.2021	CTD	16:46	54° 25,989' N	007° 25,624' E	28	on deck
MSM99/2_2-1	26.03.2021	EM712 + PS	17:15	54° 25,978' N	007° 25,652' E	28,3	profile start
MSM99/2_2-1	26.03.2021	EM712 + PS	18:47	54° 25,986' N	007° 25,747' E	29,4	profile end
MSM99/2_3-1	26.03.2021	EM712 + PS	18:59	54° 26,031' N	007° 25,777' E	29,3	profile start
MSM99/2_3-1	27.03.2021	EM712 + PS	6:21	54° 26,554' N	007° 23,727' E	30	profile end
MSM99/2_4-1	27.03.2021	GC	7:08	54° 27,027' N	007° 23,337' E	30,3	in the water
MSM99/2_4-1	27.03.2021	GC	7:10	54° 27,027' N	007° 23,337' E	30,3	max depth/on ground
MSM99/2_4-1	27.03.2021	GC	7:14	54° 27,027' N	007° 23,338' E	30,5	on deck
MSM99/2_4-2	27.03.2021	GC	7:18	54° 27,027' N	007° 23,337' E	29,8	in the water
MSM99/2_4-2	27.03.2021	GC	7:19	54° 27,027' N	007° 23,336' E	30,2	max depth/on ground
MSM99/2_4-2	27.03.2021	GC	7:24	54° 27,027' N	007° 23,336' E	30,3	on deck
MSM99/2_4-3	27.03.2021	GC	7:32	54° 27,032' N	007° 23,320' E	30,2	in the water
MSM99/2_4-3	27.03.2021	GC	7:33	54° 27,032' N	007° 23,320' E	30,1	max depth/on ground
MSM99/2_4-3	27.03.2021	GC	7:38	54° 27,032' N	007° 23,320' E	30,6	on deck
MSM99/2_4-4	27.03.2021	VGRAB	7:46	54° 27,027' N	007° 23,336' E	30,1	in the water
MSM99/2_4-4	27.03.2021	VGRAB	7:47	54° 27,027' N	007° 23,336' E	30,3	max depth/on ground
MSM99/2_4-4	27.03.2021	VGRAB	7:49	54° 27,027' N	007° 23,336' E	30	on deck
MSM99/2_4-5	27.03.2021	GC	8:09	54° 27,027' N	007° 23,338' E	30,3	in the water
MSM99/2_4-5	27.03.2021	GC	8:10	54° 27,027' N	007° 23,338' E	30,4	max depth/on ground
MSM99/2_4-5	27.03.2021	GC	8:13	54° 27,026' N	007° 23,338' E	30,7	on deck
MSM99/2_4-6	27.03.2021	GC	8:28	54° 26,994' N	007° 23,397' E	30,5	in the water
MSM99/2_4-6	27.03.2021	GC	8:29	54° 26,995' N	007° 23,397' E	30,6	max depth/on ground

MSM99/2_4-6	27.03.2021	GC	8:32	54° 26,994' N	007° 23,398' E	30,6	on deck
MSM99/2_4-7	27.03.2021	VGRAB	8:43	54° 26,994' N	007° 23,399' E	30,8	in the water
MSM99/2_4-7	27.03.2021	VGRAB	8:44	54° 26,993' N	007° 23,399' E	31	max depth/on ground
MSM99/2_4-7	27.03.2021	VGRAB	8:46	54° 26,995' N	007° 23,399' E	30,7	on deck
MSM99/2_5-1	27.03.2021	GC	9:13	54° 27,092' N	007° 23,094' E	31,3	in the water
MSM99/2_5-1	27.03.2021	GC	9:14	54° 27,092' N	007° 23,094' E	30,9	max depth/on ground
MSM99/2_5-1	27.03.2021	GC	9:17	54° 27,092' N	007° 23,094' E	31,1	on deck
MSM99/2_5-2	27.03.2021	GC	9:21	54° 27,092' N	007° 23,094' E	31,1	in the water
MSM99/2_5-2	27.03.2021	GC	9:23	54° 27,092' N	007° 23,095' E	31,2	max depth/on ground
MSM99/2_5-2	27.03.2021	GC	9:25	54° 27,092' N	007° 23,095' E	31	on deck
MSM99/2_5-3	27.03.2021	VGRAB	9:28	54° 27,092' N	007° 23,094' E	31	in the water
MSM99/2_5-3	27.03.2021	VGRAB	9:30	54° 27,092' N	007° 23,095' E	30,9	max depth/on ground
MSM99/2_5-3	27.03.2021	VGRAB	9:32	54° 27,092' N	007° 23,095' E	30,8	on deck
MSM99/2_5-4	27.03.2021	VGRAB	9:47	54° 27,103' N	007° 23,100' E	31,1	in the water
MSM99/2_5-4	27.03.2021	VGRAB	9:49	54° 27,103' N	007° 23,100' E	31,2	max depth/on ground
MSM99/2_5-4	27.03.2021	VGRAB	9:51	54° 27,103' N	007° 23,100' E	30,9	on deck
MSM99/2_5-5	27.03.2021	GC	10:01	54° 27,092' N	007° 23,093' E	31	in the water
MSM99/2_5-5	27.03.2021	GC	10:05	54° 27,092' N	007° 23,093' E	30,8	max depth/on ground
MSM99/2_5-5	27.03.2021	GC	10:08	54° 27,092' N	007° 23,092' E	31,2	on deck
MSM99/2_6-1	27.03.2021	GC	10:57	54° 27,228' N	007° 22,656' E	31,4	in the water
MSM99/2_6-1	27.03.2021	GC	11:00	54° 27,229' N	007° 22,658' E	30,6	max depth/on ground
MSM99/2_6-1	27.03.2021	GC	11:02	54° 27,228' N	007° 22,656' E	31,2	information
MSM99/2_6-1	27.03.2021	GC	11:03	54° 27,227' N	007° 22,656' E	30,8	max depth/on ground
MSM99/2_6-1	27.03.2021	GC	11:04	54° 27,228' N	007° 22,656' E	30,8	information
MSM99/2_6-1	27.03.2021	GC	11:05	54° 27,228' N	007° 22,656' E	31,2	max depth/on ground
MSM99/2_6-1	27.03.2021	GC	11:08	54° 27,228' N	007° 22,656' E	30,9	on deck
MSM99/2_6-2	27.03.2021	GC	11:28	54° 27,292' N	007° 22,423' E	31,5	in the water
MSM99/2_6-2	27.03.2021	GC	11:32	54° 27,292' N	007° 22,423' E	30,9	max depth/on ground

MSM99/2_6-2	27.03.2021	GC	11:37	54° 27,292' N	007° 22,423' E	30,9	on deck
MSM99/2_7-1	27.03.2021	GC	12:36	54° 30,806' N	007° 24,970' E	30,7	in the water
MSM99/2_7-1	27.03.2021	GC	12:39	54° 30,804' N	007° 24,970' E	30,6	max depth/on ground
MSM99/2_7-1	27.03.2021	GC	12:52	54° 30,806' N	007° 24,971' E	30,7	on deck
MSM99/2_7-2	27.03.2021	VGRAB	12:56	54° 30,806' N	007° 24,972' E	29,6	in the water
MSM99/2_7-2	27.03.2021	VGRAB	12:58	54° 30,806' N	007° 24,970' E	30,1	max depth/on ground
MSM99/2_7-2	27.03.2021	VGRAB	12:59	54° 30,807' N	007° 24,973' E	29,8	on deck
MSM99/2_7-3	27.03.2021	CTD	13:21	54° 30,805' N	007° 24,971' E	29,4	in the water
MSM99/2_7-3	27.03.2021	CTD	13:27	54° 30,805' N	007° 24,971' E	30,1	max depth/on ground
MSM99/2_7-3	27.03.2021	CTD	13:32	54° 30,805' N	007° 24,972' E	30,1	on deck
MSM99/2_8-1	27.03.2021	EM712 + PS	14:25	54° 27,792' N	007° 26,163' E	28	profile start
MSM99/2_8-1	28.03.2021	EM712 + PS	6:26	54° 27,191' N	007° 21,080' E	29,6	profile end
MSM99/2_9-1	28.03.2021	VGRAB	6:58	54° 26,120' N	007° 16,952' E	34,3	in the water
MSM99/2_9-1	28.03.2021	VGRAB	6:59	54° 26,121' N	007° 16,952' E	34,4	max depth/on ground
MSM99/2_9-1	28.03.2021	VGRAB	7:01	54° 26,121' N	007° 16,951' E	34,1	on deck
MSM99/2_9-2	28.03.2021	GC	7:19	54° 26,121' N	007° 16,951' E	34,6	in the water
MSM99/2_9-2	28.03.2021	GC	7:20	54° 26,121' N	007° 16,951' E	33,8	max depth/on ground
MSM99/2_9-2	28.03.2021	GC	7:32	54° 26,120' N	007° 16,952' E	34,8	on deck
MSM99/2_9-3	28.03.2021	MIC	7:46	54° 26,121' N	007° 16,952' E	34,8	in the water
MSM99/2_9-3	28.03.2021	MIC	7:48	54° 26,121' N	007° 16,953' E	34,1	max depth/on ground
MSM99/2_9-3	28.03.2021	MIC	7:53	54° 26,121' N	007° 16,951' E	34,1	on deck
MSM99/2_10-1	28.03.2021	VGRAB	9:09	54° 25,182' N	007° 14,466' E	38	in the water
MSM99/2_10-1	28.03.2021	VGRAB	9:11	54° 25,182' N	007° 14,468' E	37,5	max depth/on ground
MSM99/2_10-1	28.03.2021	VGRAB	9:13	54° 25,183' N	007° 14,467' E	37,2	on deck
MSM99/2_10-2	28.03.2021	GC	9:26	54° 25,182' N	007° 14,465' E	37,6	in the water
MSM99/2_10-2	28.03.2021	GC	9:27	54° 25,182' N	007° 14,465' E	37,7	max depth/on ground
MSM99/2_10-2	28.03.2021	GC	9:30	54° 25,182' N	007° 14,465' E	36,5	on deck
MSM99/2_10-3	28.03.2021	GC	9:59	54° 25,182' N	007° 14,467' E	37,6	in the water

MSM99/2_10-3	28.03.2021	GC	10:03	54° 25,182' N	007° 14,467' E	37,7	max depth/on ground
MSM99/2_10-3	28.03.2021	GC	10:05	54° 25,182' N	007° 14,469' E	37	information
MSM99/2_10-3	28.03.2021	GC	10:06	54° 25,182' N	007° 14,468' E	37,5	max depth/on ground
MSM99/2_10-3	28.03.2021	GC	10:10	54° 25,182' N	007° 14,466' E	37,1	on deck
MSM99/2_10-4	28.03.2021	MIC	10:20	54° 25,182' N	007° 14,468' E	37,1	in the water
MSM99/2_10-4	28.03.2021	MIC	10:22	54° 25,182' N	007° 14,468' E	38,1	max depth/on ground
MSM99/2_10-4	28.03.2021	MIC	10:26	54° 25,181' N	007° 14,465' E	37,2	on deck
MSM99/2_11-1	28.03.2021	VGRAB	11:02	54° 26,751' N	007° 12,333' E	40,3	in the water
MSM99/2_11-1	28.03.2021	VGRAB	11:04	54° 26,750' N	007° 12,327' E	39,3	max depth/on ground
MSM99/2_11-1	28.03.2021	VGRAB	11:06	54° 26,750' N	007° 12,336' E	39	on deck
MSM99/2_11-2	28.03.2021	MIC	11:21	54° 26,750' N	007° 12,328' E	41,2	in the water
MSM99/2_11-2	28.03.2021	MIC	11:23	54° 26,750' N	007° 12,328' E	40,8	max depth/on ground
MSM99/2_11-2	28.03.2021	MIC	11:27	54° 26,750' N	007° 12,329' E	40,3	on deck
MSM99/2_11-3	28.03.2021	GC	12:03	54° 26,751' N	007° 12,333' E	39,4	in the water
MSM99/2_11-3	28.03.2021	GC	12:04	54° 26,750' N	007° 12,328' E	39,6	max depth/on ground
MSM99/2_11-3	28.03.2021	GC	12:05	54° 26,750' N	007° 12,328' E	40,2	information
MSM99/2_11-3	28.03.2021	GC	12:10	54° 26,750' N	007° 12,329' E	40,3	max depth/on ground
MSM99/2_11-3	28.03.2021	GC	12:13	54° 26,750' N	007° 12,331' E	39,3	on deck
MSM99/2_11-4	28.03.2021	CTD	12:33	54° 26,750' N	007° 12,327' E	38,7	in the water
MSM99/2_11-4	28.03.2021	CTD	12:40	54° 26,750' N	007° 12,328' E	40,8	max depth/on ground
MSM99/2_11-4	28.03.2021	CTD	12:47	54° 26,750' N	007° 12,330' E	40,8	on deck
MSM99/2_12-1	28.03.2021	VGRAB	13:37	54° 31,488' N	007° 18,748' E	46,6	in the water
MSM99/2_12-1	28.03.2021	VGRAB	13:38	54° 31,489' N	007° 18,750' E	33	max depth/on ground
MSM99/2_12-1	28.03.2021	VGRAB	13:40	54° 31,488' N	007° 18,751' E	51,5	on deck
MSM99/2_12-2	28.03.2021	GC	13:57	54° 31,488' N	007° 18,749' E	33,1	in the water
MSM99/2_12-2	28.03.2021	GC	13:58	54° 31,488' N	007° 18,748' E	35	max depth/on ground
MSM99/2_12-2	28.03.2021	GC	13:59	54° 31,488' N	007° 18,750' E	31,4	information
MSM99/2_12-2	28.03.2021	GC	14:02	54° 31,487' N	007° 18,748' E	32,6	max depth/on ground

MSM99/2_12-2	28.03.2021	GC	14:05	54° 31,489' N	007° 18,749' E	32,4	on deck
MSM99/2_12-3	28.03.2021	MIC	14:14	54° 31,488' N	007° 18,749' E	32,3	in the water
MSM99/2_12-3	28.03.2021	MIC	14:15	54° 31,488' N	007° 18,751' E	40,5	max depth/on ground
MSM99/2_12-3	28.03.2021	MIC	14:19	54° 31,489' N	007° 18,747' E	32,6	on deck
MSM99/2_13-1	28.03.2021	EM712 + PS	14:38	54° 31,629' N	007° 18,348' E	32,4	profile start
MSM99/2_13-1	29.03.2021	EM712 + PS	4:54	54° 28,158' N	007° 22,090' E	28,8	profile end
MSM99/2_14-1	29.03.2021	CTD	6:22	54° 27,792' N	007° 22,601' E	29,2	in the water
MSM99/2_14-1	29.03.2021	CTD	6:28	54° 27,791' N	007° 22,601' E	30,3	max depth/on ground
MSM99/2_14-1	29.03.2021	CTD	6:34	54° 27,792' N	007° 22,599' E	29,2	on deck
MSM99/2_14-2	29.03.2021	MIC	6:49	54° 27,791' N	007° 22,598' E	29,5	in the water
MSM99/2_14-2	29.03.2021	MIC	6:51	54° 27,792' N	007° 22,598' E	29,2	max depth/on ground
MSM99/2_14-2	29.03.2021	MIC	6:55	54° 27,793' N	007° 22,599' E	28,8	on deck
MSM99/2_14-3	29.03.2021	MIC	7:28	54° 27,792' N	007° 22,597' E	28,7	in the water
MSM99/2_14-3	29.03.2021	MIC	7:30	54° 27,792' N	007° 22,598' E	29,4	max depth/on ground
MSM99/2_14-3	29.03.2021	MIC	7:34	54° 27,792' N	007° 22,597' E	71,5	on deck
MSM99/2_15-1	29.03.2021	MIC	8:04	54° 27,799' N	007° 22,581' E	30,4	in the water
MSM99/2_15-1	29.03.2021	MIC	8:05	54° 27,799' N	007° 22,581' E	29,4	max depth/on ground
MSM99/2_15-1	29.03.2021	MIC	8:09	54° 27,799' N	007° 22,583' E	28,9	on deck
MSM99/2_16-1	29.03.2021	MIC	8:50	54° 28,039' N	007° 21,887' E	29,4	in the water
MSM99/2_16-1	29.03.2021	MIC	8:52	54° 28,039' N	007° 21,887' E	28,9	max depth/on ground
MSM99/2_16-1	29.03.2021	MIC	8:55	54° 28,039' N	007° 21,888' E	30	on deck
MSM99/2_16-2	29.03.2021	MIC	10:05	54° 28,040' N	007° 21,888' E	30,1	in the water
MSM99/2_16-2	29.03.2021	MIC	10:06	54° 28,039' N	007° 21,887' E	30,2	max depth/on ground
MSM99/2_16-2	29.03.2021	MIC	10:10	54° 28,040' N	007° 21,886' E	30,2	on deck
MSM99/2_17-1	29.03.2021	MIC	10:32	54° 28,319' N	007° 20,877' E	32,6	in the water
MSM99/2_17-1	29.03.2021	MIC	10:34	54° 28,319' N	007° 20,877' E	33,3	max depth/on ground
MSM99/2_17-1	29.03.2021	MIC	10:38	54° 28,320' N	007° 20,881' E	33,2	on deck
MSM99/2_18-1	29.03.2021	MIC	11:25	54° 28,332' N	007° 20,861' E	30,8	in the water

MSM99/2_18-1	29.03.2021	MIC	11:26	54° 28,331' N	007° 20,859' E	32,8	max depth/on ground
MSM99/2_18-1	29.03.2021	MIC	11:31	54° 28,330' N	007° 20,860' E	33,3	on deck
MSM99/2_18-2	29.03.2021	MIC	12:02	54° 28,330' N	007° 20,860' E	32,7	in the water
MSM99/2_18-2	29.03.2021	MIC	12:04	54° 28,330' N	007° 20,860' E	33,4	max depth/on ground
MSM99/2_18-2	29.03.2021	MIC	12:08	54° 28,330' N	007° 20,858' E	32,7	on deck
MSM99/2_19-1	29.03.2021	EM712 + PS	13:18	54° 23,369' N	007° 20,599' E	31,7	profile start
MSM99/2_20-1	29.03.2021	CTD	13:47	54° 22,055' N	007° 23,494' E	31,8	in the water
MSM99/2_20-1	29.03.2021	CTD	13:53	54° 22,051' N	007° 23,486' E	32,6	max depth/on ground
MSM99/2_20-1	29.03.2021	CTD	14:02	54° 22,053' N	007° 23,487' E	30,4	on deck
MSM99/2_21-1	29.03.2021	CTD	14:48	54° 19,872' N	007° 28,146' E	32,2	in the water
MSM99/2_21-1	29.03.2021	CTD	14:54	54° 19,875' N	007° 28,144' E	32,5	max depth/on ground
MSM99/2_21-1	29.03.2021	CTD	15:03	54° 19,872' N	007° 28,157' E	33,7	on deck
MSM99/2_22-1	29.03.2021	CTD	15:58	54° 17,496' N	007° 33,210' E	38,2	in the water
MSM99/2_22-1	29.03.2021	CTD	16:04	54° 17,508' N	007° 33,184' E	39,1	max depth/on ground
MSM99/2_22-1	29.03.2021	CTD	16:14	54° 17,521' N	007° 33,145' E	39,4	on deck
MSM99/2_19-1	30.03.2021	EM712 + PS	5:30	54° 02,186' N	008° 01,841' E	27,3	profile end
MSM99/2_23-1	30.03.2021	CTD	6:07	54° 03,089' N	008° 00,603' E	28,5	in the water
MSM99/2_23-1	30.03.2021	CTD	6:11	54° 03,089' N	008° 00,602' E	28,4	max depth/on ground
MSM99/2_23-1	30.03.2021	CTD	6:17	54° 03,090' N	008° 00,603' E	28,4	on deck
MSM99/2_23-2	30.03.2021	MIC	6:37	54° 03,091' N	008° 00,606' E	28,1	in the water
MSM99/2_23-2	30.03.2021	MIC	6:39	54° 03,091' N	008° 00,606' E	28,2	max depth/on ground
MSM99/2_23-2	30.03.2021	MIC	6:42	54° 03,091' N	008° 00,605' E	28,1	on deck
MSM99/2_23-3	30.03.2021	GC	8:10	54° 03,090' N	008° 00,596' E	29,5	in the water
MSM99/2_23-3	30.03.2021	GC	8:12	54° 03,090' N	008° 00,596' E	29,3	max depth/on ground
MSM99/2_23-3	30.03.2021	GC	8:16	54° 03,090' N	008° 00,596' E	29,4	on deck
MSM99/2_24-1	30.03.2021	EM712 + PS	8:25	54° 03,140' N	008° 00,537' E	29,3	profile start
MSM99/2_24-1	30.03.2021	EM712 + PS	13:24	54° 06,766' N	008° 07,586' E	23,1	profile end
MSM99/2_25-1	30.03.2021	MIC	13:38	54° 06,769' N	008° 07,504' E	23,1	in the water

MSM99/2_25-1	30.03.2021	MIC	13:40	54° 06,769' N	008° 07,504' E	23,2	max depth/on ground
MSM99/2_25-1	30.03.2021	MIC	13:44	54° 06,769' N	008° 07,504' E	23,3	on deck
MSM99/2_25-2	30.03.2021	GC	14:45	54° 06,770' N	008° 07,497' E	22,3	in the water
MSM99/2_25-2	30.03.2021	GC	14:47	54° 06,770' N	008° 07,497' E	22,6	max depth/on ground
MSM99/2_25-2	30.03.2021	GC	14:50	54° 06,770' N	008° 07,496' E	22,7	on deck
MSM99/2_26-1	30.03.2021	EM712 + PS	15:22	54° 06,765' N	008° 07,507' E	22,1	profile start
MSM99/2_26-1	31.03.2021	EM712 + PS	7:00	54° 22,663' N	007° 48,261' E	24,2	profile end
MSM99/2_27-1	31.03.2021	MIC	7:19	54° 22,640' N	007° 48,232' E	24	in the water
MSM99/2_27-1	31.03.2021	MIC	7:20	54° 22,640' N	007° 48,232' E	24	max depth/on ground
MSM99/2_27-1	31.03.2021	MIC	7:23	54° 22,640' N	007° 48,232' E	24,1	on deck
MSM99/2_28-1	31.03.2021	EM712 + PS	7:30	54° 22,638' N	007° 48,234' E	24,2	profile start
MSM99/2_28-1	31.03.2021	EM712 + PS	8:13	54° 20,520' N	007° 53,623' E	21,5	profile end
MSM99/2_29-1	31.03.2021	CTD	8:48	54° 21,868' N	007° 50,173' E	24	in the water
MSM99/2_29-1	31.03.2021	CTD	8:54	54° 21,868' N	007° 50,173' E	24	max depth/on ground
MSM99/2_29-1	31.03.2021	CTD	8:59	54° 21,868' N	007° 50,176' E	24,1	on deck
MSM99/2_29-2	31.03.2021	MIC	9:07	54° 21,874' N	007° 50,200' E	24,3	in the water
MSM99/2_29-2	31.03.2021	MIC	9:08	54° 21,874' N	007° 50,200' E	24,3	max depth/on ground
MSM99/2_29-2	31.03.2021	MIC	9:12	54° 21,874' N	007° 50,200' E	24,4	on deck
MSM99/2_29-3	31.03.2021	GC	10:04	54° 21,871' N	007° 50,203' E	24,7	in the water
MSM99/2_29-3	31.03.2021	GC	10:05	54° 21,871' N	007° 50,203' E	25,1	max depth/on ground
MSM99/2_29-3	31.03.2021	GC	10:09	54° 21,871' N	007° 50,203' E	25	on deck
MSM99/2_29-4	31.03.2021	GC	10:24	54° 21,874' N	007° 50,203' E	25,2	in the water
MSM99/2_29-4	31.03.2021	GC	10:25	54° 21,874' N	007° 50,203' E	25	max depth/on ground
MSM99/2_29-4	31.03.2021	GC	10:32	54° 21,874' N	007° 50,203' E	25,2	on deck
MSM99/2_29-5	31.03.2021	GC	11:09	54° 22,057' N	007° 50,611' E	25,4	in the water
MSM99/2_29-5	31.03.2021	GC	11:11	54° 22,057' N	007° 50,611' E	25,5	max depth/on ground
MSM99/2_29-5	31.03.2021	GC	11:15	54° 22,057' N	007° 50,611' E	25,5	on deck
MSM99/2_29-6	31.03.2021	GC	12:49	54° 22,057' N	007° 50,608' E	25,8	in the water

MSM99/2_29-6	31.03.2021	GC	12:50	54° 22,057' N	007° 50,610' E	25,7	max depth/on ground
MSM99/2_29-6	31.03.2021	GC	12:55	54° 22,057' N	007° 50,611' E	26	on deck
MSM99/2_29-7	31.03.2021	MIC	14:11	54° 22,551' N	007° 51,552' E	25,7	in the water
MSM99/2_29-7	31.03.2021	MIC	14:14	54° 22,551' N	007° 51,552' E	25,7	max depth/on ground
MSM99/2_29-7	31.03.2021	MIC	14:15	54° 22,551' N	007° 51,552' E	25,5	on deck
MSM99/2_30-2	31.03.2021	EM712 + PS	14:29	54° 22,523' N	007° 51,774' E	24,6	profile start
MSM99/2_30-2	31.03.2021	EM712 + PS	17:09	54° 32,442' N	007° 10,256' E	38,3	profile end
MSM99/2_31-1	01.04.2021	CTD	10:15	54° 39,452' N	007° 33,686' E	24,8	in the water
MSM99/2_31-1	01.04.2021	CTD	10:18	54° 39,452' N	007° 33,682' E	23,8	max depth/on ground
MSM99/2_31-1	01.04.2021	CTD	10:23	54° 39,457' N	007° 33,691' E	24,4	on deck
MSM99/2_31-2	01.04.2021	MIC	10:34	54° 39,404' N	007° 33,697' E	25,4	in the water
MSM99/2_31-2	01.04.2021	MIC	10:36	54° 39,404' N	007° 33,697' E	25,7	max depth/on ground
MSM99/2_31-2	01.04.2021	MIC	10:39	54° 39,404' N	007° 33,698' E	25,7	on deck
MSM99/2_32-1	01.04.2021	PS	10:40	54° 39,404' N	007° 33,698' E	24,2	profile start
MSM99/2_32-1	01.04.2021	PS	11:50	54° 34,276' N	007° 26,142' E	30,3	profile end
MSM99/2_33-1	01.04.2021	MIC	12:17	54° 34,683' N	007° 26,709' E	30,1	in the water
MSM99/2_33-1	01.04.2021	MIC	12:19	54° 34,682' N	007° 26,709' E	30	max depth/on ground
MSM99/2_33-1	01.04.2021	MIC	12:22	54° 34,682' N	007° 26,709' E	29,1	on deck
MSM99/2_33-2	01.04.2021	MIC	12:29	54° 34,682' N	007° 26,710' E	28,6	in the water
MSM99/2_33-2	01.04.2021	MIC	12:31	54° 34,683' N	007° 26,708' E	30,1	max depth/on ground
MSM99/2_33-2	01.04.2021	MIC	12:35	54° 34,683' N	007° 26,709' E	30,3	on deck
MSM99/2_34-1	01.04.2021	PS	12:44	54° 34,711' N	007° 26,577' E	30,3	profile start
MSM99/2_34-1	01.04.2021	PS	14:57	54° 38,937' N	007° 00,814' E	39,9	profile end
MSM99/2_35-1	01.04.2021	MIC	15:11	54° 38,782' N	007° 01,712' E	37,9	in the water
MSM99/2_35-1	01.04.2021	MIC	15:13	54° 38,781' N	007° 01,711' E	38	max depth/on ground
MSM99/2_35-1	01.04.2021	MIC	15:16	54° 38,782' N	007° 01,713' E	37,4	on deck
MSM99/2_35-2	01.04.2021	VGRAB	15:27	54° 38,782' N	007° 01,713' E	38	in the water
MSM99/2_35-2	01.04.2021	VGRAB	15:29	54° 38,782' N	007° 01,712' E	37,7	max depth/on ground

MSM99/2_35-2	01.04.2021	VGRAB	15:32	54° 38,782' N	007° 01,713' E	37,2	on deck
MSM99/2_36-1	01.04.2021	PS	15:37	54° 38,835' N	007° 01,635' E	37,5	profile start
MSM99/2_37-1	01.04.2021	MIC	16:23	54° 36,179' N	007° 02,286' E	42,3	in the water
MSM99/2_37-1	01.04.2021	MIC	16:26	54° 36,179' N	007° 02,286' E	42,9	max depth/on ground
MSM99/2_37-1	01.04.2021	MIC	16:29	54° 36,179' N	007° 02,286' E	42,1	on deck
MSM99/2_37-2	01.04.2021	GC	16:46	54° 36,182' N	007° 02,283' E	41,7	in the water
MSM99/2_37-2	01.04.2021	GC	16:47	54° 36,182' N	007° 02,282' E	42,4	max depth/on ground
MSM99/2_37-2	01.04.2021	GC	16:51	54° 36,182' N	007° 02,282' E	42	on deck
MSM99/2_37-3	01.04.2021	GC	17:00	54° 36,182' N	007° 02,283' E	41,4	information
MSM99/2_37-3	01.04.2021	GC	17:02	54° 36,182' N	007° 02,282' E	42,1	max depth/on ground
MSM99/2_37-3	01.04.2021	GC	17:06	54° 36,182' N	007° 02,282' E	41,8	on deck
MSM99/2_36-1	02.04.2021	PS	6:30	54° 23,937' N	007° 48,078' E	25	profile end
MSM99/2_38-1	02.04.2021	MIC	7:06	54° 24,201' N	007° 51,264' E	22,9	in the water
MSM99/2_38-1	02.04.2021	MIC	7:08	54° 24,201' N	007° 51,262' E	22,1	max depth/on ground
MSM99/2_38-1	02.04.2021	MIC	7:11	54° 24,200' N	007° 51,262' E	191,6	on deck
MSM99/2_38-2	02.04.2021	GC	7:35	54° 24,130' N	007° 51,276' E	22,5	in the water
MSM99/2_38-2	02.04.2021	GC	7:36	54° 24,131' N	007° 51,277' E	22,3	max depth/on ground
MSM99/2_38-2	02.04.2021	GC	7:40	54° 24,130' N	007° 51,276' E	22,2	on deck
MSM99/2_39-1	02.04.2021	PS	7:52	54° 24,155' N	007° 51,468' E	22,1	profile start
MSM99/2_39-1	02.04.2021	PS	8:17	54° 22,846' N	007° 55,807' E	22,1	profile end
MSM99/2_40-1	02.04.2021	GC	8:36	54° 22,865' N	007° 55,739' E	22,2	in the water
MSM99/2_40-1	02.04.2021	GC	8:37	54° 22,865' N	007° 55,738' E	22,2	max depth/on ground
MSM99/2_40-1	02.04.2021	GC	8:40	54° 22,865' N	007° 55,739' E	22,3	on deck
MSM99/2_41-1	02.04.2021	PS	8:51	54° 22,879' N	007° 55,731' E	21,8	profile start
MSM99/2_41-1	02.04.2021	PS	9:48	54° 28,532' N	007° 53,206' E	20,8	profile end
MSM99/2_42-1	02.04.2021	MIC	10:01	54° 28,999' N	007° 52,972' E	20,2	in the water
MSM99/2_42-1	02.04.2021	MIC	10:02	54° 28,999' N	007° 52,973' E	20,9	max depth/on ground
MSM99/2_42-1	02.04.2021	MIC	10:06	54° 28,999' N	007° 52,973' E	19,8	on deck

MSM99/2_43-2	02.04.2021	EM712 + PS	10:50	54° 29,108' N	007° 46,994' E	22,6	profile start
MSM99/2_43-2	02.04.2021	EM712 + PS	12:00	54° 26,180' N	007° 36,062' E	26,6	profile end
MSM99/2_44-1	02.04.2021	CTD	12:17	54° 27,026' N	007° 36,481' E	27,3	in the water
MSM99/2_44-1	02.04.2021	CTD	12:24	54° 27,030' N	007° 36,491' E	26,6	max depth/on ground
MSM99/2_44-1	02.04.2021	CTD	12:31	54° 27,042' N	007° 36,490' E	28	on deck
MSM99/2_44-2	02.04.2021	MIC	12:35	54° 27,027' N	007° 36,480' E	26,5	in the water
MSM99/2_44-2	02.04.2021	MIC	12:38	54° 27,027' N	007° 36,481' E	27,8	max depth/on ground
MSM99/2_44-2	02.04.2021	MIC	12:40	54° 27,027' N	007° 36,480' E	28,3	on deck
MSM99/2_45-1	02.04.2021	EM712 + PS	12:53	54° 27,027' N	007° 36,481' E	27	profile start
MSM99/2_45-1	02.04.2021	EM712 + PS	13:16	54° 25,810' N	007° 34,562' E	28,6	profile end
MSM99/2_46-1	02.04.2021	MIC	13:19	54° 25,841' N	007° 34,558' E	28	in the water
MSM99/2_46-1	02.04.2021	MIC	13:21	54° 25,841' N	007° 34,556' E	28,8	max depth/on ground
MSM99/2_46-1	02.04.2021	MIC	13:24	54° 25,841' N	007° 34,559' E	28,1	on deck
MSM99/2_46-2	02.04.2021	MIC	13:36	54° 25,842' N	007° 34,558' E	29,3	in the water
MSM99/2_46-2	02.04.2021	MIC	13:37	54° 25,843' N	007° 34,556' E	28,9	max depth/on ground
MSM99/2_46-2	02.04.2021	MIC	13:41	54° 25,842' N	007° 34,557' E	28,6	on deck
MSM99/2_47-1	02.04.2021	EM712 + PS	13:52	54° 25,840' N	007° 34,554' E	28,5	profile start
MSM99/2_47-1	02.04.2021	EM712 + PS	14:12	54° 24,409' N	007° 31,860' E	29,4	profile end
MSM99/2_48-1	02.04.2021	MIC	14:23	54° 24,235' N	007° 31,641' E	28,7	in the water
MSM99/2_48-1	02.04.2021	MIC	14:25	54° 24,234' N	007° 31,641' E	28,4	max depth/on ground
MSM99/2_48-1	02.04.2021	MIC	14:29	54° 24,235' N	007° 31,640' E	29,4	on deck
MSM99/2_48-2	02.04.2021	MIC	14:36	54° 24,235' N	007° 31,641' E	29	in the water
MSM99/2_48-2	02.04.2021	MIC	14:37	54° 24,236' N	007° 31,641' E	28,7	max depth/on ground
MSM99/2_48-2	02.04.2021	MIC	14:40	54° 24,235' N	007° 31,641' E	28	on deck
MSM99/2_49-1	02.04.2021	EM712 + PS	15:25	54° 19,753' N	007° 36,314' E	29,6	profile start
MSM99/2_49-1	03.04.2021	EM712 + PS	4:01	54° 18,802' N	007° 36,095' E	33,9	profile end
MSM99/2_50-1	03.04.2021	EM712 + PS	4:05	54° 18,555' N	007° 35,903' E	33,3	profile start
MSM99/2_50-1	03.04.2021	EM712 + PS	5:45	54° 05,006' N	007° 58,055' E	33,2	profile end

MSM99/2_51-1	03.04.2021	MIC	6:06	54° 05,007' N	007° 58,038' E	32,9	in the water
MSM99/2_51-1	03.04.2021	MIC	6:09	54° 05,007' N	007° 58,038' E	33,6	max depth/on ground
MSM99/2_51-1	03.04.2021	MIC	6:13	54° 05,007' N	007° 58,038' E	33,6	on deck
MSM99/2_51-2	03.04.2021	GC	7:09	54° 05,009' N	007° 58,039' E	32,7	in the water
MSM99/2_51-2	03.04.2021	GC	7:11	54° 05,008' N	007° 58,037' E	33	max depth/on ground
MSM99/2_51-2	03.04.2021	GC	7:16	54° 05,008' N	007° 58,038' E	33,1	on deck
MSM99/2_51-3	03.04.2021	GC	7:37	54° 05,003' N	007° 58,035' E	33,3	in the water
MSM99/2_51-3	03.04.2021	GC	7:41	54° 05,003' N	007° 58,034' E	32,8	max depth/on ground
MSM99/2_51-3	03.04.2021	GC	7:45	54° 05,003' N	007° 58,034' E	33,1	on deck
MSM99/2_52-2	03.04.2021	EM712 + PS	7:58	54° 05,074' N	007° 58,158' E	32,5	profile start
MSM99/2_52-2	03.04.2021	EM712 + PS	8:31	54° 05,702' N	008° 04,425' E	23,3	profile end
MSM99/2_53-1	03.04.2021	MIC	8:55	54° 05,705' N	008° 04,385' E	23,7	in the water
MSM99/2_53-1	03.04.2021	MIC	8:56	54° 05,705' N	008° 04,385' E	23,6	max depth/on ground
MSM99/2_53-1	03.04.2021	MIC	9:00	54° 05,705' N	008° 04,385' E	23,5	on deck
MSM99/2_54-2	03.04.2021	EM712 + PS	9:14	54° 05,971' N	008° 04,186' E	23,6	profile start
MSM99/2_54-2	03.04.2021	EM712 + PS	11:27	54° 19,689' N	007° 39,605' E	28,6	profile end
MSM99/2_55-1	03.04.2021	MIC	11:51	54° 19,675' N	007° 39,605' E	29,1	in the water
MSM99/2_55-1	03.04.2021	MIC	11:53	54° 19,676' N	007° 39,605' E	29,3	max depth/on ground
MSM99/2_55-1	03.04.2021	MIC	11:56	54° 19,675' N	007° 39,605' E	29,4	on deck
MSM99/2_56-1	03.04.2021	MIC	12:32	54° 19,668' N	007° 39,586' E	29,6	in the water
MSM99/2_56-1	03.04.2021	MIC	12:34	54° 19,668' N	007° 39,586' E	30,1	max depth/on ground
MSM99/2_56-1	03.04.2021	MIC	12:38	54° 19,668' N	007° 39,586' E	29,4	on deck
MSM99/2_56-2	03.04.2021	MIC	12:46	54° 19,668' N	007° 39,586' E	30,1	in the water
MSM99/2_56-2	03.04.2021	MIC	12:48	54° 19,668' N	007° 39,587' E	29,6	max depth/on ground
MSM99/2_56-2	03.04.2021	MIC	12:51	54° 19,668' N	007° 39,586' E	29,7	on deck
MSM99/2_57-1	03.04.2021	MIC	13:29	54° 19,662' N	007° 39,573' E	30,1	in the water
MSM99/2_57-1	03.04.2021	MIC	13:32	54° 19,662' N	007° 39,572' E	29,7	max depth/on ground
MSM99/2_57-1	03.04.2021	MIC	13:32	54° 19,662' N	007° 39,572' E	29,8	on deck

MSM99/2_58-1	03.04.2021	EM712 + PS	13:52	54° 19,650' N	007° 39,793' E	30,1	profile start
MSM99/2_58-1	03.04.2021	EM712 + PS	17:11	54° 19,222' N	007° 41,110' E	28,7	profile end
MSM99/2_59-1	03.04.2021	EM712 + PS	17:11	54° 19,222' N	007° 41,107' E	28,1	profile start
MSM99/2_59-1	03.04.2021	EM712 + PS	18:26	54° 25,583' N	007° 36,722' E	26,8	profile end
MSM99/2_60-1	03.04.2021	EM712 + PS	18:26	54° 25,585' N	007° 36,722' E	26,2	profile start
MSM99/2_60-1	04.04.2021	EM712 + PS	0:24	54° 28,679' N	007° 36,130' E	25,1	profile end
MSM99/2_61-1	04.04.2021	EM712 + PS	0:24	54° 28,717' N	007° 36,126' E	25,2	profile start
MSM99/2_61-1	04.04.2021	EM712 + PS	1:16	54° 27,789' N	007° 26,253' E	29,4	profile end
MSM99/2_62-1	04.04.2021	EM712 + PS	1:16	54° 27,789' N	007° 26,253' E	29,4	profile start
MSM99/2_62-1	04.04.2021	EM712 + PS	7:52	54° 27,842' N	007° 26,271' E	27,8	profile end
MSM99/2_63-2	04.04.2021	EM712 + PS	7:55	54° 27,808' N	007° 26,638' E	27,4	profile start
MSM99/2_63-2	04.04.2021	EM712 + PS	8:45	54° 24,066' N	007° 09,589' E	38,8	profile end

GC: Gravity corer VGRAB: Van-Veen Grab

MIC: Mini Multi corer PS: Parasound

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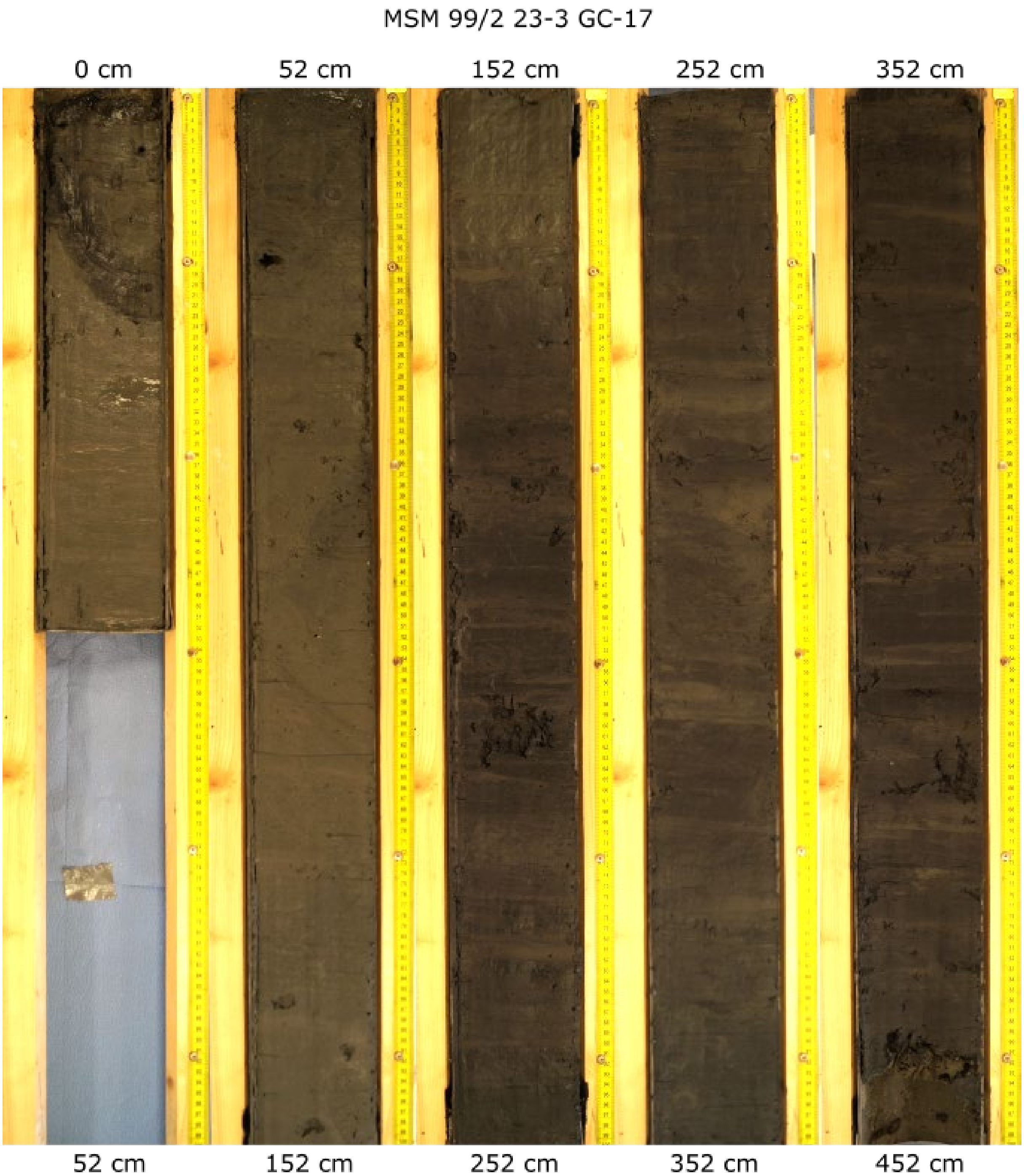
10 Abbreviations

BAW	Bundesamt für Wasserbau
BFN	Bundesamt für Naturschutz
CAU	Christian Albrecht Univwersität zu Kiel
GC	Gravity Core
MIC	Mini Multi Corer
PS	Parasound
SVP	Sound Velocity Probe
TA	Total Alkalinity
TOC	Total Organic Carbon
VGRAB	Van-Veen Grab
WA	Working Area

11 Appendix

11.1 Photos of GCs



MSMS 99/2
29-3 GC-19
0 cm

60 cm

MSM 99/2 25-2 GC-18