Cruise Report Poseidon 491 POS491

Marine Geophysical Excursion

Poseidon 491: 05 – 09.10.2015

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2015

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1. List of participants

Crew:	Rank or rating	Presence
Günther, Matthias	Master	05. – 09.10.2015
Wichmann, Gent	Chief Officer	05. – 09.10.2015
Nannen, Hero	2nd Officer	05. – 09.10.2015
Kröger, Kurre-Klaas	Chief Engineer	05. – 09.10.2015
Freund, Hans-Jörg	2nd Engineer	05. – 09.10.2015
Blunck, Volker	Electrican	05. – 09.10.2015
Engel, Rüdiger	Motorman	05. – 09.10.2015
Schrage, Frank	Bosun	05. – 09.10.2015
Graf von Keller, Magnus Tarik	AB	05. – 09.10.2015
Meyer, Felix	SM	05. – 09.10.2015
Kuhn, Ronald	AB	05. – 09.10.2015
Rauh, Berndt	SM	05. – 09.10.2015
Pleuler, Merlin Till	SM	05. – 09.10.2015
Malchow, Klaus Peter	Cook	05. – 09.10.2015
Gerischewski, Bernt	Steward	05. – 09.10.2015
Prof. Dr. Christian Berndt	Chief Scientist	05. – 09.10.2015
Wetzel, Gero	Scientist	05. – 09.10.2015
Kemme, Jöran	Scientist	05. – 09.10.2015
Schwarz, Stefanie	Scientist	05. – 09.10.2015
Götte. Johann	Scientist	05. – 09.10.2015
Mommsen, Thomas	Scientist	05. – 09.10.2015
Popp, Kristina	Scientist	05. – 09.10.2015
Hagemann, Katlina	Scientist	05. – 09.10.2015
Jan Ridderbusch	Scientist	05. – 06.10.2015
Wulff, Pierre	Scientist	05. – 06.10.2015
Löhndorf, Malte	Scientist	05. – 06.10.2015

Watch:

Day 1 – 2:	00:00 - 04:00 / 12:00 – 16:00	Pierre Wulff, Malte Löhndorf
(5. - 6.10.15)	04:00 – 08:00 / 16:00 - 20:00	Stefanie Schwarz, Jöran Kemme
	08:00 – 12:00 / 20:00 - 00:00	Johann Götte, Jan Ridderbusch, Thomas Mommsen
Day 2 – 4	00:00 – 04:00 / 12:00 - 16:00	Katlina Hagemann, Kristina Popp
(7. - 9.10.15)	04:00 – 08:00 / 16:00 - 20:00	Stefanie Schwarz, Jöran Kemme
	08:00 – 12:00 / 20:00 - 00:00	Johann Götte, Thomas Mommsen

2. Abstract / Zusammenfassung

English Version:

The expedition POS491 with the Poseidon took place from the 05.10.2015 – 09.10.2015 in the western Baltic Sea and started and finished in Kiel. As part of the marine geophysical exercise of the Christian Albrecht University of Kiel the students were introduced to scientific data acquisition on a research vessel. After the trip the students collected preliminary results. The surveyed area was primarily in Eckernförde Bay north of known pockmark sites. First a zone was mapped with the multibeam echo sounder, sediment echo sounder and the side scan sonar. Later an additional seismic profile was created with a p-cable set up. On the fourth day five ocean bottom seismometers were deployed to determine the seismic velocities of the seismic layers. Though only one OBS collected usable data.

Deutsche Ausführung:

Die Ausfahrt der Poseidon POS491 fand vom 05.10.2015 – 09.10.2015 in der westlichen Ostsee statt und begann und endete in Kiel. Im Rahmen eines marinegeophysikalischen Praktikums der Christian Albrecht Universität Kiel wurde den Studenten das wissenschaftliche Sammeln von Daten auf einem Forschungsschiff näher gebracht. Im Anschluss wurden vorläufige Auswertungen der gesammelten Daten von den Studenten erstellt. Das zu untersuchende Gebiet befand sich in erster Linie in der Eckernförder Bucht, nördlich bekannter Pockmarkpositionen. Zuerst wurde ein Areal mit dem Fächerecholot, dem Sedimentecholot und dem Seitensichtsonar kartiert. Danach wurde zusätzlich ein seismisches Profil mit dem P-Cable erstellt. Am vierten Tag wurden fünf ocean bottom seismometer ausgesetzt, wobei nur ein OBS brauchbare Daten lieferte.

3. Motivation and Scientific background

3.1. Motivation

The ambition of POS 491 was giving students the opportunity of practical work in marine geophysics onboard of a research vessel to introduce them to different methods of data acquisition. The goal was to obtain more information about the surrounding of the known pockmarks and gas inclusions in the sediments near the surface. To visualize the subsurface composition of the seafloor refraction and reflection seismic was used. Furthermore the side scan sonar, the Sediment echo sounder and the jaw gripper were used to analyze the structure of the sediments to identify possible gas inclusions.

Earlier studies primarily focused on the proximity of the pockmarks. Due to this measurements should deliver new data about the geological background and might discover new pockmarks.

3.2. General

The importance of pockmarks was increasing since their discovery in the late 1960s by Lew King and Brian McLean offshore of Nova Scotia. Pockmarks play an important role for the fluid flow in oceans, especially on the continental margins. Despite this importance the understanding of pockmarks is still insufficient because of a lack of proper 3D- data of the internal structure. First steps to improve the data were taken in Plaza-Faverola et al. (2010) with the placing of Ocean Bottom Seismometers (OBS) around a pockmark. The OBS`s were recording shots fired from surface towed mini GI guns (also recorded by near surface hydrophones). A relevant spot of studying pockmarks is situated the Bay of Eckernförde.

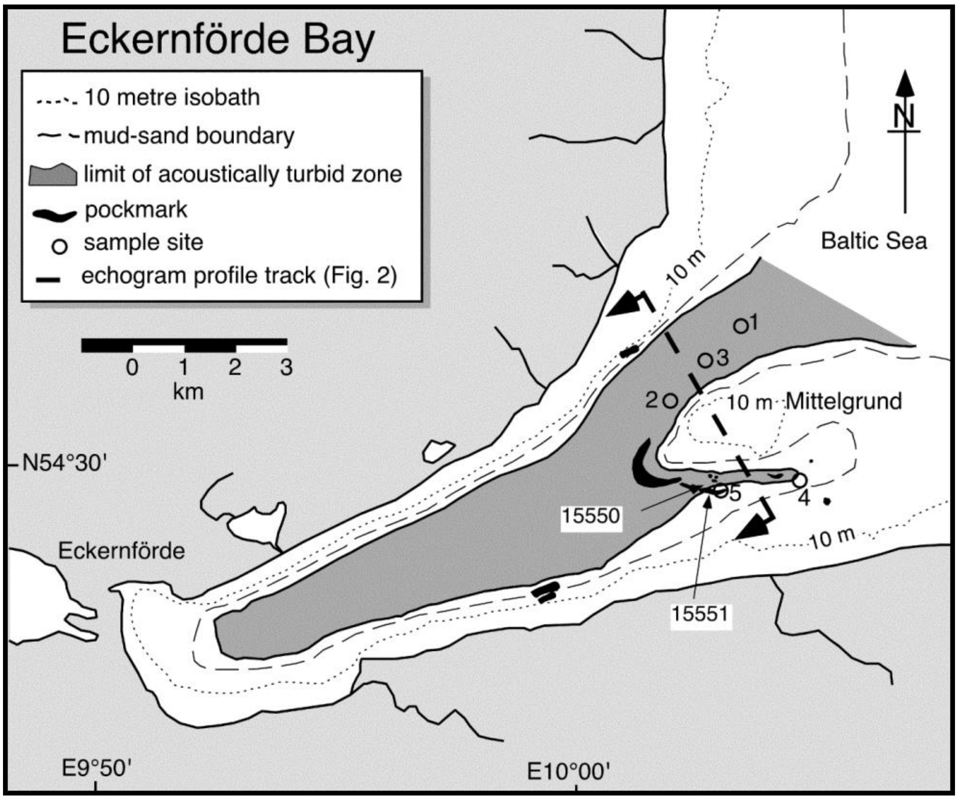

Fig. 1: Bathymetric map of Eckernförde Bay, Baltic Sea, Germany (from Whiticar 2002).

In 1966 pockmarks were discovered (Edgerton et al., 1966) in this area. Early explanations were erosion and military activities (Edgerton et al., 1966). Even methane bubbles from the Holocene sediments in this place have been considered as an explanation for the origin of the Pockmarks (Werner, 1978), but the methane consuming rate in this area is 3-10 times greater than the formation rate of methane (Whiticar, 2002). Due to the spatial coincidence to the Schwedeneck oil field (Fabian and Roese, 1962) another assumption was suggesting that the pockmarks might be caused by rising hydrocarbon gas.

However Whiticar and Werner in 1981 measured that the isotopic gas composition not contains signs of a deeper hydrocarbon reservoir, but methane was found in high concentrations in and near to the pockmarks. Hence this hypothesis has been rejected.

Interstitial salinities are drastically decreasing in and near by the pockmarks with depth (Whiticar and Werner, 1981). This observation is confined to the pockmarks, so freshwater outflow could be responsible for the pockmarks. From this point the freshwater hypothesis was improved more and more.

Moreover, Khandriche and Werner (1995) observed a spatial connection between pockmark occurrence and a Pleistocene outwash channel that represents an important regional aquifer. Whiticar in 2002 figured out that sand layers under the Holocene sediments transport meteoric freshwater from onshore into the Eckerförde Bay. Southwestern of Mittelgrund the freshwater exits episodically forming the pockmarks.

Also in 2002 Jensen et al. recorded new data improving the knowledge of the geological setting greatly. The data show that the Tertiary aquifer sediments may have hydraulic connections with a younger Quaternary aquifer. In the basin near to Mittelgrund clayey late glacial sediments probably prevent groundwater leakage. Furthermore seismic, lithological, macrofossil and AMS ^{14}C data indicate that late glacial and preboreal lakes existed in the region. However further investigations are necessary to find out whether Eckernförde Lakes were part of the Baltic Ice Lake and the Ancylus Lake.

In conclusion groundwater outflow is responsible for the pockmarks and the methane seepage. A similar situation where groundwater outflow is triggering methane seepage is described in Starke et al., 2014.

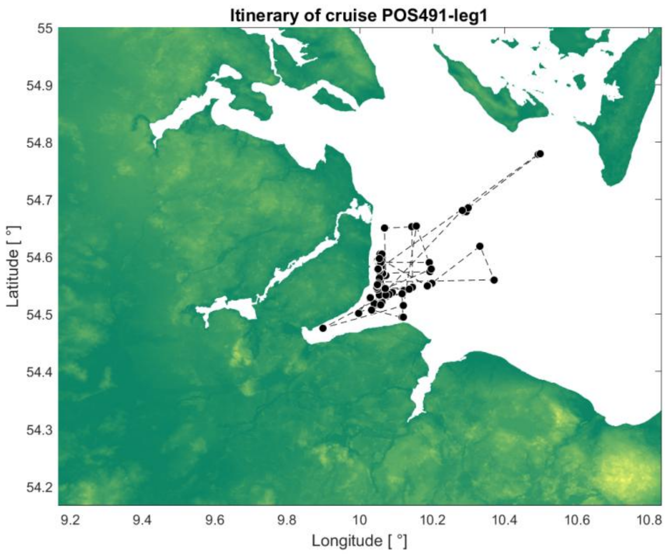

Fig. 2: Itinerary of the whole cruise POS491-leg1. Points of alternating course are marked with black dots.

4. Narrative

4.1. Day 1 (5.10.15)

Time	
9:00	Arrival of the participants
10:00	Safety briefing by second Officer
11:00	Calculation of route and profile with Matlab 2010b
12:00	Departure from Kiel
13:00	Security exercise
13:20	Arrival at measuring point for CTD measurement
13:30	CTD-Measuring
14:00	Calibrating data processing software Hypack 2014 with acoustic velocity from the CTD measurement for multibeam echo sounder measurement
14:30	Talk about the formation of the Baltic sea (see appendix for details)
14:55	Arrival at starting point of profile for Sediment echo sounder, multibeam echo sounder and side scan sonar (54° 31.2' N, 10° 3' E)
15:39	Start of profile 1 (54° 31,2' N , 10° 3' E, see excel sheet for details) Settings: Side scan sonar :70m beamwidth, 300 kHz, 8 m depth Multibeam echo sounder: 53 kHz Sediment echo sounder: 8 kHz
15:45	Classification of watch
16:23	Multibeam echo sounder first visualized the second, lower sediment layer. After manual correction of depth the uppermost layer of seafloor is shown.
16:37	Side scan sonar is ready for operation

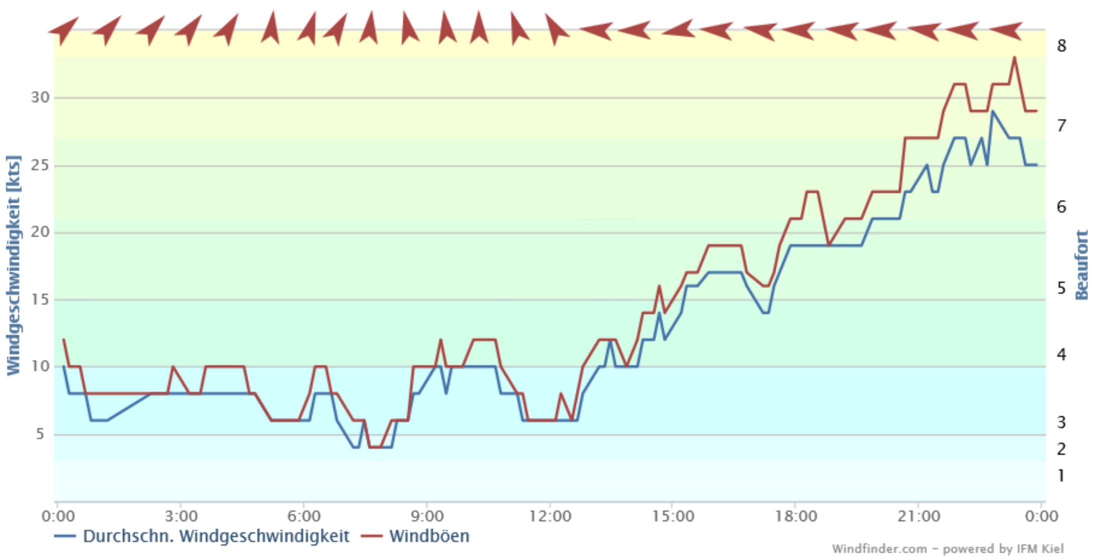

Fig. 3: Wind velocity of 05.10.2015

Weather: Sunny and around 10 knots wind speed, no clouds. In the afternoon more and more cloudy and windy (easterly, up to 30 knots, increasing, 2 m waves).

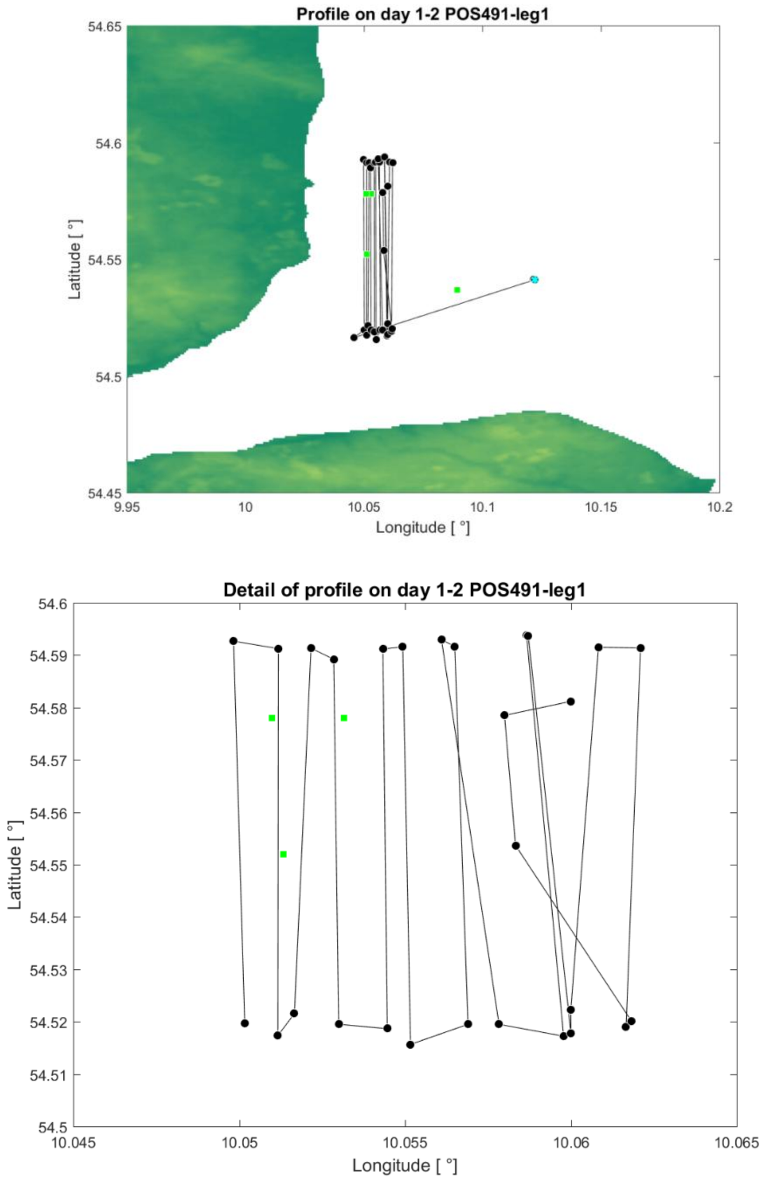

Fig. 4: Profile of measurements between day 1 (15:39) and day 2 (11:20). Points of sediment samples (cf. Day 4) marked with green squares, point of CTD sample marked in cyan.

4.2. Day 2 (6.10.15)

Time
11:20 End of profile / endlogging, Cover of the equipment (Sediment Echo Sounder)
11:30 Transit to Kiel
14:20 Arrival in Kiel
15:00 Talk about seafloor mapping (see appendix for details)
15:15 Press conference BMBF in Kiel
16:00 Planning positions for taking probe of seafloor based on side scan sonar

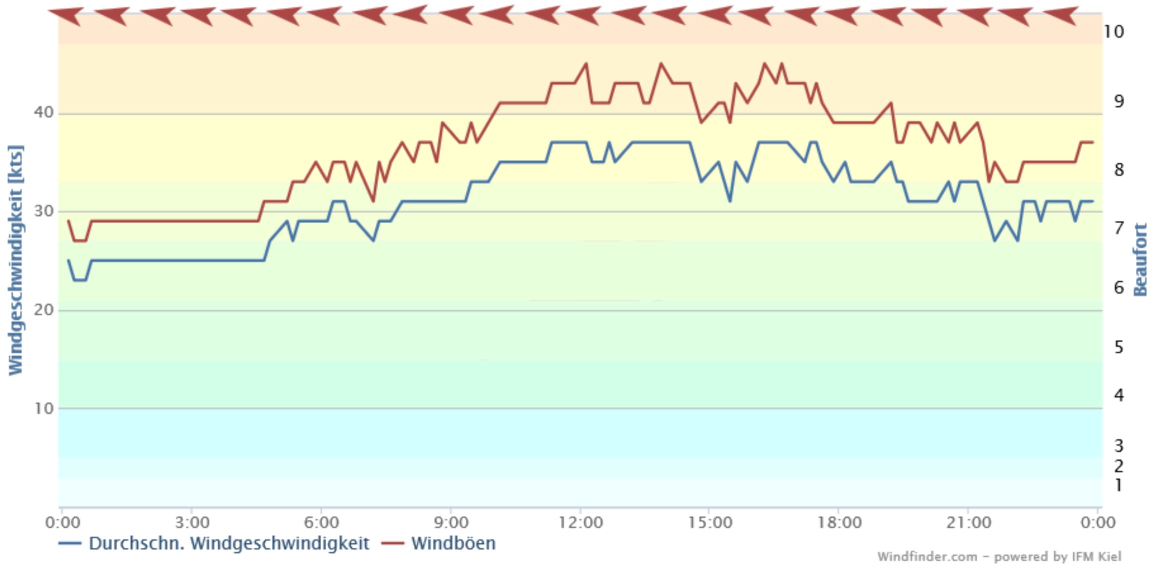

Fig. 5: Windvelocity of 06.10.2015

Weather: Cloudy and windy (easterly, up to 40 knots, stable and later increasing, 3m waves).

<u>4.3. Day 3 (7.10.15)</u>

Time
8:00 Departure from Kiel
12:02 Arrival at starting point of profile (54° 46,717' N , 10° 29,924' E) for Sediment echo sounder and side scan sonar
14:00 Side scan sonar is ready for operation after error
16:00 Endlogging of side scan sonar
16:25 Equipment for Seismics launched
16:38 Side scan sonar launched, Seismics ready for operation
17:00 Arrival at starting point of profile (54° 40.059' N , 10° 15.838' E) for seismics and side scan sonar

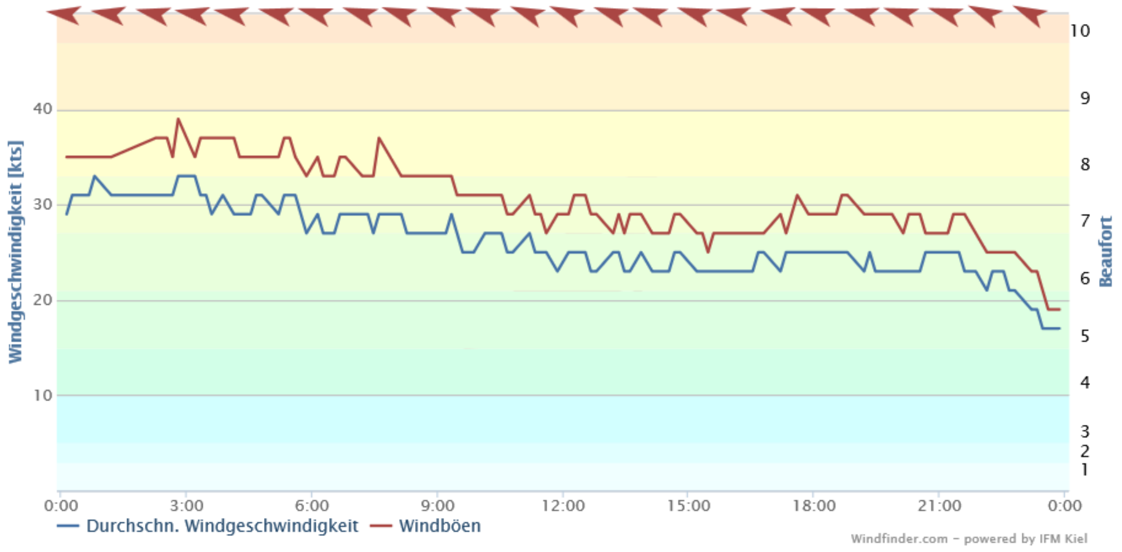

Fig. 6: Windvelocity of 07.10.2015

Weather: cloudy and windy (easterly, up to 35 knots, decreasing, 2 m waves decreasing).

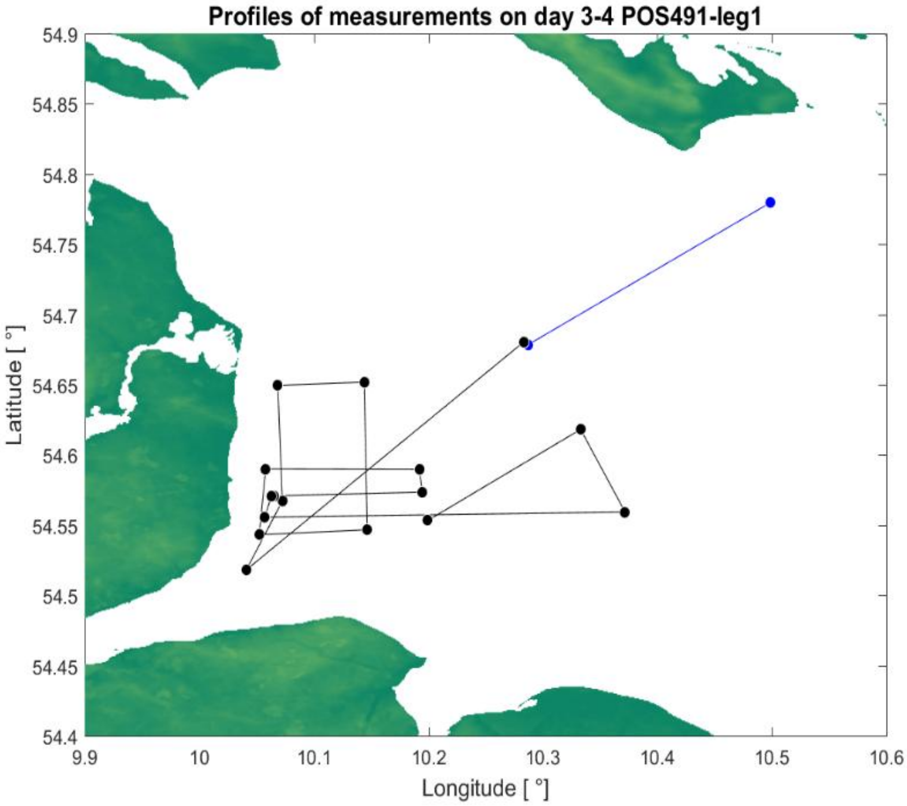

Fig. 7: Profile of Sidescan sonar and sediment echo sounder on day 3 (marked in blue), and profile with additional seismic measurement between day 3 (17:00) and day 4 (8:26) (marked in black).

4.4. Day 4 (8.10.15)

Time	
8:26	Profile ending/endlogging of the side scan sonar, air gun & Streamer
8:32	Preparation of the Ocean Bottom Seismometer
8:39	Removed side scan sonar, air gun and streamer
9:22	Launch of OBS Geomar 37
9:42	Launch of OBS Geomar 33
10:01	Launch of OBS Claudia
10:14	Launch of OBS Ercan
10:31	Launch of OBS Manni
?	Launch of the Mini GiAir gun
10:57	Start of the first profile with the Ocean Bottom Seismometer (54°31.011'N & 10°3533'E)
12:08	End of Profile
12:34	Remove of the first OBS

Weather: The Wind flows up so the apparatus can measure without restriction

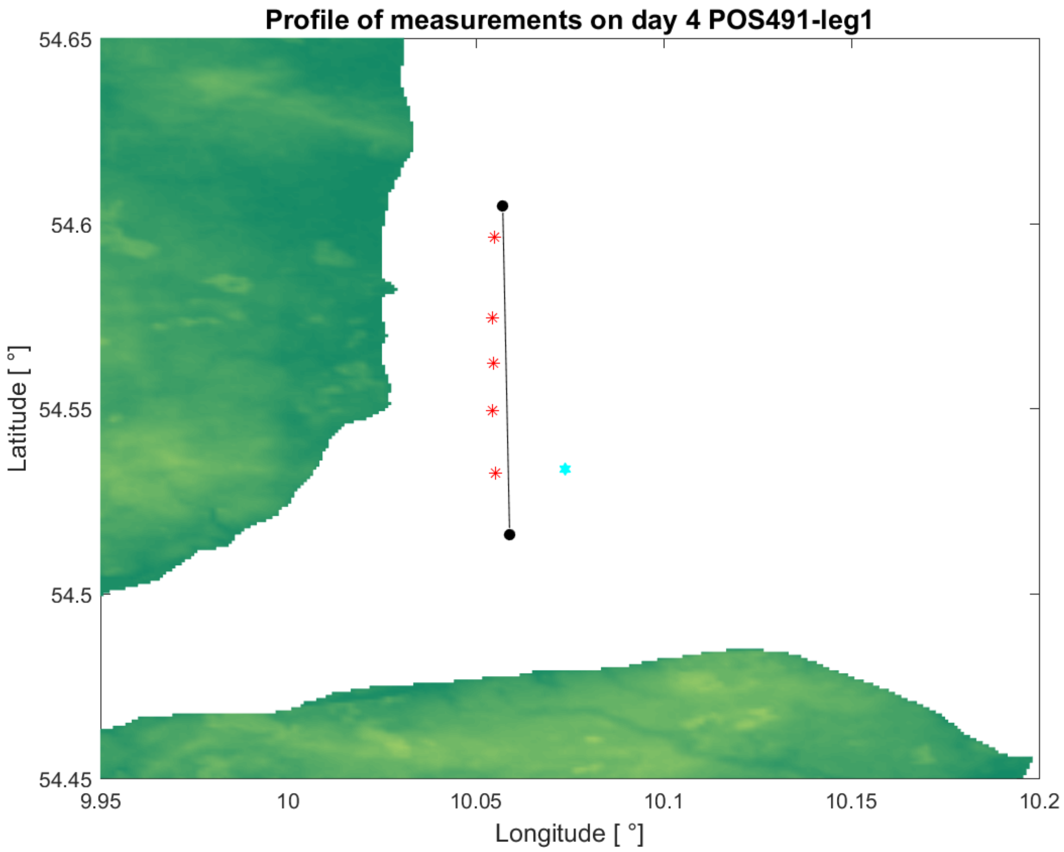

Fig. 8: Seismic reflection profile on day 4, the location of the OBSs are marked with red stars. The cyan star shows the location of the CTD sample

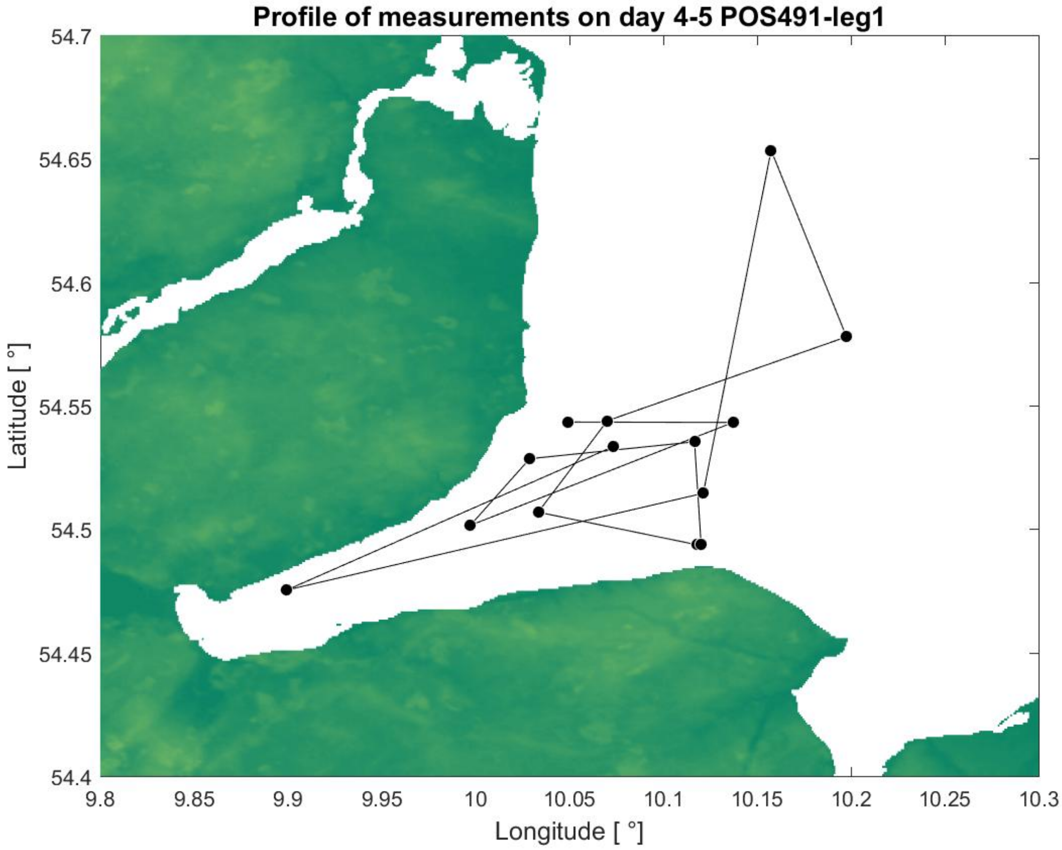

Fig. 9: Profile of the side scan and seismic measurements between day 4 (17:37) and day 5 (6:30).

4.5. Day 5 (9.10.15)

Time	
6:30	Profil ending / endlogging of the side scan sonar, seismic, multibeam, sediment echo sounder
8:00	Arrival at Kiel

5. Preliminary results

5.1. Seismic surveying

5.1.1. Seismic surveying in general

In seismic surveying, waves of different kinds from an acoustic signal are propagated through the earth's interior. The travel times are measured of waves that return to the surface after reflection or refraction at geological boundaries in the ground. These travel times can be converted into depth values and therefore the geological interfaces can be mapped systematically. In marine seismic surveying large areas can be mapped in rather short time because a lack of disturbing obstacles, which makes marine seismic surveying an attractive surveying method.

5.1.1.1. Mini GI Airgun

To induce an acoustic Signal, we used the Mini-GI Gun, which produces a Compressed air Explosion and is positioned 1.5 meters below the sea level. The Mini GI Gun consists of two upper and two lower pressure chambers with 2*45in^3 and 200 bar, which are connected by a spool channel. By Compressors on board, the compressed air first reaches the first upper pressure chamber and flows from there through the spool channel in the second pressure chamber. For safety reasons, this happens only, after the GI Gun is underwater. An electrical pulse opens a solenoid valve, to trigger the seismic pulse of the air gun, which has a penetration of about 500ms(600m). The airgun is deeper below sea level, the more energy it induces and the higher the frequency of the signal is. The trigger takes place every 3 ms. To prevent the formation of bubbles, second shot take place 25ms after the first shot. The second shit is called Injector and reduces the decrease of bubbles significantly.

Fig. 10: Mini-GI-Gun, 2 x 45 in^3

5.1.1.2 Streamer

Fig. 11: The two 25m long streamers located hydrophones

The induced seismic signal, which is reflected from the sea floor, is logged with in the two 25m long streamers located hydrophones. In each streamer are 8 groups of respectively 4 hydrophones. Moreover there is an analog digital converter in the streamer to convert the seismic signal from the hydrophones with a little linux computer in a digital signal and to send this data set to the boarding computer.

Because of the digital converter the noise is minimized.

The streamer starts after 21m meter behind the boat tail and the Mini GiGun is located 15m behind the Boat.

5.1.1.3. Ocean Bottom Seismometer (OBS)

OBS are geophysical systems of the seismic sub discipline of refraction seismic. An OBS is a stationary seismometer, which works completely alone, that means without cable- or GPS-connection to the ship. That means that the devices need a extreme precise clock, because there is no way to synchronize with other systems. Normally an OBS is set out on the sea bottom, and stays there while the whole measurement. It's only a stationary receiver and don't send out own waves. The main parts of every OBS are: A geophone, a hydrophone, a data recorder (often with A/D converter), Batteries (sometimes for over a year), an anchor (with release mechanism in deep sea) and an acoustic or optical transmitter for finding deep sea OBS on sea surface. By larger offsets and the detection of sound waves

This type of seismic allows the refraction in contrast to seismic reflection modeling of detailed Speed profiles.

If the velocity of the seismic signal in the lower layer is larger, than the upper layer velocity is the signal forms a head wave, which continues along the seafloor.

Fig. 12: geomar/IfG Kiel selfmade 4,5 kHz Ocean-Bottom-Seismometer

This head wave transmits during their journey along the seabed energy in the form of a seismic signal to the surface. The hydrophones register this signal. We used two different OBS. On the one hand we used the from the geomar self-made OBS with a 4,5 kHz Geophone inside, which register the vertical relative movement of the seafloor. On the outer side a hydrophone detects the acoustic spherical waves transmitted through the water. The analog measured data, become digitized in the OBS-Box with an AD-converter, to save them on a hard disk.

Data:
Name: Geomar selfmade OBS “Ercan”, “Manni” and “Claudia”
Facturer: Geomar Kiel, IfG CAU Kiel
Frequency: 4,5 kHz
Anchor: Stone plate
Frame: hard Polymer/Plastic
Operation Depth: Shallow Sea, Baltic Sea

On the other hand we used the OBS from the producer Kum Lobster with a 250 Hz sample frequency. First we determine the Position by GPS-Systems to position the OBS on the right place of the seafloor. To minimize the noise, created by the motion of the marker buoy an additional weight between buoy and the OBS is used to absorb the tension stress.

Data:
Name: Kum Lobster
Facturer: Kum Meeres- und Klimatechnik Kiel GmbH
L/W/H(mm): 1650/1300/720
Weight: 335 kg
Operation depth: 6000m – 7300m
Frame: Titan, flexible
Anchor: Steel

Fig. 13: Kum Logstar 250 Hz Ocean-Bottom-Seismometer

On top of the Kum Lobster OBS, there is a hydrophone to receive the signal to detach from the anchor weight and float to the surface. Because of the shallow water we are able to use a marker buoy which is a much safer method to recover the OBS.
With the OBS, we want to create a symmetric seismic figure with direct, reflected and refracted wave signals. These signals will be shown in a seismogram, in which we want to calculate the intercept times and seismic velocities. This data we use to calculate the thickness of sedimental layers. Because of the high frequency of the Geomar self-made OBS the data has a high resolution, but the seismic waves don’t reach high depths.

5.1.2. Results of seismic survey

The OBS Data we extracted from the seismometer “Ercan” resulted in three layers, which are inclined. We can see that in the seismogram “Ercan”.

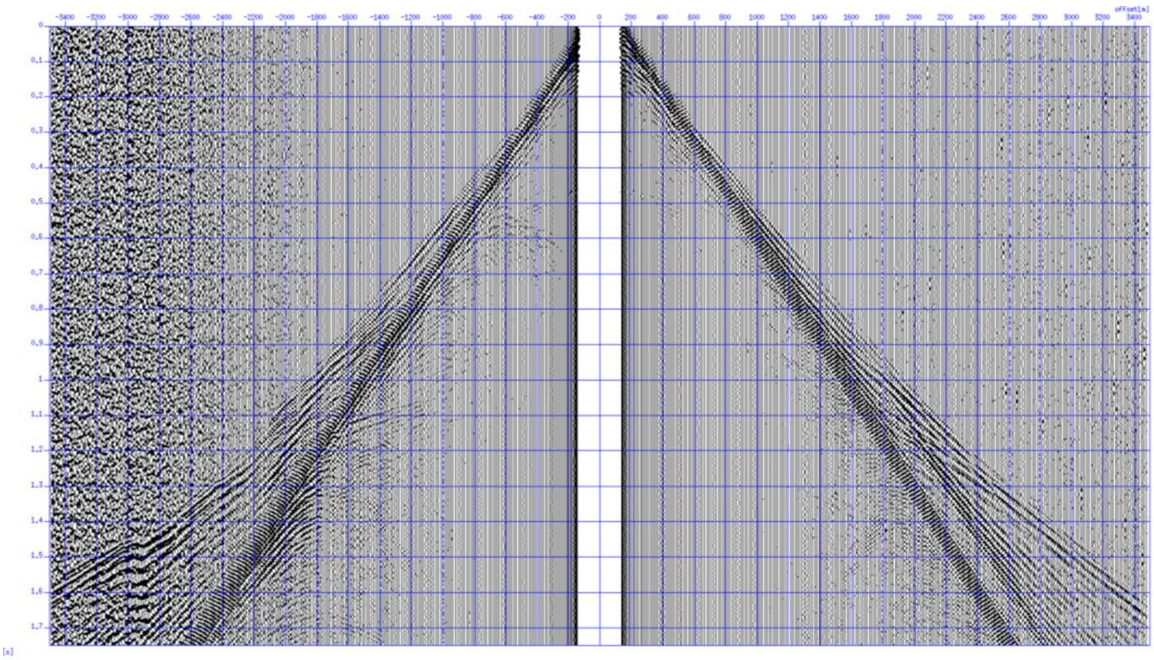

Fig. 14: seismogram “Ercan”

As you can see the both sides of the seismogram are similar, but not exact the same. This leads us to the conclusion, that we have an inclination/declination in the sea bottom.
At first we can calculate the seismic velocities by computing the gradient of the waves. This leads us to the result, that the velocity increases with the depth. With this information we can easy calculate the intercept-times of the layers and so the thickness of the layers too.

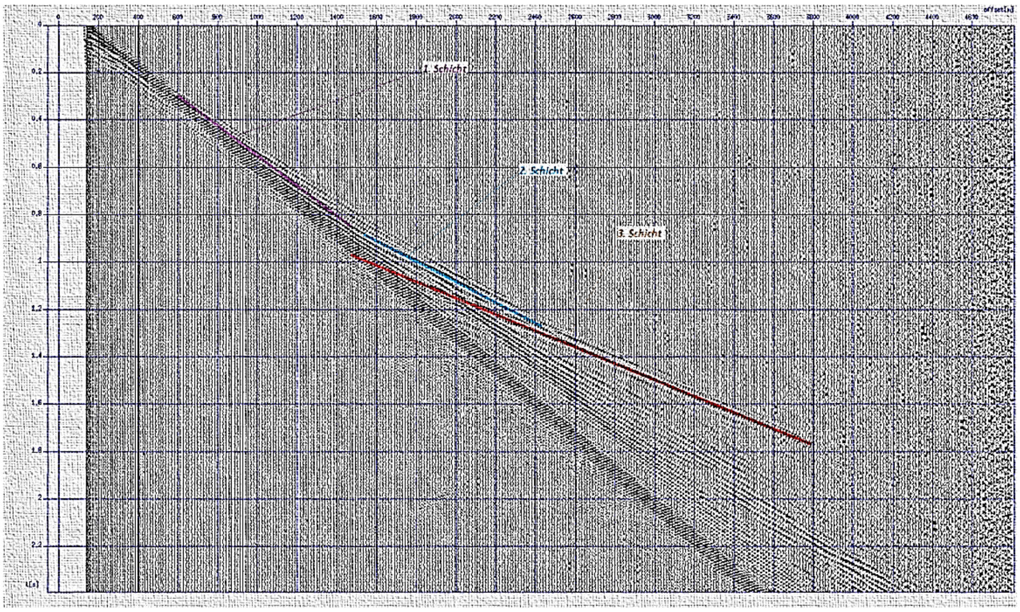

Fig. 15: seismogram “Ercan” zoom, with layers

Layer	*Velocity v_p*	*Thickness*	*Possible Sediments*
Layer 1	1,6 km/s	60,25m	Loose sediments
Layer 2	2 km/s	226,67m	Granular soil
Layer 3	2,67 km/s	302,32m	Siltstone, sandstone

To summarize it, we have 3 layers of sediments between 60-300m thickness. An interpretation on the data results is only possible in relation to the seismic velocities. If we compare this calculations with known typical seismic velocities of sediments, we can hint the possible sediments, which can exist in the Baltic-Sea-bottom.

During the research cruise on RV Poseidon within the Eckernförde Bay we used seismic reflection profiling to investigate gas deposits and rising gas and fluids. For three days we were measuring twenty different profiles.

Our equipment consists of a Mini GI-Gun as transmitter and a Solid State streamer with hydrophones as receiver. The additionally data processing included CMP-Stacking, NMO-Correction, Stacking and Stolt Migration.

We expected two types of gas deposit. First biogenic gas (particularly methane and carbon dioxide) formed by organic material, which was decomposed from bacteria. Therefore biogenic gas exists mainly closed to the seafloor. Thermogenic gas (particularly methane, propane and ethane) is a result of chemical reactions in high temperatures and pressures in great depths.

Seismic reflection profiling is based on the fact that acoustic waves are partly reflected from boundary layers and recorded at the sea surface. During this process, the contrast of impedance of the layers is important, because the larger the contrast of impedance is, the more energy of the acoustic wave is reflected. In addition, the impedance depends on the density of the material and his seismic velocity.

The seismic reflection of gas deposits can show different anomalies. First, Acoustic Blanking Zones (fig. 16a) are areas with weak reflection, which often occur below gas-zones. Most of the acoustic energy is reflected by the gas-zone and the remaining energy is mostly absorbed. As result, you received only weak signals from the underlying areas. It also can be layer of gravel or coal. Multiplen-Ringing (fig. 16c) are strong reflections, which occur below the gaszone. They repeat in long runtimes.

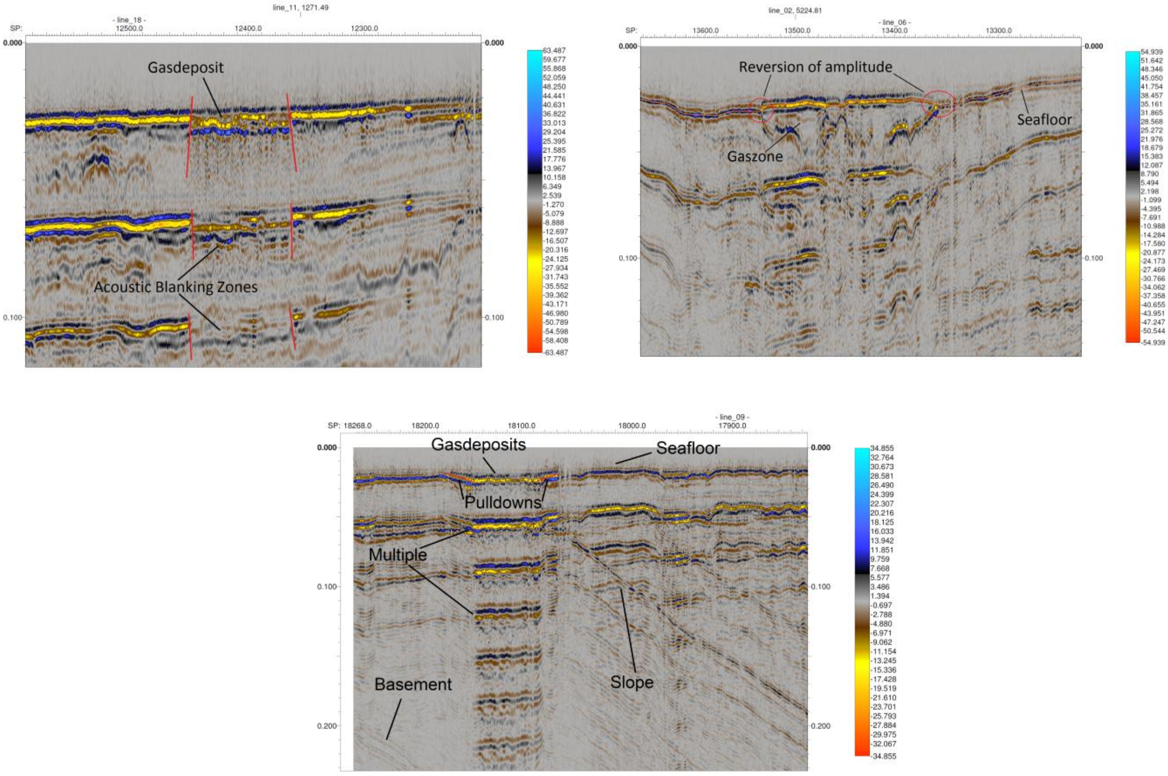

Fig. 16: different gas deposits of the seismic reflection profiles a) with Acoustic Blanking Zone, b) Reversion of amplitude, c) with Multiplen- Ringing and small Pulldowns

Furthermore, abrupt a reversion of amplitudes (fig. 16b) is a clear indication for gas deposits. Upward migration of free gas or fluids can be seen by Gas-Chimneys. Gas-Chimneys are vertical orientated anomalies in the sediment, whose amplitudes are relatively weak. Pulldowns (fig. 16c) appear in the area of adjacent reflector sections. They are bent down in direction of the gas-zone. Besides, Pulldowns are caused by low velocity in the gas-zone, which also affects the adjacent sediment. This results in a higher runtime.
Unfortunately, some profiles cannot be analysed completely or partially or only with great caution due to incorrect calibration, erroneous measurement and bad weather. Especially, details are recognizable only to a depth of 0.05 seconds TWT because of the strong Multiples. Furthermore, the seafloor is partially not unrecognizable, because there are zones of mud, which have a low contrast of impedance with water.

5.2. Side scan sonar

5.2.1. Side scan sonar in general

A side scan sonar is used to get more detailed information about the seafloor with high resolution imaging and the possibility to derive the seafloors composition from the measured amplitudes. It operates with frequencies of 9-500 kHz and has two single, separately adjustable beams of 20-40° orthogonal to the ships keel with a width of 1-2°. As they can have different settings, e.g. a sloping seafloor can be leveled out. Generally, solid items as metal and rocks backscatter very well and sediments and other weak areas don't. The intensity of backscattering is pictured by different shades of grey. It differs from model to model, if dark colours are used for high or low backscatter.

5.2.2. Results of Side scan sonar survey

On cruise POS491-leg 1 a profile of Side Scan Sonar data was generated. At this cruise a DeepVision Side Scan Sonar with a frequency of 340 kHz was used. It operates with 70m beamwidth and at a depth of 8m. The data of this profile has been taken along the shore of the Baltic Sea between Damp and Mittelgrund, a morainal sill at the entrance of Eckernförde Bay (*Orsi et al.(1996)*). This area is called "Boknis Eck". We used this data for two efforts.

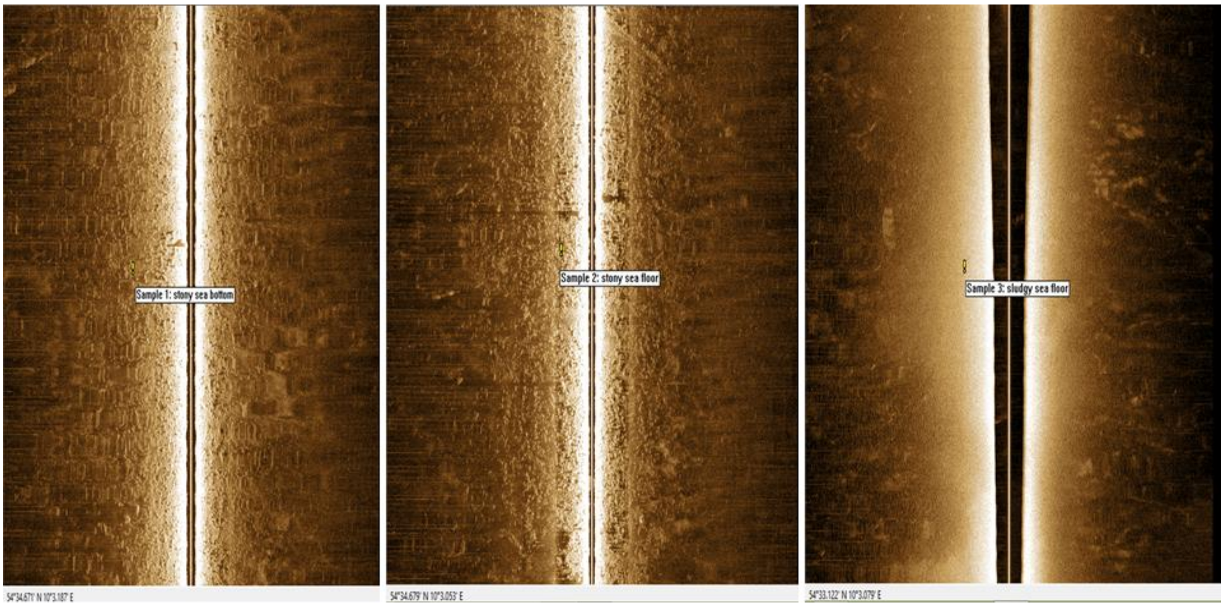

Fig. 17: Side Scan Sonar data at sample stations 1 to 3(marked with yellow exclamation mark).

Mainly we were interested in the Baltic Sea's sediment distribution. Side Scan Sonar data can show how the sea bottom looks like. If we take a look at the received data, we see that there is a significant difference in backscattered signals between lower and higher depths. At lower depths we have mostly high backscattering and vice versa there is less backscattering as deeper as you go. By means of this observation a coarse conclusion about the appearance of the sea bottom is possible. But for statements about the sediment this not sufficient. On this account sediment samples were taken. Results yield out of these are described at chapter 5.6.2..

On the other hand it is possible to measure objects visible in the Side Scan Sonar data in height. With help of these calculations, information about distributions of objects as boulders can be gathered. The height is calculated from the distance between the sonar fish and the sea bottom, the distance between fish and object and the length of object shadow (*Bohling et* *al.(2009)*). In lower depths of Boknis Eck boulders up to sizes of 2 m can be found. These boulders are rounded due to erosional currents. This is also essential for smaller grain-sizes at this area.

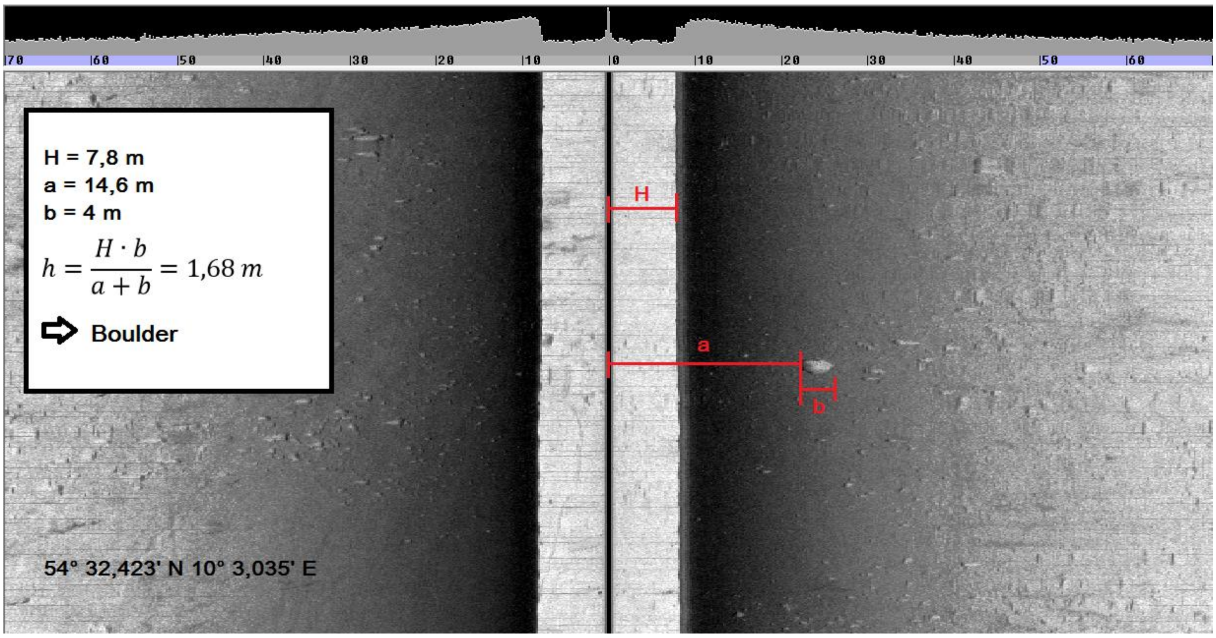

Fig. 18: Example of height measurement of a boulder.

5.3 CTD

A CTD sensor was used to measure temperature, depth and conductivity. With this data it was possible to calculate a sound velocity profile from temperature, salinity and pressure. A sound velocity profile is important to calibrate the multibeam echo sounder and the seismic measurements, because of the needed time for the rays to penetrate the water before reaching the sea bottom. Only with a sound velocity profile correct depths can be calculated by the analysis software.

On this cruise two sound velocity profiles were generated. The first one on 05.10.2015 at 12:09 and at 54° 32.47' N 10° 7.33' E. The water depth is 18.2 m at this point. The second one was measured on 08.10.2015 at 14:55. The ship position was 54° 32.01' N 10° 4.42' E, the water was 23.1 m deep. At both locations the sensor was let down nearly to sea bottom with help of a rope on the port side of the ship. The maximum depth of the sample location was marked on the rope to prevent a too long rest of the sensor at sea bottom. The data saved inside of the used sensor was transferred to a computer after the measurement.

Fig. 19: CTD Sea and Sun technology from the Geomar

5.4. Multibeam echo sounder

5.4.1. Multibeam echo sounder in general

A multibeam echo sounder measures water depth and helps to map a rather large topography in short time with an acceptable resolution. It has about 20-80 beams, which emit a frequency of 12-15 kHz.

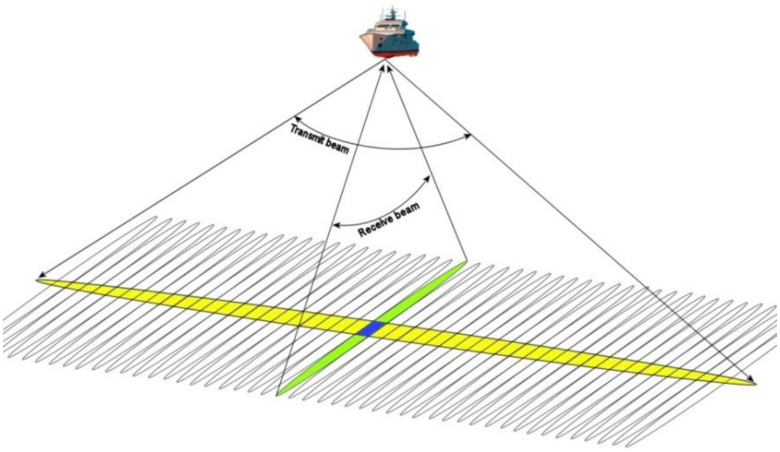

Fig. 20: Multibeam echo sounder

For shallow water, higher frequencies around 50 kHz are used. The transmit beam (yellow)(Fig. 20) has a opening angle of 140° orthogonal to the ships keel and about 1-2.5° in width. For creating a "single" beam of these extends, the positive and negative interference of several circle-shaped beams is used. Their shape depends on water depth and it's sound velocity, the used frequency and impulse length and the transmitter's diameter.
Hydrophones, which only receive from a certain area parallel to the ships movement direction record the backscattered signals (green)(Fig. 20). Therefore, the only data collected is from the small overlapping area of the transmitting and receiving beam (blue).
We used the multibeam echo sounder system, which is called “SB 3050”, produced from the company named Elac. The system operates at 50 kHz frequency band up to a water depth of approximately 3000m.

5.4.2. Results of Multibeam echo sounder survey

The SeaBeam 3100 produced by the ELAC company has been used. The swath angle was 140°, the beaming rate 193 beams per second and the frequency 53 kHz.

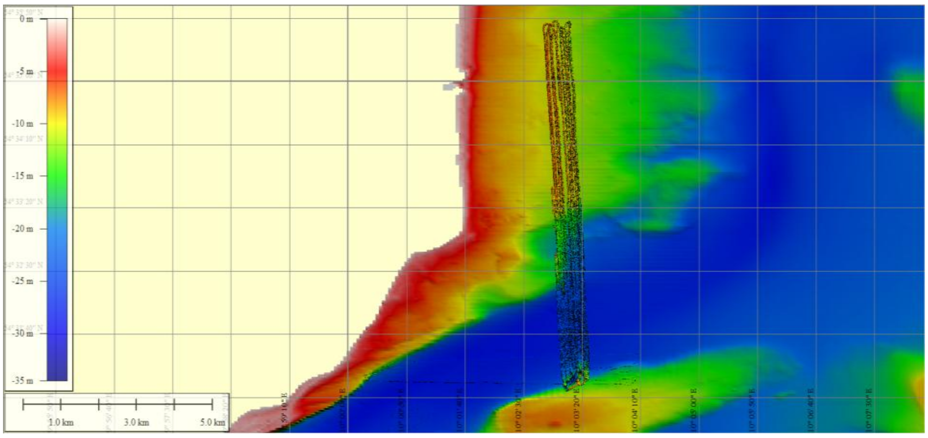

Fig. 21: Recorded Multibeam data vs. BSH/Alkor447 data

In an area (54° 35.5‘ N, 10° 3‘ E; 54° 35.5‘ N, 10° 3.7‘ E; 54° 31.2‘ N, 10° 3‘ E; 54° 31.2‘ N, 10° 3.7 ‘) situated northern of Mittelgrund a more or less continuous Multibeam data set has been recorded. The data set has been reprocessed with the second sound velocity profile (08.10.15) because the first one (05.10.15) seems to have some errors. There are some gaps in the data due to the shift of the ship track because of the bad weather.
The heavy weather conditions even influenced the data quality.

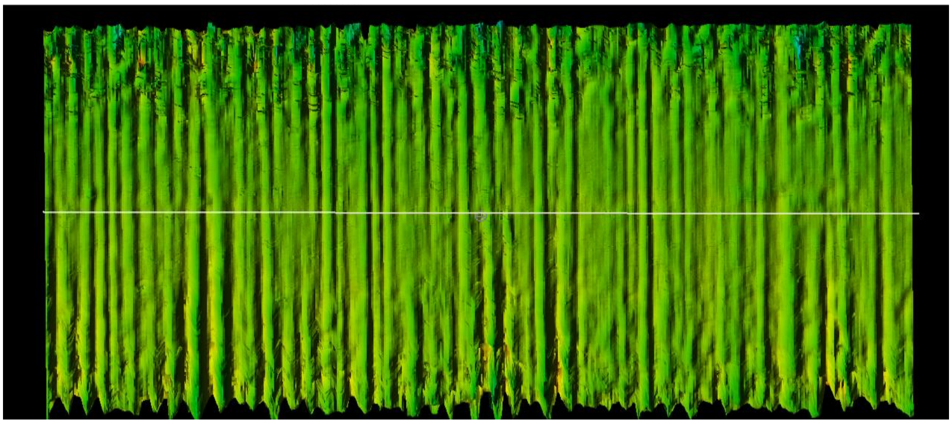

Fig. 22: Example for a long Track Data Not Corrected for Heave.

In the data the significant wavy pattern is visible (Fig. 22 and Fig. 23) caused by none or wrong heave correction. This fact makes also pitch and roll artifacts probably (Fig 26, 27, 28).

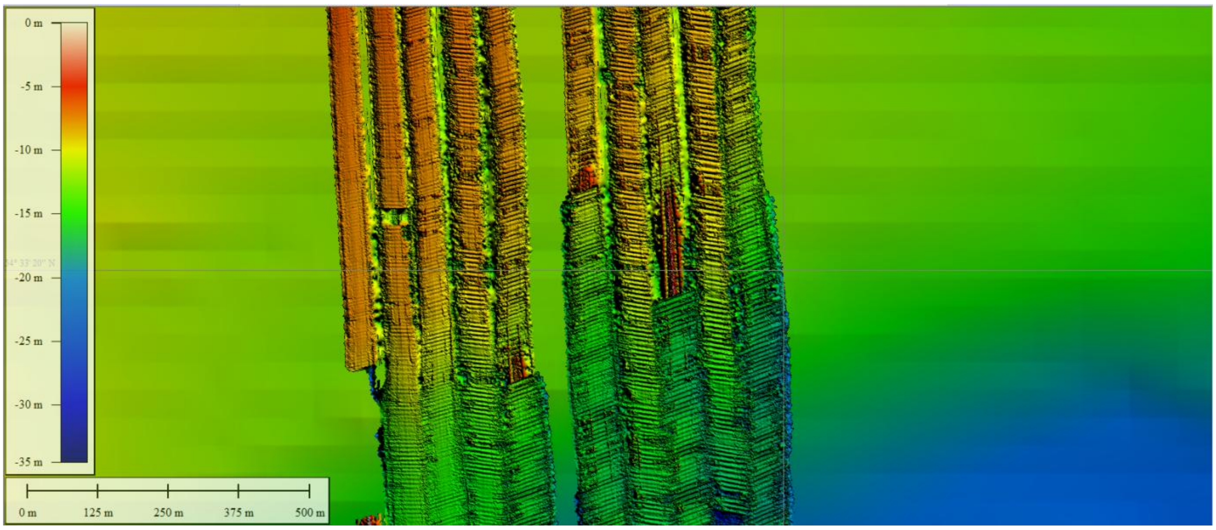

Fig. 23: Wavy patterns in the data and depth errors through manual depth ranging.

Another problem was that automatically depth ranging was not working because of the muddy underground in the deep area north of Mittelgrund. Therefore the center depth of the Multibeam system had to be adjusted manually. This led to errors in case of fast changes in depth (see Fig. 23).
In general the measured data has a shift of up to 4m depth compared to the data from the Federal Maritime and Hydrographic Agency (BSH) and the data from Alkor cruise 447. This problem and the wavy patterns (also the pitch and roll errors) maybe can be solved with the further processing of the data (no processing of the data except the new sound velocity).

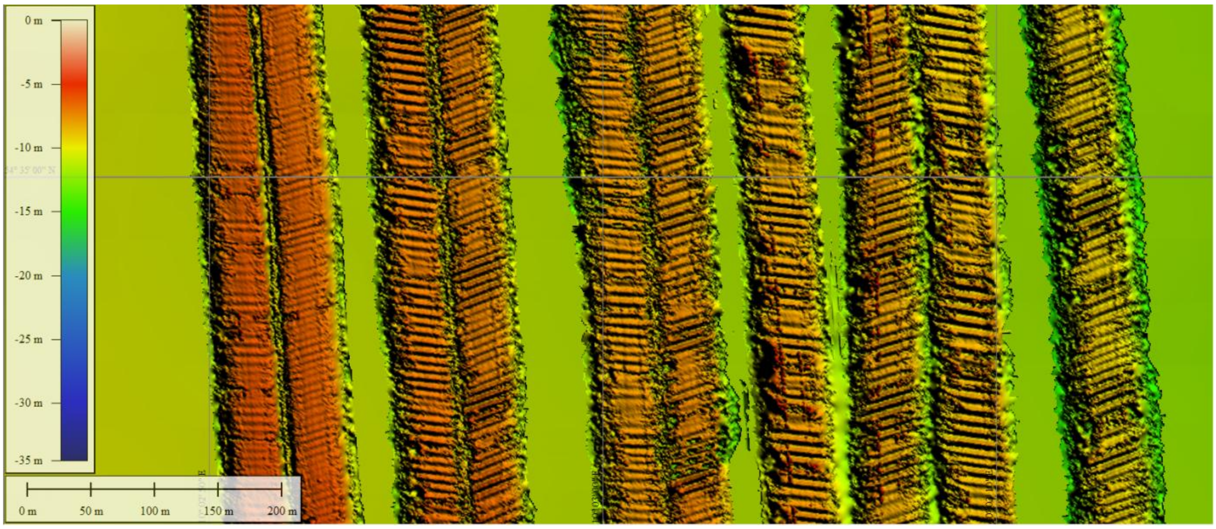

Fig. 24: Unnatural looking lines of peaks.

Unless of this problems some features are notable with the restriction that this possibly even could be artifacts or the appearance of the features could be deformed.
Firstly in Figure 25 a straight line of peaks can be found on the third and fourth track from the right. This looks more like an artifact or error due to the continuous orientation in movement direction. But on these tracks moreover some bigger more natural looking elevations can be found. These are maybe rocks or at least things which are disturbing the ray paths.

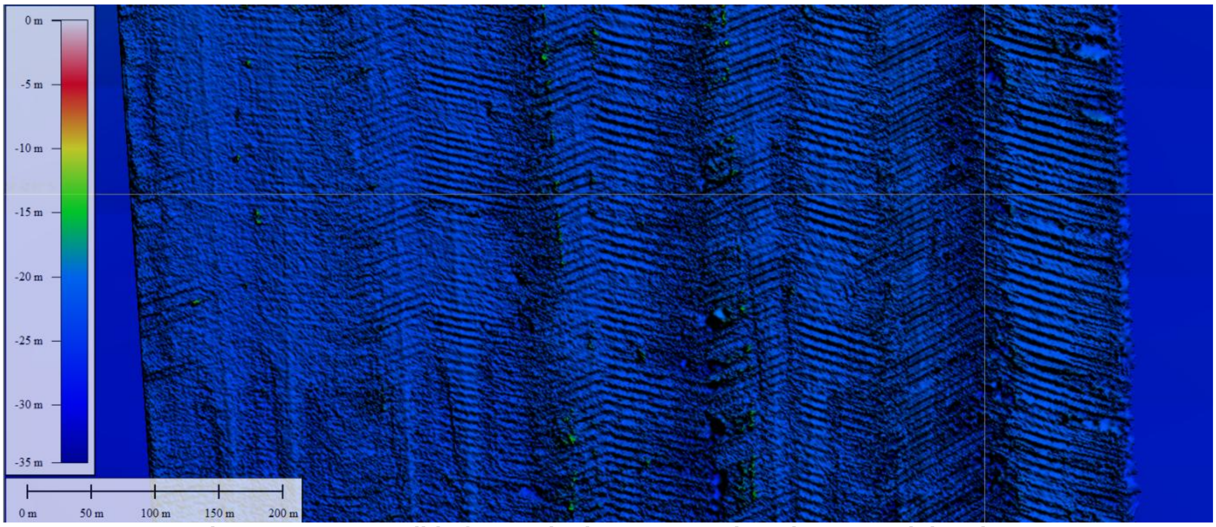

Fig. 25: Some possible feature in the center and on the upper right edge.

Furthermore in Figure 25 some peaks are shown. This area should be muddy so it is not clear what could cause this (possibly rocks). At the right edge some pockmark similar features can be found but they are probably shadow zones of rocks or other things on the ground.

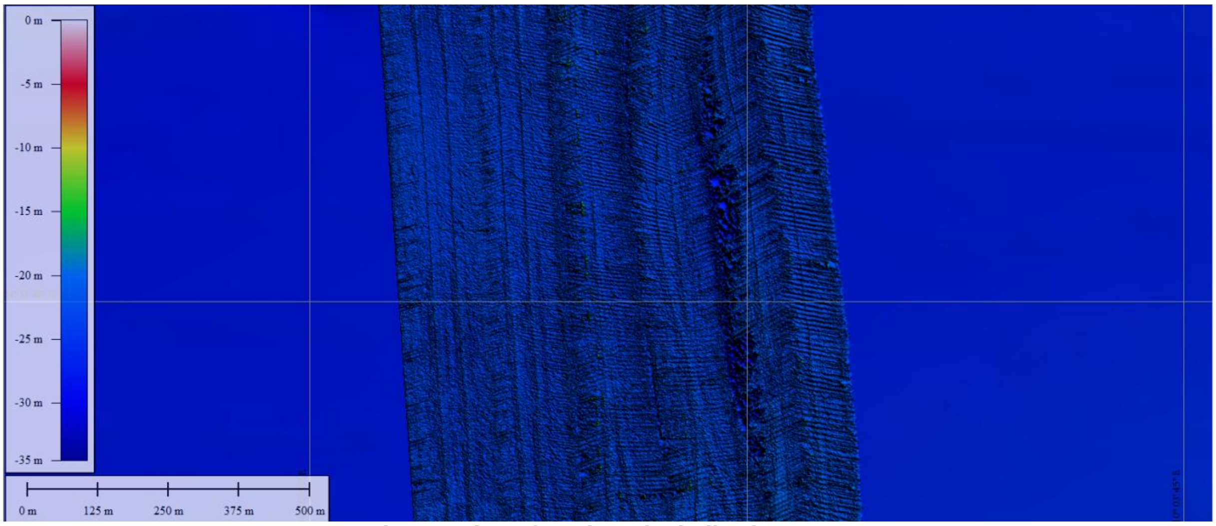

Fig. 26: Line of pockmark similar features.

The most notable feature takes place in Figure 26. A 750 m long line of pockmark similar features can be found. Although such big a group of unknown pockmarks is improbable, there must be something triggering these abnormal signals. The fact that this place was covered from both sides with Multibeam survey makes this phenomenon more interesting because an error or artifact becomes more improbable.

But before interpreting all these features the dataset need to be corrected, freed from artifacts and processed more in detail.

5.4.2.1 Roll Artifacts

Roll affects the MBES data in both the horizontal and vertical planes, and more so on the outer beams.

There are 2 cases of the roll artifacts:

• Roll Angular Misalignment between the MBE transducer and the MRU.
• Bad roll data from MRU.

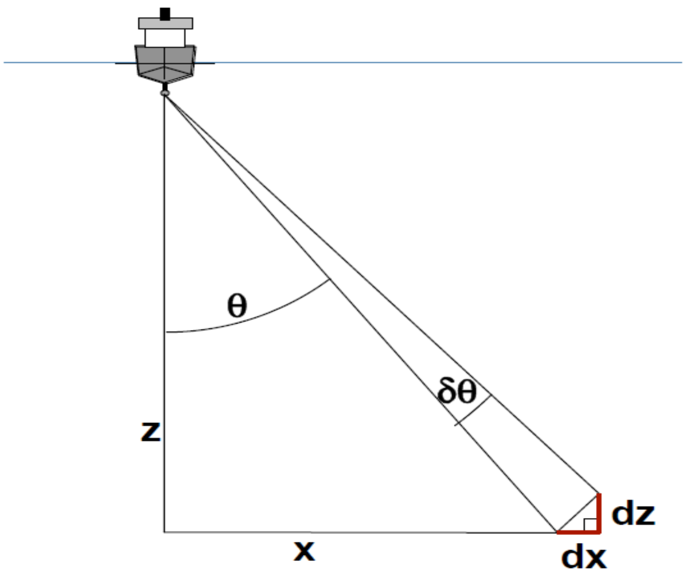

Fig. 27: Roll effect.

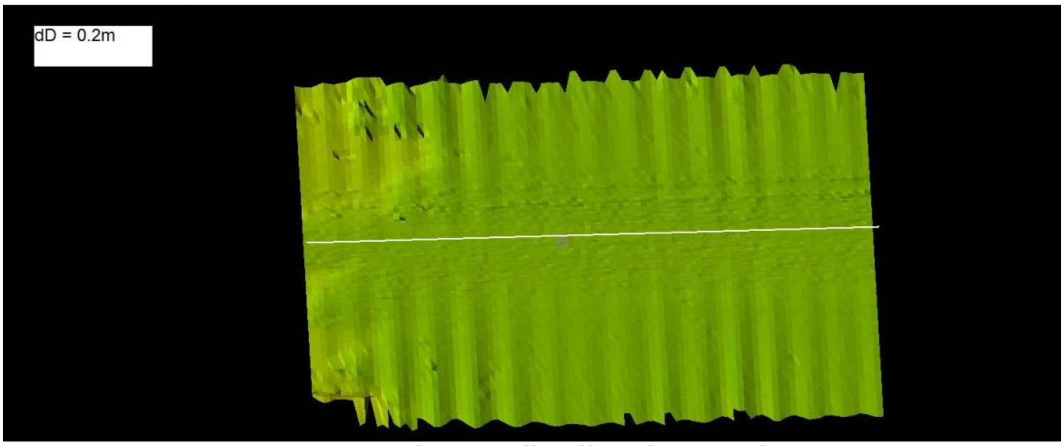

Fig. 28: Roll Artifacts in MBES data.

5.4.2.2 Pitch angle artifacts

Pitch misalignment between the MBE transducer and the MRU (δφ) can lead to horizontal and vertical error.

For example, 5o pitch angle errors can result in a depth error of 0.5%of the total water depth. But, since the ensonified area is generally aimed downward, the horizontal error is always greater and the significance of the pitch error is increased with depth. Such Pitch alignment can be verified by comparing two lines run in opposite directions over a slope or an object at the same place.

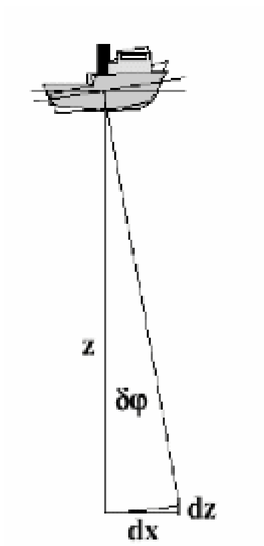

Fig. 29: Pitch misalignment between MRU and MBE.

5.5. Sediment echo sounder

5.5.1 Sediment echo sounder in general

A sediment echo sounder can be considered a single beam echo sounder operating with a very low frequency of 0.5 - 16 kHz. Due to the low frequency, it is possible to get some seismic images of the upper sediments up to 200m depth. As it takes a lot of energy to create a low frequency signal, often parametric echo sounders are used. They are able to interfere two high frequencies to create a narrow beam with a low frequency as a result.

Fig. 30: Sediment echo sounder of the posidon (POSEIDON-Handbuch-2012)

We used the SES-2000 standard system from Innomar with a low frequency bandwidth of 2-22 kHz and a sediment penetration of up to 50 meters. We reached a penetration of about 15 meters. The frequency dependent resolution can be as high as 5cm. The SES-2000 consists of a signal transmitter- and receiver module mounted in a shaft in the ship's hull and a computer for visualizing the data.

5.5.2. Results of Sediment echo sounder survey

The SES collected data almost throughout the entire expedition, though due to the heavy swell the first two days a lot of the data was unusable.

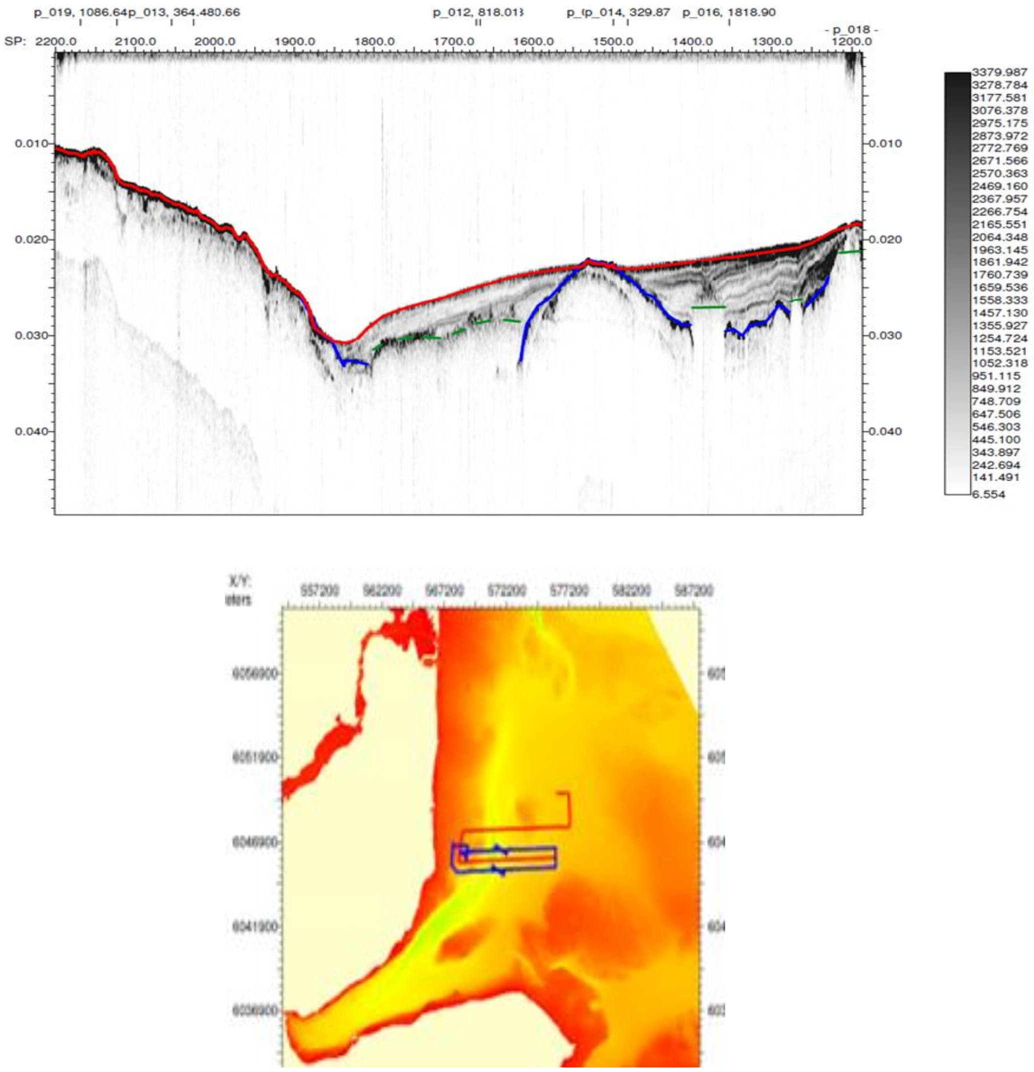

Fig. 31: Profile from the Eckernförder Bay made with Matlab 10b

Fig. 32: Transmitter/receiver module of the SES-2000

Figure 31 shows a pass along the exit of the Eckernförde Bay. It depicts a sector of 1 kilometer from northwest to southeast. The seafloor (red line) is clearly visible. Up to 6 meters deeper another strong reflector (blue line), partially reaching to the seafloor, can be found. We can distinguish between two different types of sediments. In the shallower waters there is a fairly homogeneous sediment layer consisting of sand and gravel (found out with sediment probes). This might originate from washed out glacial marl and continues beneath the second type of sediment, which fills the deeper channels between the coarse sediments. The sediment probes we took indicate this to be the water saturated black Baltic mud with a depth determined with the two way travel time of up to six meters. Within the mud there are several weaker reflectors that may be formed by varying sedimentation rates over time. The lower reflector is partially interrupted by another reflector beneath which the signals disappear. This is caused by a rapid change of the acoustic impedance in the different layers. One reason for that can be gas saturated sediments (green lines). Gases like methane and carbon dioxide can be formed by fermenting organic materials, being collected at the seafloor.

5.6 Sediment Samples

5.6.1 Jaw gripper

Fig. 33: jaw gripper of the Poseidon (GEOMAR)

The gripper, also named Van-Veen-gripper is available in various sizes and for different weights of sediments. It consists of two dredger bucket. Before the dredger buckets get deployed, they are pulled apart and hold open with a hook. If the gripper reaches the sea floor, the tension of the rope gets released and the buckets close when the gripper is pulled up to the surface. Because the gripper is small, you can’t see layers of the sediment. It’s only possible to get an impression of the sediment layer of the sea floor.
If the waves are high or the water is depth, the gripper is unusable.

We used the gripper to get probes of the sediments at the following measuring points.

1. Stony sea floor: 54° 34’ 42.5’’N & 10° 3’ 11.5’’E
2. Second probe of a stony sea floor: 54° 34’ 40.7’’N & 10° 3’ 3.2’’E
3. Sandy/sludgy sea floor: 54° 33’ 7.6’’N & 10°3’ 4.9’’E
4. Second probe of Sandy/sludgy sea floor 54° 33’ 14’’N & 10°3’ 4.9’’E

5.6.2. Results of sediment samples

The sediment samples of this cruise were collected with a jaw gripper. On this way we get samples of some cm of the upper laying sea bottom. These samples are from different stations along the Side Scan Sonar track and have distinctions in appearance. Sample 1 from 54° 34.67' N 10° 3.19' E consists of coarse sand with small rests of plants and marine animals. It was retrieved from 7.2 m depth. Sample 2 (54° 34.68' N 10° 3.07' E) located at nearly the same depth contains also gravel and some bigger parts of plants. In sample 3 (54° 33.12' N 10° 3.08' E) the content of sand is low, also it is much finer in grain-size. This sample is lightly muddy. Located at 54° 32.21' N 10° 5.37' E and in a depth of 22 m sample 4 is very muddy and includes a putrid smell. A comparison of these samples with the collected Side Scan Data confirms the dependence on depth. Sediment distribution at low depths has a coarser graining and includes marine life. With increasing depth the grain-size gets smaller and the percentage of mud rises. At depths below 20-22m sediments are anoxic and very muddy. Anoxia comes from a lack of ventilation. This results are coherent with the distribution shown by *Orsi et al.(1996).*

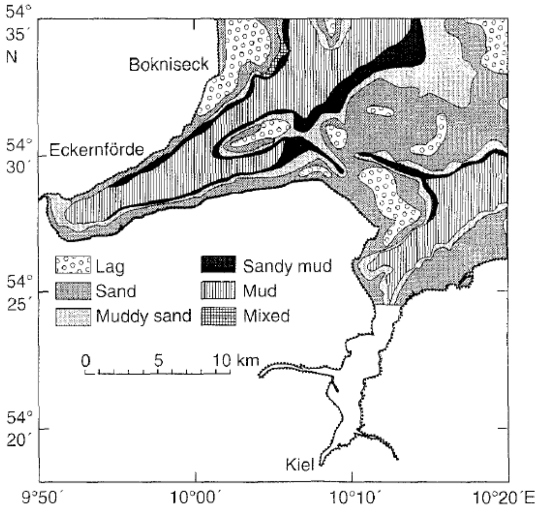

Fig. 34: Sediment samples (1=a, 2=b, 3=c, 4=d).

Fig. 35: Sediment distribution after *Orsi et al. (1996)*.

Sample No.	Position	Depth	Comments
1	54° 34.67' N 10° 3.19' E	7,6 m	coarse sand, rests of plants and small marine animals
2	54° 34.68' N 10° 3.07' E	7,4 m	gravel, coarse sand, rests of plants and small marine animals
3	54° 33.12' N 10° 3.08' E	13 m	Light muddy, fractions of fine sand
4	54° 32.21' N 10° 5.37' E	22 m	muddy, putrid smell

Tab. 1: Overview of sediment samples.

6. Conclusion

The goal of the expedition was to identify the structure of the Baltic seafloor, especially the existence of subsurface gas inclusion.

The ocean bottom seismometer data used from one OBS yielded three inclined seismic layers with increasing velocities up to a thickness of about 300m. The reflection seismic showed high impedance changes within the seafloor indicating gas inclusions. With the pictures of the side scan sonar different locations were selected to take sediment samples. These show the depth dependency of the sediment distribution with coarse sediments in shallow water and anaerobic mud in deeper water. Due to the heavy weather the multibeam data contain a lot of artifacts (e.g. roll and pitch artifacts), which need to be processed to get usable data. With the sediment echo sounder the coarse sediments can be distinguished from the Baltic mud, which contains gas inclusions. The preliminary results yield signs of subsurface gases but for proof of pockmarks and further interpretation more in-depth processing of the data is needed.

7. Appendix

7.1. Talk about the formation of the Baltic Sea

7.1.1. Introduction

The „Ostsee“, also named the Baltic Sea, is a marginal sea of the Atlantic Ocean. It is with an age of about 12.000 years a relatively young sea and has an extend of 1.720.000 km^2 and a volume of 21.700 km^3. The maximum depth is 462m and the mean depth is 52m. Because of the 472 km^3 of Inflow of fresh water from the neighboring rivers, the Baltic Sea has a very low salt content.

7.1.2. History of the Baltic Sea

Morphological seen the Baltic Sea is divided in two parts, by the continental shelf.
On the one hand, there is the west European shelf, which is young and instable and on the other hand there is the old a stable east European craton.
A part of the east European craton is the Baltic Shield, which collides with the supercontinent Gondwana, so the ocean Tornquist, was closed. Because of erosion, the mountains where dissipate. In place of the mountains in this area stayed the “Transeuropäische Störungszone”, which is still seismic active. So, the formation of the Baltic Sea take place in the Tertiary (for about 2,6 million years), because of continental drift.
An unexpectedly strong sign of the ongoing geological development yielded the earthquake of 16 December of 2008. The epicenter was about 30 km east of Malmö , in the middle in the Tornquist Zone and the concussion was noticeable up to Schleswig Holstein.
The History of the Ostsee, starts with the ending of the last Ice Age, which was 110.000 – 12.000 years before today. While the glaciation of Scandinavian, the transport of unconsolidated rocks with the glacier, big rills where scraped in the bottom. Because of this the Baltic Sea basin was formed. The transported material was sediment in form of Endmoränen in Schleswig Holstein.

7.1.3. Formation of the Baltic Sea

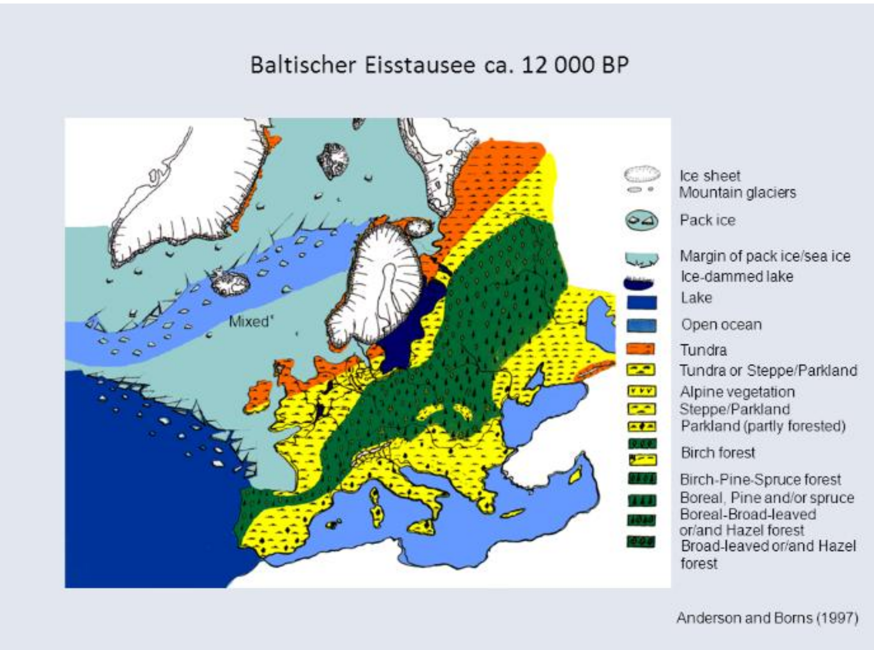

Fig. 36: Baltic Ice Lake

The origins of the Baltic Sea can be divided into five phases.
First, the Baltic Ice Lake was created by the melting of the Vistula ice and melt water, which was dammed.

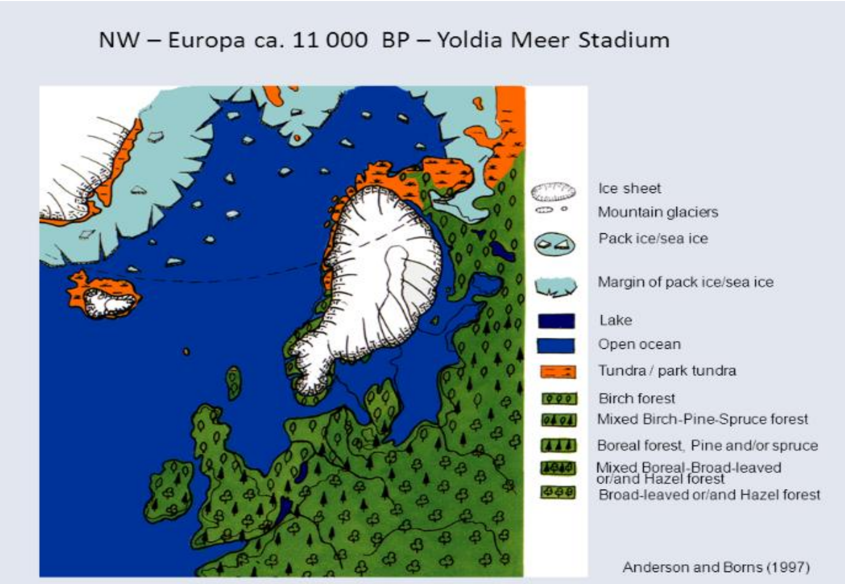

Fig. 37: Baltic Yoldia Sea

The water level increased because of still melting ice cover over Scandinavia and for about 10.000 years ago, there was an overflow of the Baltic ice sea at the Swedish central valley. This led to a lowering of the water level and because of the suction of the water to the increasing connection between the north and the Baltic Sea. Therefore for the first time, saltwater entered in the Baltic Sea. The new sea was named Yoldia sea.

Due to the continuing isostatic compensation of the Baltic shield, led to the closing of the connection between the North Sea and the Baltic Sea again, this resulted about 9500 years ago to the decrease in salinity. The new lake was called the Ancylus Lake. Overall, the Scandinavian Peninsula in Norway rose a total of 300 meters. In Stockholm, the uplift is still 4.2 millimeters per year. The Ancylus Lake had a bigger Area, than the Baltic Sea of today. Due to the strong melting of ice cover about 8,000 years ago, this led to an increased sea water level. Moreover the water level of the Ancylus Lake was rising too, which led to an overflow at the Skagerrak 8000 years ago.

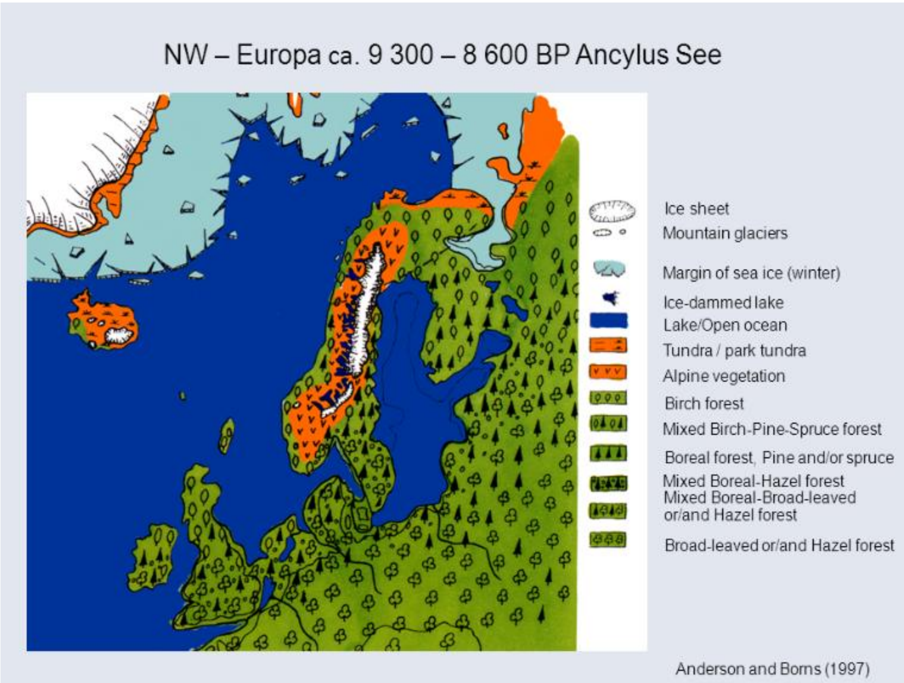

Fig. 38: Baltic Ancylus Sea

Since Öresund and the Belt were much lower than today, more salty seawater from the north sea could enter the new Litorina Sea. The emergence of the Litorina sea finally initiated the formation of a Baltic Sea in its present form. Sea level rise and land uplift particular continue designing the Baltic Sea Region: The isostatic uplift results that the Litorina Lake became narrower and the inflow of saltwater was decreasing. Through the rivers there was an additional inflow of fresh water. The Baltic Sea exists in that form since about 1500 years. The former High water level can be detected on the basis of fossil cliffs at the coast of the Baltic Sea.

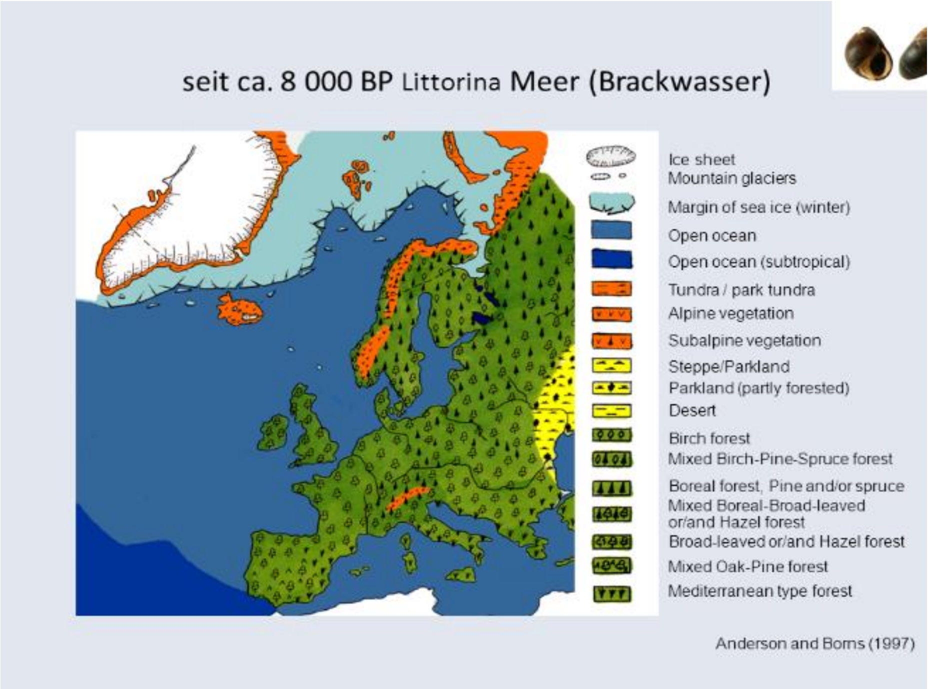

Fig. 39: Baltic Littorina Sea

7.2 Talk about Seafloor mapping

7.2.1. Introduction

As an introduction, let's talk about why seafloor mapping is such an important thing in marine geophysics. The first intention in the late 19th century to do simple mapping by manual sounding was to improve navigation. Knowing water depth is a great safety factor for ship and crew. As the geophysical and oceanographically background got more and more important around the same time, many interesting facts could be revealed. Wegener's theory of plate tectonics got evidence by the discover of mid-oceanic ridges and the hotspot line near Hawaii. In biology, big steps were made as well, e.g. by surveying the new ecosystems in seamounts, and even the exploration of resources like oil and mangan was taken to the next step.

Before discussing some important tasks for the correction of data, let's first have a look at the procedure of seafloor imaging and depth measurement with sound itself:

1. sound signal is transmitted
2. energy gets scattered back by seafloor and other obstacles
3. amplitude and traveltime is saved by receiver
4. optional display of data and image in nearly real time

Traveltime is measured for determining depth and the amplitude enables us to create a image of the seafloor beneath us. For imaging some of the system's properties are important: For example, the geometry of sensor and target, regarding slopes or the angle of the incoming energy, as well as the physical properties of the backscattering item, like its microscale roughness, composition and density.

As we deal with sound, a common medium, there are several other possibilities to have data errors. Disturbing noise by the ship and crushing ice, coverage by ice shields, air bubbles and fish swarms, as well as the ships movement are just some of them.

7.2.2. Sound propagation in water

There are 3 topics concerning the sound propagation in water which should be discussed. For getting correct data their correction is very important.

First, we should remind us of the fact that water attenuates. Therefore we should always consider which frequencies to use for a certain survey. High frequencies mean a high attenuation, but a good resolution as well, for lower frequencies it is the other way around.

Second, sound velocity depends on water properties. Values of 1450 - 1550 m/s are normal - but with changes of ±3m/s per Δ°C in temperature, ±1.2m/s per Δ ppt in salinity and ±0.5m/s per Δ 30m in depth a CTD survey is of great importance. A sensor measures conductivity, temperature and depth on its way down to the seafloor and back. Therefore we can calculate a sound velocity profile for the surveyed area.

Third, snell's law has to be taken into account. As we measure depth with traveltime, having incorrect data for the path length is inacceptable. The water column has different sound velocities in depth, so according to snell's law sound is refracted towards the area of slower sound speed. With the CTD data it is possible to calculate the path sound rays will take and correct our depth measurements.

7.2.3. Multibeam echo sounder

A multibeam echo sounder measures water depth and helps to map a rather large topography in short time with an acceptable resolution. It has about 20-80 beams, which emit a frequency of 12-15 kHz.

For shallow water, higher frequencies around 50 kHz are used. The transmit beam (yellow)(Fig. 40) has opening angles of 45 -180° orthogonal to the ships keel and about 1-2.5° in width. For creating a "single" beam of these extends, the positive and negative interference of several circle-shaped beams is used. Their shape depends on water depth and its sound velocity, the used frequency and impulse length and the transmitter's diameter.

Hydrophones, which only receive from a certain area parallel to the ships movement direction record the backscattered signals (green)(Fig. 40). Therefore, the only data collected is from the small overlapping area of the transmitting and receiving beam (blue).

7.2.4 Sediment echo sounder

A sediment echo sounder can be considered a single beam echo sounder operating with a very low frequency of 0.5 - 6 kHz. Due to the low frequency, it is possible to get some seismic images of the upper seafloor up to 200m depth. As it takes a lot of energy to create a signal of these properties, often parametric echo sounders are used. They are able to interfere two high frequencies with a narrow beam of low frequency as a result.

7.2.5. Sidescan sonar

A side scan sonar is used to get more detailed information about the seafloor with high resolution imaging and the possibility to derive the seafloors composition from the measured amplitudes. It operates with frequencies of 9-500 kHz and has two single, separately adjustable beams of 20-40° orthogonal to the ships keel with a width of 1-2°. As they can have different settings, e.g. a sloping seafloor can be leveled out. Generally, solid items as metal and rocks backscatter very well and sediments and other weak areas don't. The intense of backscattering is pictured by different shades of grey. It differs from model to model, if dark colours are used for high or low backscatter. If operating with a side scan sonar, it is always important to consider, that big objects or a rough seafloor have big shadow areas which can cover up many things. Besides, only objects which scatter enough energy back to the side scan sonar are visible at all.

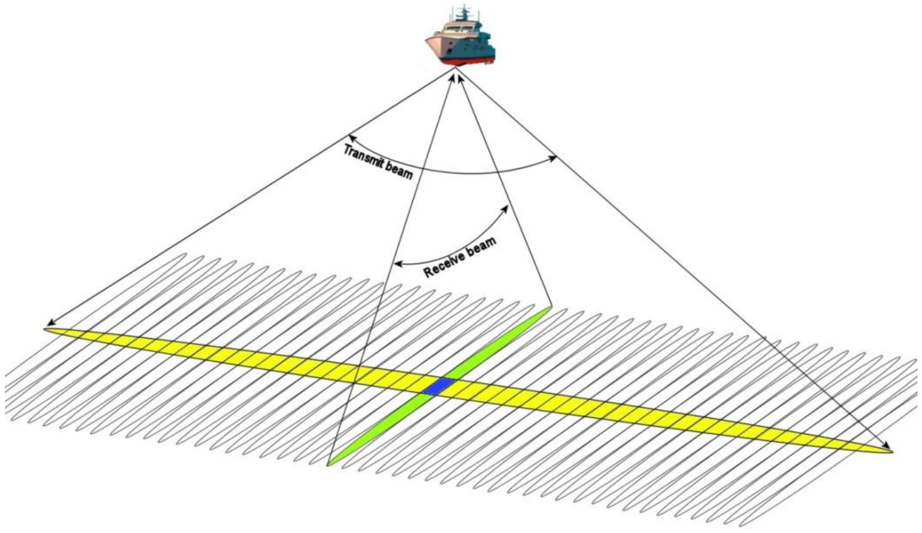

Fig. 40: Side Scan Sonar

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Cruise Report
POS491/2 *Poseidon*

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Jill Peikert   Antonia Wilke

December 4, 2015

Contents

1 Introduction

The second part of the research cruise POS491 on *RV Poseidon* took place from October 09.–13. 2015 in the Belt Sea located in the south-western Baltic Sea. Measurements were done in the Bays of Eckernförde and Kiel and around Fehmarn (Fehmarn Belt and western Bay of Mecklenburg) in German as well as Danish territories. The cruise is operated by the *Christian-Albrechts-University Kiel* in tight cooperation with the *GEOMAR Helmholtz Centre for Ocean Research Kiel* and has its starting and ending point in Kiel, Germany.
The aim of the cruise was to practically teach the contents of the course *Messgeräte der Geophysik* (measuring instruments in Geophysics). The students were supposed to get a first impression of the tasks on board of a research vessel and learn the handling of geophysical instruments, techniques and data. After the cruise, they evaluated the preprocessed data and interpreted the results.
During the entire time, the multibeam- and the sediment echosounder collected data. In the German territories Bay of Eckernförde, north and west of Fehmarn and on the connecting, long profile between the Bay of Eckernförde and the western Bay of Mecklenburg additional 2D seismic profiles were recorded. Three Ocean Bottom Seismometers (*OBS*) were set out at the east coast of Fehmarn to survey a refraction seismic profile. In both, the German and Danish part of the Fehmarn Belt, tightly gridded areas of sidescan sonar were recorded. In the Bay of Eckernförde, the target of investigation was to map the distribution of gas in the sediments. The intention around Fehmarn was to further understand the sedimentation processes filling the Fehmarn belt. The long seismic profile between the Bay of Eckernförde Bay and the western coast of Fehmarn gave additional information on the structure of the westernmost Baltic Sea and the OBS - as well as the sediment echosounder data extended the geophysical information on this region.

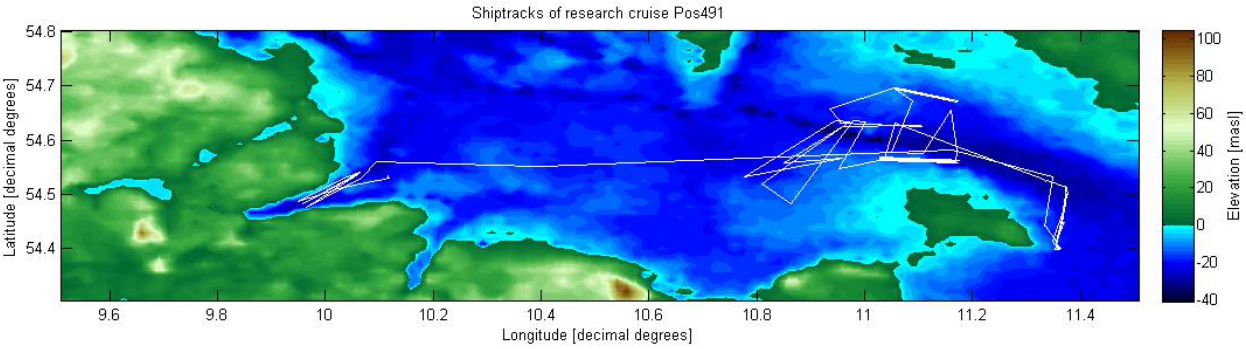


Figure 1: Shiptrack of *Poseidon* on cruise POS491/2

2 Narrative

2.1 09.10.2015

Poseidon left Kiel on the 9th of October 2015 at about 10:30 a.m. heading towards the Bay of Eckernförde. First we took a CTD measurement at $54°31.997N$ $10°06.997E$ on the western side of the *Stoller Grund* in a water depth of $17.7m$. We were interested in the sound speed profile along the water column for calibrating the multibeam-system. From there on, we started recording both multibeam-system and sediment-echosounder. At 1:45 p.m. we intended to release sidescan-sonar, streamer and airgun. We started recording sidescan-sonar at 2:30 p.m. The airgun instead was not operable because of a missing sealing ring. The second air gun on board was observed to be inoperable as well due to an air leakage. Therefore, the first airgun had to be repaired and could not be released before 2:40 p.m. There we started recording a seismic profile in the Bay of Eckernförde in form of 5 parallel lines in northeast-southwestern direction northwards to the shallow water *Mittelgrund* which is located about $54°30.5N$ $10°03.0E$. Afterwards we continued the seismic recording on our way to Fehmarnbelt. The airgun was shot in intervals of 3 seconds.

2.2 10.10.2015

We continued seismic measurements using both, streamer and ocean-bottom-seismometer and took several sediment-samples. Only a few minutes after midnight the airgun failed because of water inside the lifting body but could soon be repaired. The measurement was continued until morning when we reached the eastern shore of Fehmarn. We prepared three ocean-bottom-seismometers which were placed along a north-west-south-eastern profile with about $2nm$ distance from each other. We shot the airgun in intervals of 6 seconds on the profile passing the OBS one by another. Additionally, we recorded sidescan and were explicitly searching for possible sediment sample stations. We determined five different locations with different types of backscattering on the sidescan image. We were expecting different types of particle size, rocks and sediments on the seafloor. After successfully recollecting all three ocean-bottom-seismometers we took the predetermined sediment samples using a *Van-der-Veen-Grab*. Actually all samples were pretty similar. On top always was to be found a layer of clay – sometimes with worms or mussels. The silt-content was very low. Below was another layer of clay but without any oxidation processes left. At first ($54°23.840N$ $11°21.573E$) and fifth station ($54°29.943N$ $11°22.484E$)where the sidescan image showed no features at all, we found nothing besides these two layers. At the third station ($54°24.372N$ $11°21.383E$)where sidescan imaging showed high amount of backscattering, we found some smaller rocks on the seafloor and inside the sediments. Namely, a lot of flint and a few granites and marine (biogene) sediments. This sample was badly sorted. Finally, in the sample of the fourth station ($54°26.859N$ $11°22.005E$), the two layers were disturbed by wormholes. Afterwards we released airgun and streamer again and headed towards the western shore of Fehmarn where a profile in north-southern direction was planned. Originally we intended to record sidescan as well but the sidescan failed after a short time. Therefore this measurement was cancelled.

2.3 11.10.15

We continued the profile for seismic measurements of the previous night westwards of Fehmarn until late morning when we reached the German-Danish border where airgun use was no longer permitted. We then intended to start sidescan measurements but the sidescan was defect because of a short circuit inside the cable which happened because the cable was heavily squeezed on its mounting at higher speeds above $4kn$. The reparation took about 3 hours and we could not start recording before 6:30 p.m. Being inside the survey area, we went along a narrow profile of 6 lines in north-west-south-eastern direction with line intervals of $70m$ to cover the entire survey area. To prevent damages as happened in the afternoon, speed was reduced to $3kn$.

2.4 12.10.15

The profile from last night was continued until early morning. We left the survey area southwards and crossed the Danish-German border for a second sidescan-survey area located north of Fehmarn. We started following 13 lines in east-western direction at about quarter to 10. Again we tried not to exceed $3kn$. As we intend to arrive in Kiel at about 10 in the next morning, we started packing computers, cables, streamer and additional devices into crates. We took apart the airgun for an intense cleaning before packing. Besides the sidescan (which still is towed behind the ship) and its computer, one computer remained for processing the seismic data i.e. converting into seismic units, stacking for CMPs (common-midpoints) and migration. A lot of multiples remained but a first view already showed some subsurface features along the track from Bay of Eckernförde to Fehmarnbelt.

3 Study area

The area of investigation during our research cruise was the south-western Baltic Sea along German coasts. Figure 1 displays the cruise's route through the Bay of Eckernförde, east and west of Fehmarn and to the north into Danish territory. The Baltic Sea is adjacent to the Atlantic Ocean connected through the North Sea. When the ice shield covering most of Scandinavia approximately $12,000$ years ago melted, the compensatory movement due to decreasing weight and the melted water masses led to the formation of the Baltic Sea in its current extend. Its area comprises $412,000km^2$, it holds a volume of $21,000km^3$ and the mean depth is 52 m. The many river influxes in the northern part decrease the salinity and raise the sea surface regionally, compared to the lower salty influx in the south-west from the North Sea. The ground of the Baltic Sea consists of different sedimentary rocks. In our area, specifically, the soil cover is composed of soft bottom (mainly silt, clay and mud) as well as sand and hard bottom, like till.

swath angle	$140°$
beaming rate	193 beams per second
vertical heave	$< 5cm$ ($8m/s$ wind velocity)
pitch	$< 0.5°$ ($8m/s$ wind velocity)
roll	$< 3°$ ($8m/s$ wind velocity)
frequency	$53Hz$

Table 1: Characteristics of the *SeaBeam 3100* multibeam-System

4 Measuring instruments

4.1 Multibeam echosounder

A multibeam echosounder transmits acoustic waves and reveals information of the ocean floor that is off the ship-track. The principle for this is the scattering of particles on the seafloor which can be induced by incoming beams. This can be used to image structures on the ocean floor which are off the track. The directional characteristic of the multibeam is realized by beam forming and beam steering. As a result acoustic waves coming from different angles can be recorded individually. The high beaming rate can be ensured by a piezoelectric converter that forms an electrical signal into a winging of a small crystal. This avoids vibrations and a stable acoustic signal is generated. The echosounder used during this research cruise is *SeaBeam 3100* by *ELAC* company. A swath angle of $140°$ and the rate of 193 beams per second are used for the measurements. For further information see table 1. One beam has an opening angle of $1°$ longitudinal and $2°$ transversal to the direction of shipping. For $20m$ water depth, often found in the western Baltic Sea, theoretically a resolution of $0.17 \times 0.35m$ per beam can be reached. The measurements in practice show that the entire lateral resolution for a water depth of $27m$ is $\pm 60m$. High resolution data requires an exact velocity depth profile of the water column. The used profile is shown in figure 2.

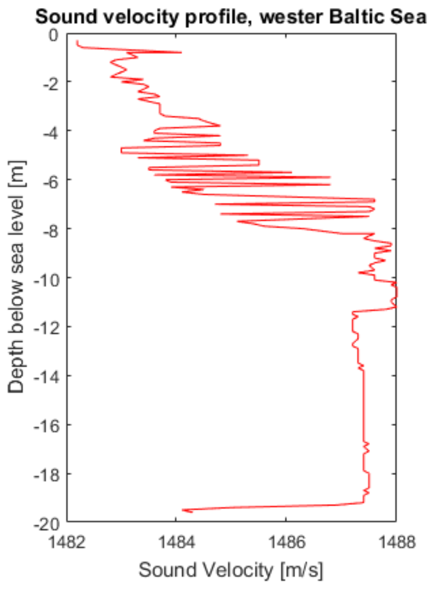


Figure 2: The velocity-profile as measured with the CTD

opening angle	$4°$
penetration depth	$4 - 64m$
vertical heave	$< 2cm$ ($8m/s$ wind velocity)
pitch	$< 0.5°$ ($8m/s$ wind velocity)
roll	$< 3°$ ($8m/s$ wind velocity)
frequency bands	$94 - 110kHz$

Table 2: Characteristics of the *Ennomar SES-2000 standard* sediment-echosounder

4.2 Sediment echosounder

In contrast to multibeam echosounding the sediment echosounder only transmits one vertically oriented beam. The generated pulse is not only reflected by the ocean floor but also by layer borders or other objects in the sub-bottom area. The echosounder is located in the moon pool (a hole in the hulk) of the ship and collects continuously data. The vertical and lateral resolution of the beam, also called *footprint*, is controlled by the reflection coefficient, the attenuation of the signal and the roughness of the layer boundary. As for the multibeam a velocity model is required to convert the travel time into a distance. The non-linear parametric echosounder *Innomar SES-2000 standard* was used during the research cruise. It is widely used for shallow water systems like the Baltic Sea and offers a penetration up to $50m$ into the sediment. The transducer sends a sweep with two slightly different high frequency bands (see Table 2). Interaction between those frequencies leads to interference and a new high or low frequency (secondary frequency) is generated by the parametric effect. The secondary frequency is transmitted in the small window of the primary frequency band and allows a high resolution. Both secondary frequencies are recorded by the receiver, but only the low frequency reflects the sub-bottom data. More data is shown in Table 2.

4.3 Ocean Bottom Seismometer (OBS)

The Ocean Bottom Seismometer is a device for the exploration of the sea floor. It is placed on the seabed and records seismic waves, either simulated induced or of natural earth crust movements. It works self-depended without a cable connection to the ship and can rest on the seafloor for a couple of days. In addition the Ocean Bottom Seismometer records not only reflected, but also refracted waves and it is possible to develop seismic - and sound waves velocity profiles of the seafloor. The OBS operated on this cruise is a self-built device of the Kiel University. It consists of a plastic cylinder which is closed by a cap, so that no water can enter. The cylinder is equipped with a 4.5 kHz vertical geophone, a recorder for the signals and two 12 V batteries. The void can be filled with slabstock to protect the unit. A broadband hydrophone is fitted on top of the cap. The cylinder is mounted on massive cement blocks and a buoy is fixed to mark the position of the OBS. The rope of the buoy has a small anchor, because the signal could be bothered by waves or other water movements. At first a calibration on board of the ship is necessary to make sure, that the instruments work. In order to know when the record begins, a test signal must be induced in the laboratory, which's time is noted. Three Ocean Bottom Seismometers were used for this research, called *Manni*, *Ercan* and *Claudia*, placed in different water depths. The times of entering the ocean as well as reaching the seafloor and the water depth are shown in table 3.

4.4 GI-Gun and Streamer

The seismic configuration of a source and a receiver was realized with a Mini GI-Gun and a streamer cable with hydrophones. If compressed air is released explosively in water, the sent out acoustic waves are reflected, refracted or converted at layers of different impedance. This aides

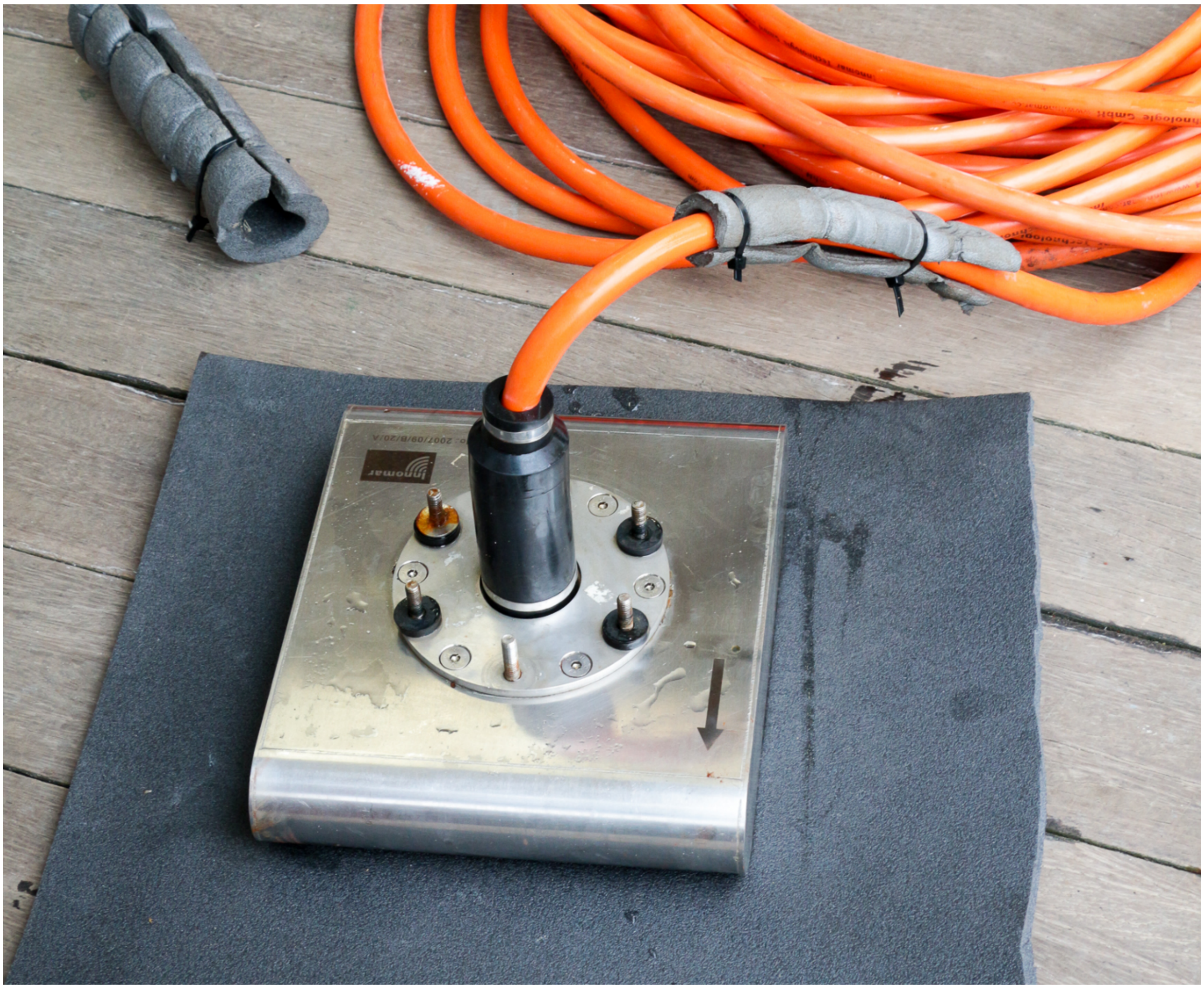


Figure 3: The sediment echolot after recovering it from the moon pool

OBS	time of place (UTC)	time of catch (UTC)	depth
Manni	7:37	12:55	20m
Ercan	8:05	12:20	20m
Claudia	8:36	12:40	23m

Table 3: Release- and catch times for the three OBS

(a) One of the Ocean Bottom Seismometer prepared to be released

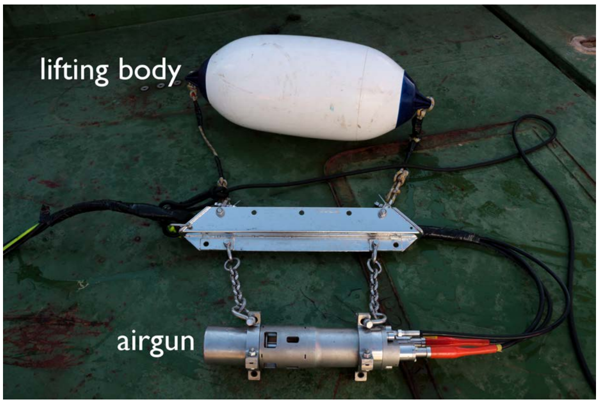
(b) The OBS from inside

Figure 4: The Ocean Bottom Seismometer

to identify structures below the sea floor. An air gun has two chambers that are connected by a small channel. To initiate the explosion, compressed air is inserted under the piston, moving it into the first chamber. Now, the air escapes as a bubble through the second chamber, releasing the sound impulse. The bubble expands until it collapses because of the surrounding hydrostatic pressure. The interfering bubble-signal of the collapse and the oscillation can be restricted with the use of a second air gun. GI-Guns contain two air guns: the generator and injector. The generator is fired first; this blast of compressed air produces the primary pulse and the released bubble expands. When the bubble reaches its maximum size, the injector ports are encompassed. At this point, the generator's internal pressure is far below the outside hydrostatic pressure. Next, the injector is fired and injects air directly inside the bubble. The internal pressure of the bubble is increased by the volume of air released by the injector, preventing its collapse. The oscillation of the bubble and the resulting secondary pressure pulses are therefore reduced. The Mini GI-Gun used during this excursion, has a chamber volume of $45in^3$. for each air gun and works at a frequency of $2Hz - 10kHz$ at $200bar$ pressure and $1m$ depth. It was triggered to send out a signal every 3 seconds. The delay was adjusted to $10ms$. Streamers receive the reflected acoustic waves at a frequency range of $35 - 450Hz$ with a sample interval of $0,5ms$. The $25m$ long oil-filled cable holds 8 channels and an analogue digital converter. Each channel consists of 4 parallel-connected hydrophones.

4.5 Sidescan-sonar

The sidescan-sonar is a sideway scanning acoustic survey method which uses high frequency sound waves transmitted by hullmounted or fishmounted transceiving transducers which beam the sea floor on one or both sides of a vessel. The sidescan gives valuable data on configuration and orientation of sedimentary bedforms, pattern of rock outcrops and location of artefacts, cables and wrecks. A major part of the acoustic energy is reflected away from the sonar, a minor part is lost in the ground and the rest is reflected back to the sonar, amplified and recorded. This part, called backscatter, is used to produce the sidescan images. The reflection towards the transducers shows rock outcrops and sedimentary bedforms in a darker shade. The reflections away from the transducers like features facing away or featureless seafloor parts are shown in lighter shade. We used the *Deep Vision* sidescan-sonar with a frequency of $300kHz$ and a width of $70m$. For further



(a) The GI-Gun

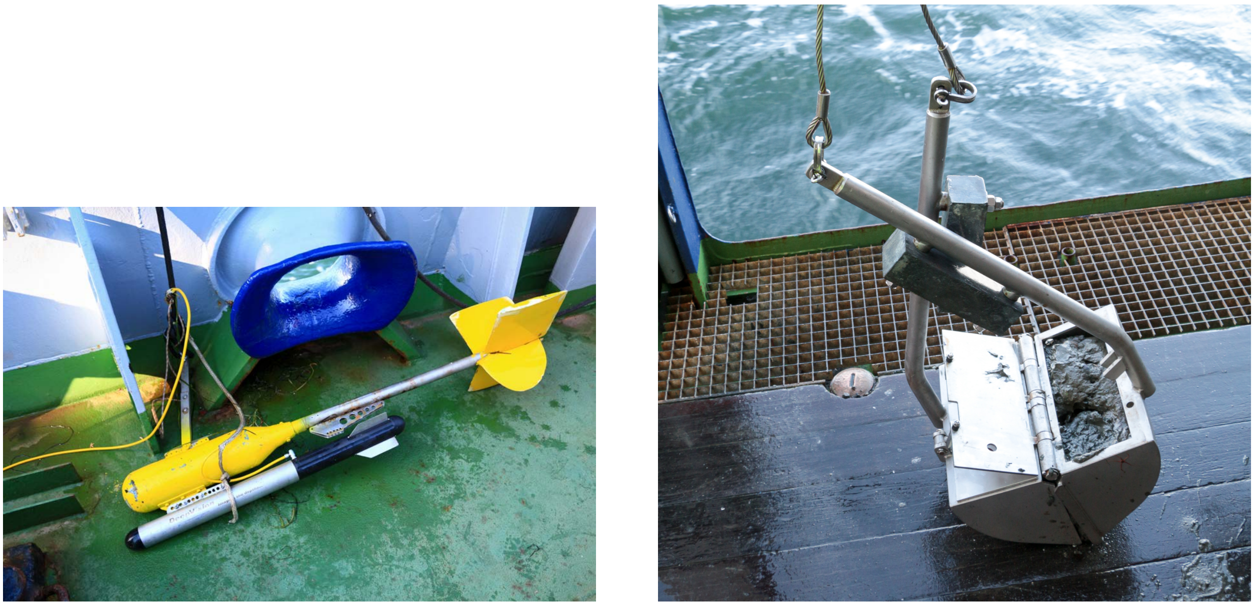

(b) The streamer

Figure 5: Instruments for marine seismics

exploration of the rock outcrops and sedimentary bedforms we used a grab.

4.6 Grab

We used a Van-der-Veen-grab to extract samples of the seafloor surface. Before the grab can be lowered the cheeks have to be pulled apart and the pawl must be fastened in its position. A slow and steady lowering is important to assure that the grab will not close too early. While dropping, the rest of the air within the grab escapes through small holes so the sample will not be contaminated. When the grab reaches the ground the pawl loosens and with a pull of the guide rope the cheeks close. The heavier the grab the more exact the extraction. In our case we took five samples, which were for the most part quite similar.



(a) Sidescan sonar *Deep Vision* (b) Van-der-Veen-grap

Figure 6: Instruments to determine and recover sediment samples

5 Participiants

Name	Discipline	Institution
Prof. Dr. Berndt, Christian	Chief Scientist	GEOMAR
Wetzel, Gero	Engineer	GEOMAR
Hagemann, Katlina	Tutor	CAU
Schramm, Bettina	Tutor	CAU
Eckel, Felix	Student	CAU
Franz, Gesa Katharina	Student	CAU
Freisen, Pia	Student	CAU
Haas, Peter	Student	CAU
Müller, Katja	Student	CAU
Peikert, Jill	Student	CAU
Wilke, Antonia	Student	CAU
Günther, Matthias	Captain	Briese
Wichmann, Gent	Chief Mate	Briese
Nannen, Hero	2. Mate	Briese
Kröger, Kurre	Ltd. Engineer	Briese
Freund, Hans-Jörg	2. Engineer	Briese
Blunk, Volker	Electrician	Briese
Engel, Rüdiger	Motorman	Briese
Malchow, Klaus-Peter	Cook	Briese
Gerischewski, Bernd	Steward	Briese
Schrage, Frank	Bosun	Briese
Graf von Keller, Magnus T.	Ship Mechanic	Briese
Kuhn, Ronald	Ship Mechanic	Briese
Pleuer, Merlin Till	Ship Mechanic	Briese
Rauh, Bernd	Ship Mechanic	Briese
Meyer, Felix	Ship Mechanic	Briese

Table 4: Participiants of cruise POS491/2
GEOMAR: GEOMAR Helmholtz Centre for Ocean Research Kiel
CAU: Christian-Albrechts-University Kiel
Briese: Briese Schiffahrt, Research Department

6 Deck plan

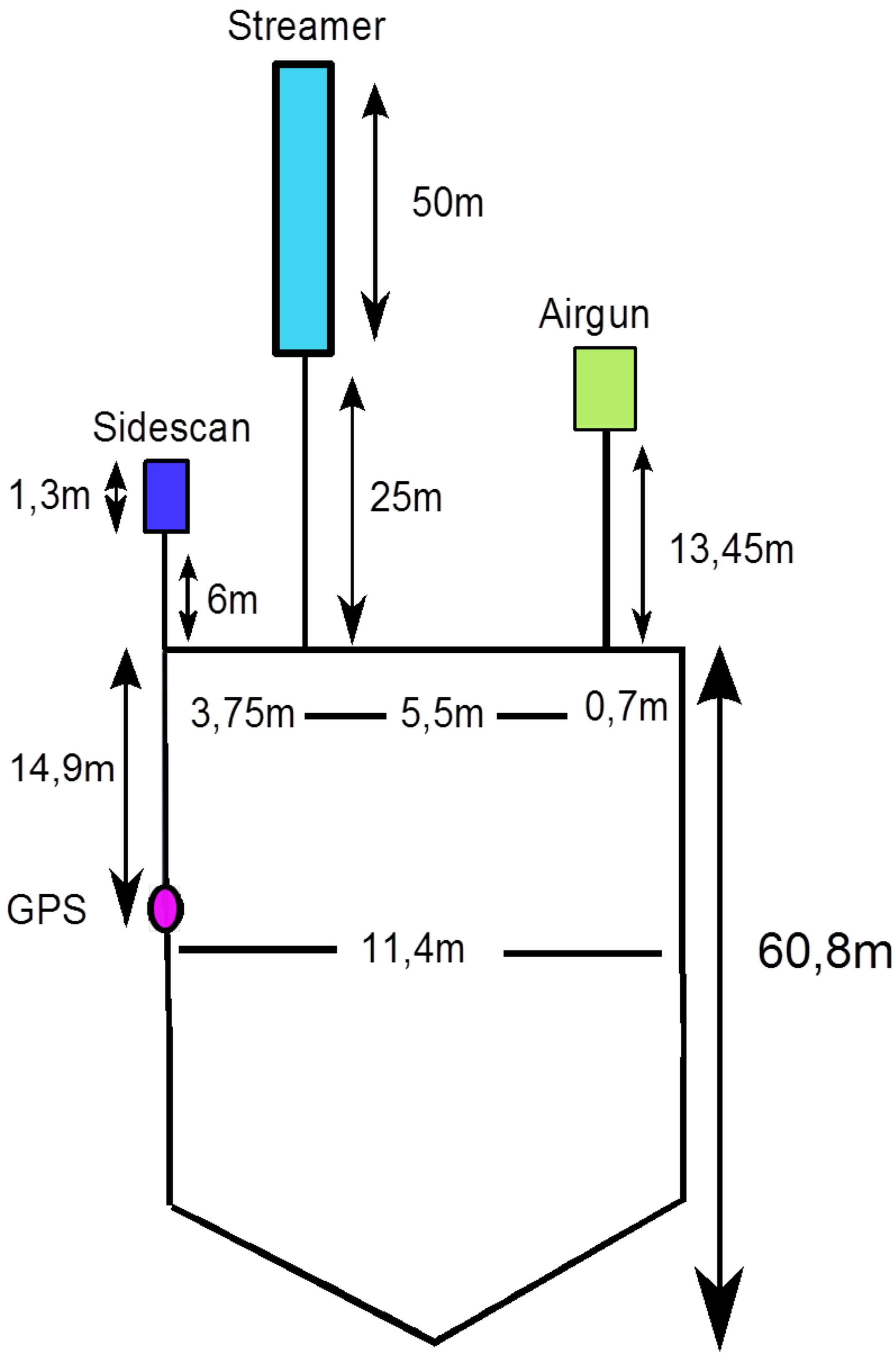


Figure 7: Deck plan of *Poseidon*

7 Results

7.1 Gas distribution in the Bay of Eckernförde

Biogenic gas which occurs in marine sediments is produced by bacteria that degrade buried organic matter. Methane (CH_4) is one of those gases and has among others a relevance on climate change and sea-level rise. Due to this hazard potential scientists spent time to investigate near-surface gas distribution of the Baltic Sea with geophysical methods (for example Mathys et al. 2005 and Toth et al. 2014). Acoustic data provided from the airgun and the sediment echosounder could detect gas features in the Bay of Eckernförde. The bay is characterized by a huge discharge of near-surface gas. In Figure 8 the shiptracks and the occurence of gas are plotted. As in the figure visible there is a concentration of gas in the coastal area of the Bay of Eckernförde. Also the firth of Eckernförde is filled with gas. Gas structures can be found as anomalies in seismograms due to a high contrast

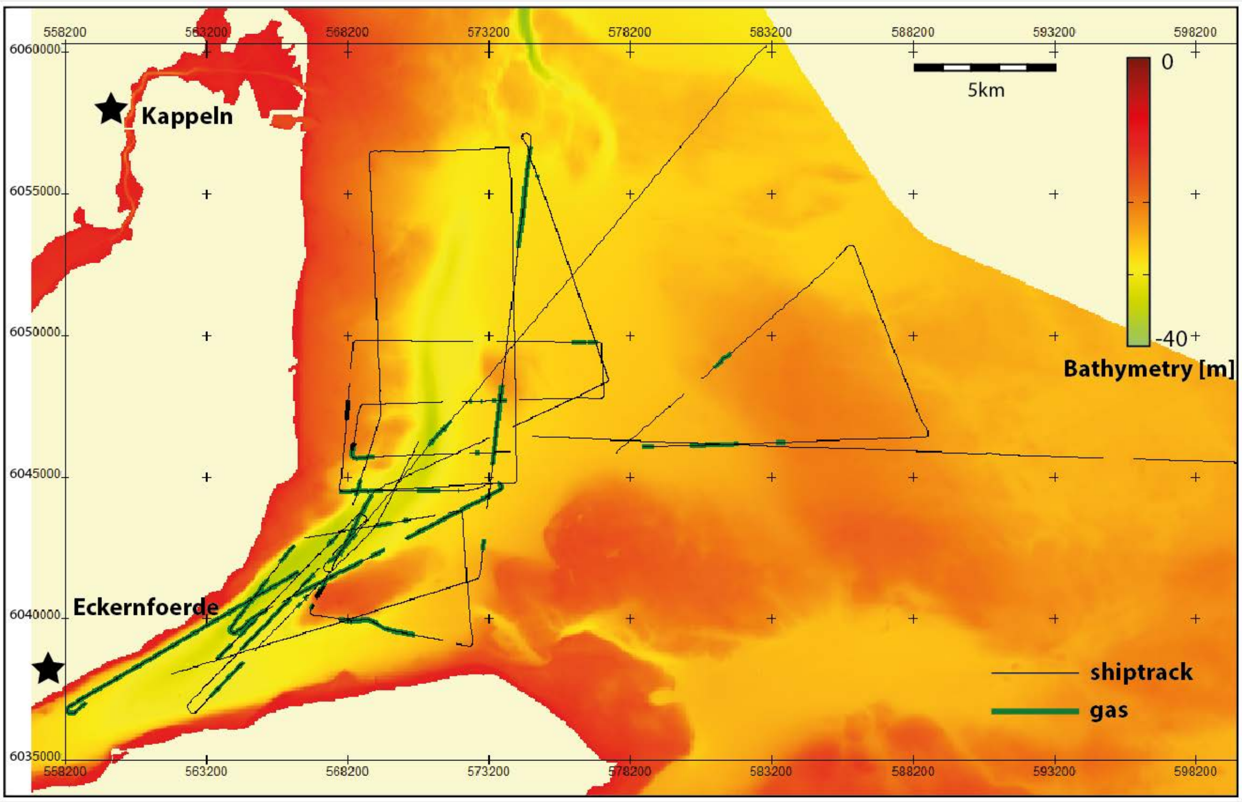


Figure 8: Ship tracks with lines 1-24 in the Bay of Eckernförde shown in light black colour. Parts of the shiptracks are shaded with green colour and illustrate the gas content in the seismic data. The bathymetry is plotted in the background. The used coordinate system is UTM32N.

in impedance between gas-saturated and gas-free media. Several characteristic structures of gas could be detected especially in the data provided from the airgun-streamer combination. Figure 9 shows all together five significant artefacts that are typically linked to shallow gas. There are also fields in the seismograms where seafloor seems on a large scale to release gas. Because of this a lot of ship tracks in Figure 8 are shaded in green. An example for this phenomenon is shown in figure 10. The enhanced reflections in combination with multiple ringing appear on an area larger than 1 kilometre.

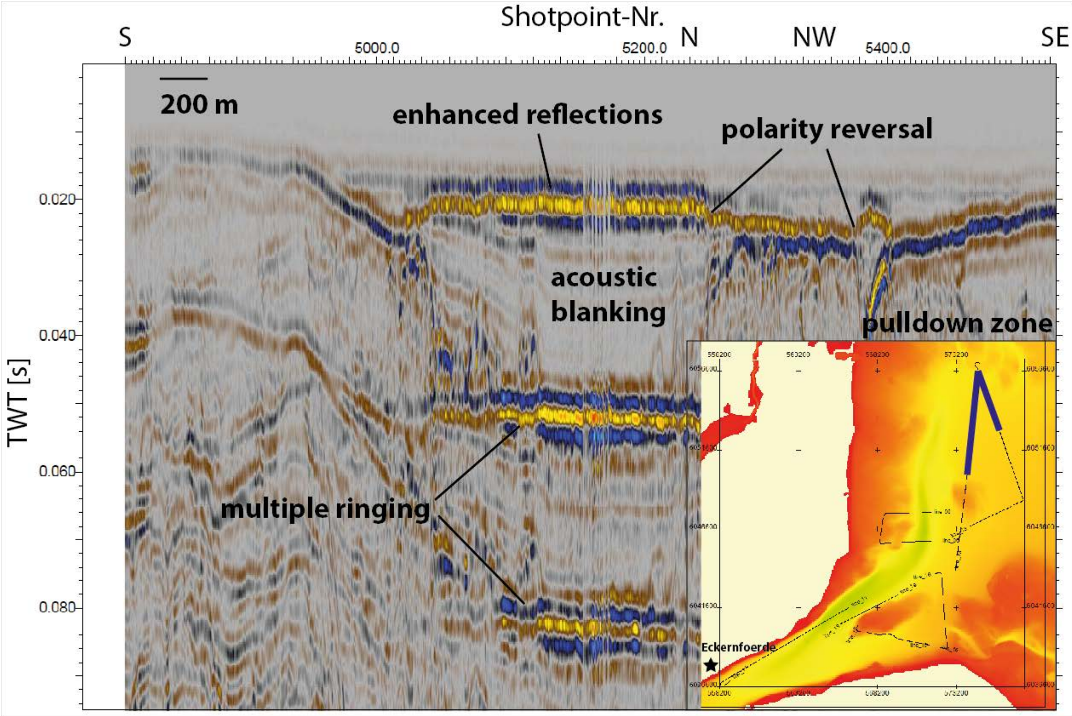


Figure 9: Stacked seismic section for line 13. Blue colour of the ship track represents the section. Features with incidence of gas are shown in the profile.

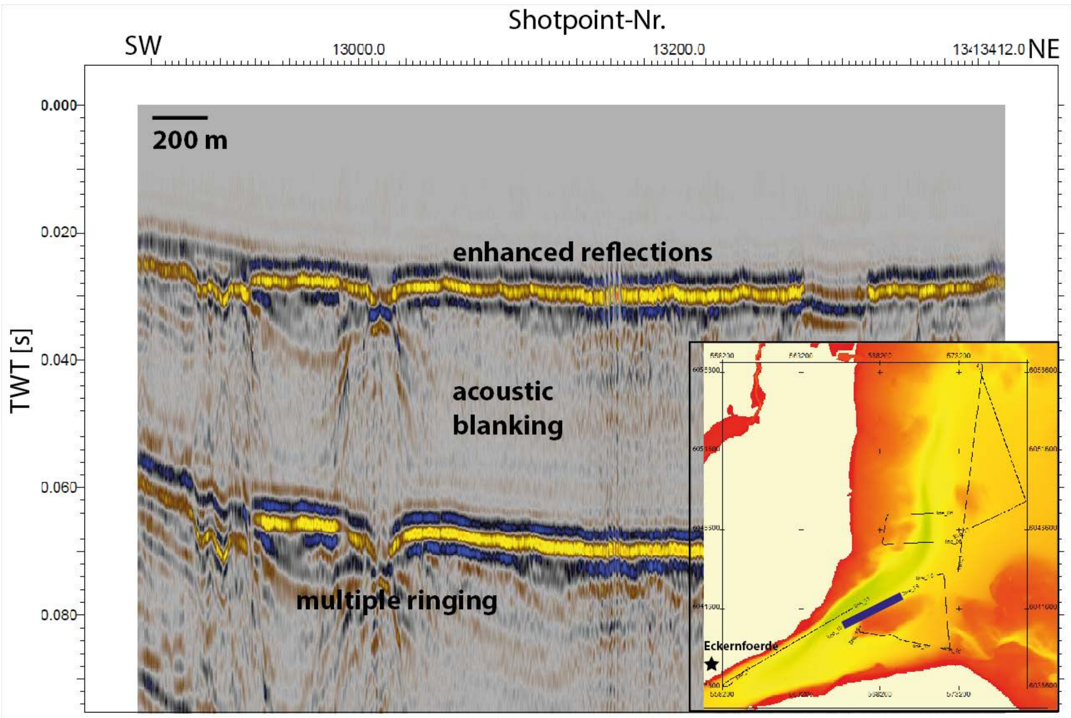
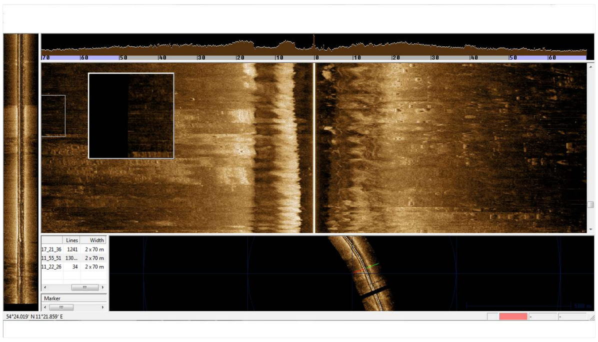


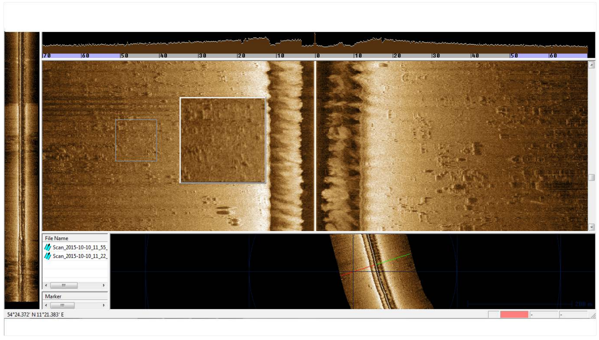
Figure 10: Stacked seismic section for line 19. Blue colour of the ship track represents the section. Features with incidence of gas are shown in the profile.

7.2 Sediment samples and sediment echolot

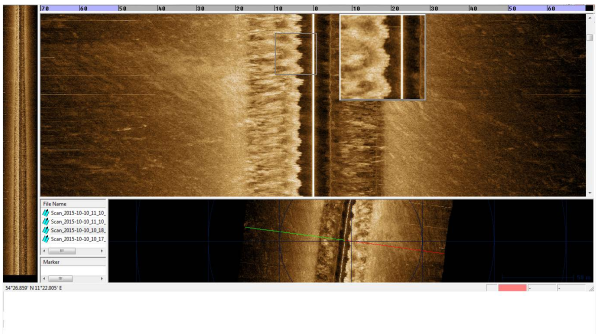
In the eastern Fehmarnbelt we took 5 samples of the seafloor surface and compared them to the images of the side-scan-sonar. Unfortunately only 4 samples could be found on the sidescan. Sample 2 (fig. 11a) ($54°23.970N$, $11°21.859E$) was of a brown-greyish colour, quite fine grained and sandy. Sample 3 (fig. 11b) was extracted at $54°24.372N$, $11°21.383E$. It was of a grey, green colour and a lot of bigger rocks in it. The fourth sample (fig. 11c) ($54°26.859'N$, $11°22.005E$) was fine grained, good oxidized, with light and dark strips and of a brown-greyish colour (see figure 12). It also had some shells and worm casts. And the last sample (fig. 11d) ($54°29.943N$, $11°22.462E$) had a dark green to black colour, was fine grained, quite muddy and with less silts. So all samples were as expected for the eastern Fehmarnbelt.



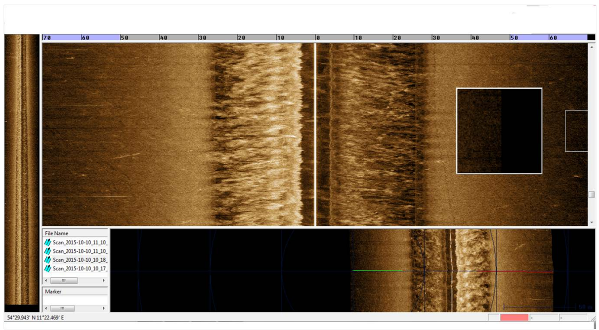
(a) position of sample 2 on the sidescan image



(b) position of sample 3 on the sidescan



(c) sample 4 on the sidescan



(d) sample 5 on the sidescan

Figure 11: The sidescan images of the sediment samples

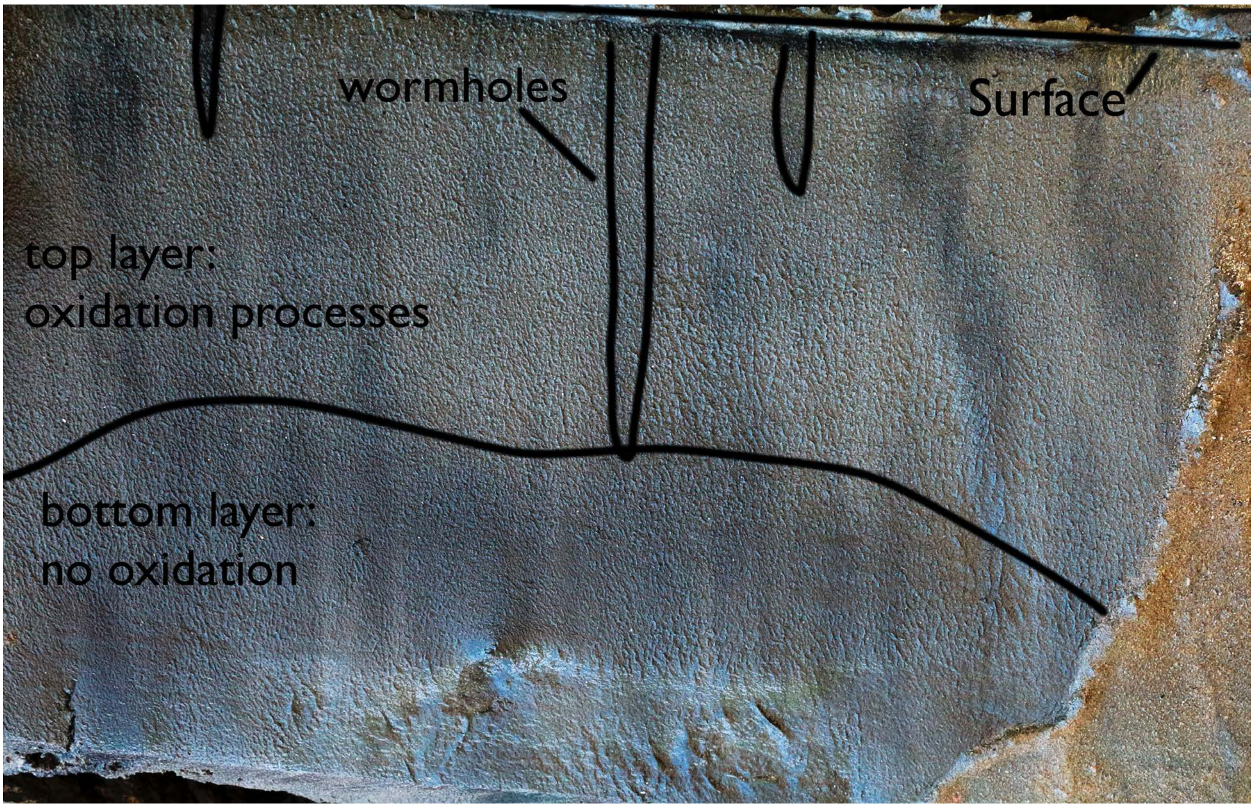


Figure 12: Sediment sample 4. Visible are the two layers. The subsurface layer is brighter and oxidation processes are still enabled whereas into the darker layer below, no oxygen can penetrate through.

7.3 Structures in the western Baltic Sea

Several seismic profiles were recorded using airgun and streamer as mentioned in chapter 4.4. The data was processes using the regular processing methods for reflection seismics, i.e. CMP-sorting, Normal-Moveout-correction, stacking and migrating. We will focus in this chapter on the long profile (approx. $90km$ from the Bay of Eckernförde to the eastern shore of Fehmarn (see figure 1). Several features are conspicuous and will be discussed in the following. In figure 13 the seafloor is marked in blue. A former trench then is marked in red. Considering that this area once has been covered by the glaciers of the last ice age, this trench definitively must have been eroded by those glaciers. In the seismogram it is about $35ms$ two-way-travel-time deep. Assuming that the area has been covered by water for about 7000 years and that seismic velocities are about $1,500ms^{-1}$, we can determine a depth of ca. $0.5 \cdot 0.035s \cdot 1500ms^{-1} \approx 26m$ and that it must have been sedimented with an average sedimentation rate of $26m/7000years \approx 3mm/year$. Further, a lot of multiples, i.e. multiple reflection from the same reflector, are visible. In figure 14 two reflectors are marked. One near-surface reflector (green) and a deeper reflector (yellow). The deep reflector is one of the deepest structures in the seismogram. Further structures below $600 - 800ms$ no longer can be identified. These reflectors are both folded up the same way. Therefore a pressure must come from below. The BGR (*Bundesanstalt für Geowissenschaften und Rohstoffe*) has located a salt diapir in this area. Salt is less dense than the surrounding rocks and rises up. This form of tectonics (*salt tectonics* folded up the layers as it can be seen in the seismogram.

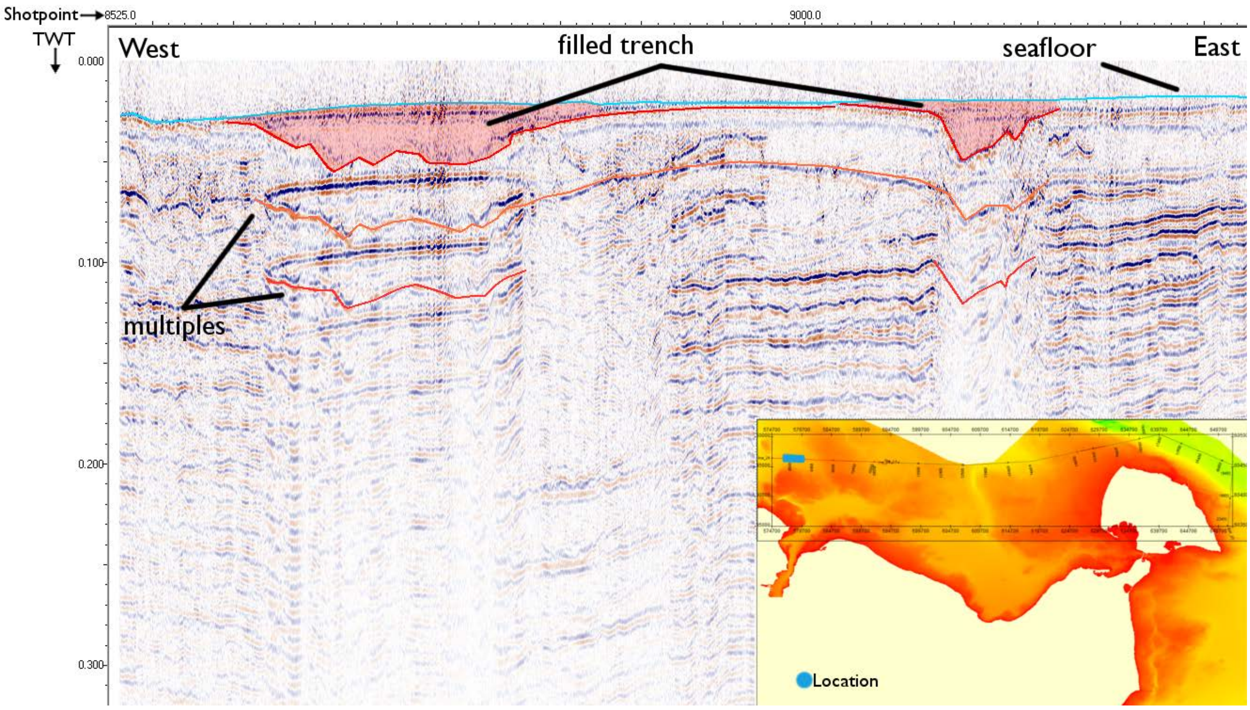


Figure 13: A filled trench in the seismogram. Location is marked in the right bottom corner. Further details see text

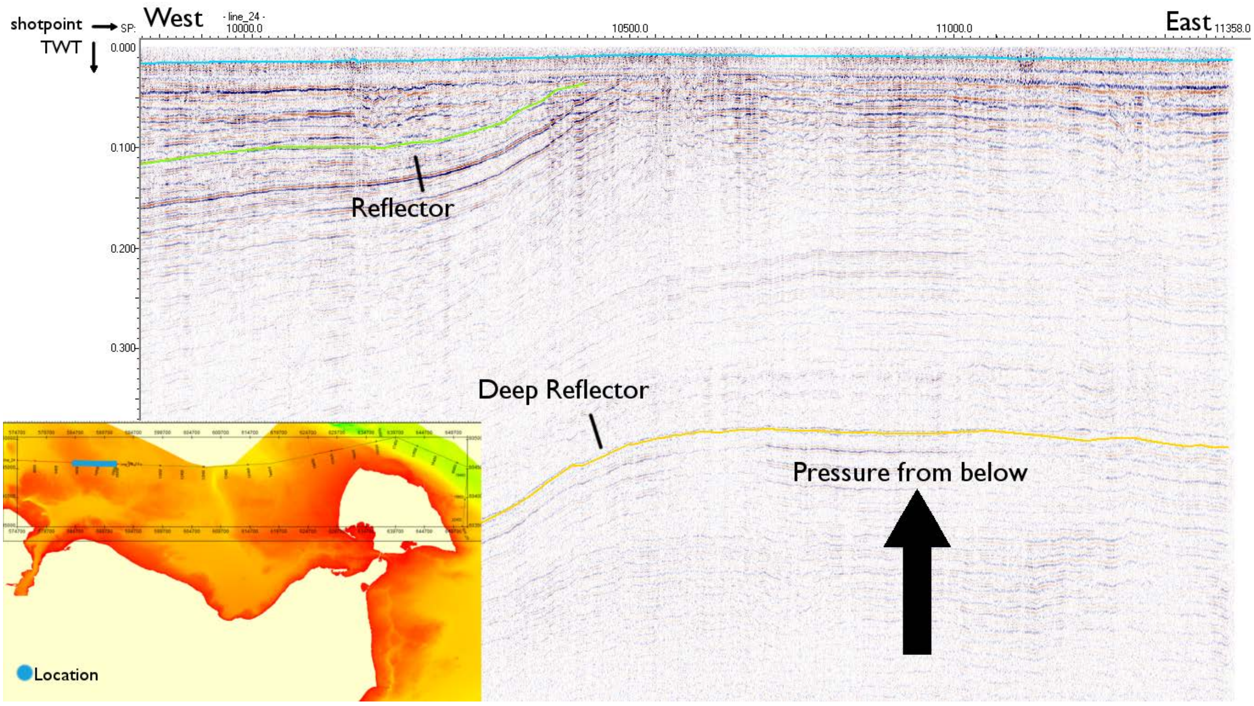


Figure 14: The layers are pushed up by a force from below. Location is marked in the left bottom corner. Further details see text

7.4 Multibeam echosounder bathymetry

The bathymetric data collected on this cruise fit the hitherto existing bathymetry of the western Baltic Sea well. North of Fehmarn the Vindsgrav or Fehmarnbelt channel is a major transport path for the high saline currents from the North Sea flowing into the deeper basins in the eastern Baltic Sea. Where the lines of this survey cross the location of the channel as proposed by the BSH (Federal Maritime and Hydrographic Agency of Germany) bathymetric grid, the depths correlate well, being up to $20m$.

By the northern flank of the Vindsgrav channel, Werner and Newton (1970, *Riesenrippeln im Fehmarnbelt*) described a total of five fields of large sand ripple marks. However, in the recent BSH bathymetry grid, which serves as base for comparison, no clear evidence for these structures is visible. In contrast, the now collected multibeam data clearly maps these so called *mega ripples* on several lines (see figure 15). As the ripple marks are pictured above as well as below the BSH grid (see figure 15b), the mean depths of the new multibeam data correlate well with the depth of the BSH grid. Werner and Newton describe them to have a wavelength of $40m$ to $70m$ and a height of $1m$ to $2m$. These values are consistent with the extents pictured in this survey.

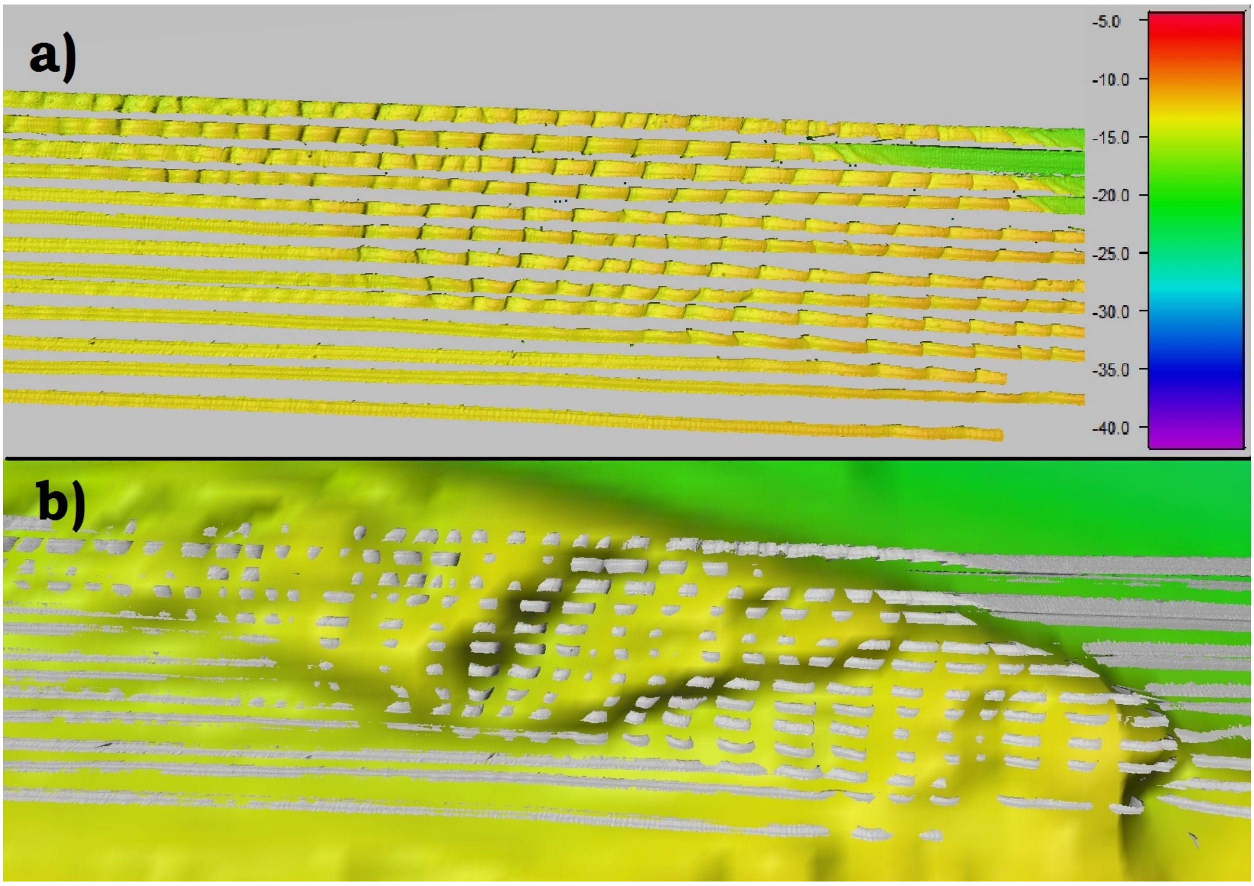


Figure 15: a) multibeam traces, clear illustration of sand ripple marks b) multibeam traces over BSH bathymetry, ripples were not detectable on BSH

7.5 Sedimentation processes in the Fehmarnbelt

The study area is located in the Fehmarnbelt, between Denmark and Fehmarn (Germany) with water depths between $10m$ and $30m$. The target was the survey of the seafloor with the sidescan sonar. There are two sidescan sonar profiles, one in the north of the Fehmarnbelt on the Danish side and one in the south near Fehmarn on the German side. The backscatter profiles provide differences of the seafloor material and textures and detect objects and morphological structures. Dark imaged areas mean low reflections (fine-grained material) and bright imaged areas mean high reflections (coarse–grained material).
Several sedimentary structures were founded at different locations.On the whole Danish side (figure 16) were detected heterogeneities in materials (figure 17). The sedimentary base is sand with lower backscatter (dark color) and across are bigger or smaller areas with higher backscatter (bright areas). This could be coarse material like sand and gravel. Another theory is vegetation on the seafloor, because the brighter areas look higher located then the darker areas. The seafloor surface looks very smooth, sometimes it is abundant of small ripples (Figure 17a).In general the sediment on the Danish side is fine. There is no cobble and rocks. In addition no morphological structures were found. No dunes or bigger ripple marks. So it is unable to make a conclusion about the current in this region, only the small ripple are indications of a weak current. Off the German side (figure 18) were found different structures of material and morphology. The basic sediment here is sand, exactly like on the Danish side. The eastside has some heterogeneities, dark areas consisting of fine – grained sediment between the base of sand (figure 19a) and bright areas consisting of coarse – grained sediment between sand (figure 19b). But due to some problems with the sidescan fish this interpretation is not for sure, because the water column shows similar coloring. Nevertheless the sediment on the German side consists of more coarse material than in Denmark. On the west side of the profile are fields of cobbles, that is shown on Figure 20a. An interesting restricted structure of morphology is located in the middle of the profile (figure 20b). Giant asymmetric ripple marks with crest heights up to $2m$. The lee side shows eastbound, so the current comes from the west. The ripple marks become smaller in the north and in Denmark no ripple marks remain. This is an evidence that the current is different in this part of the study area.

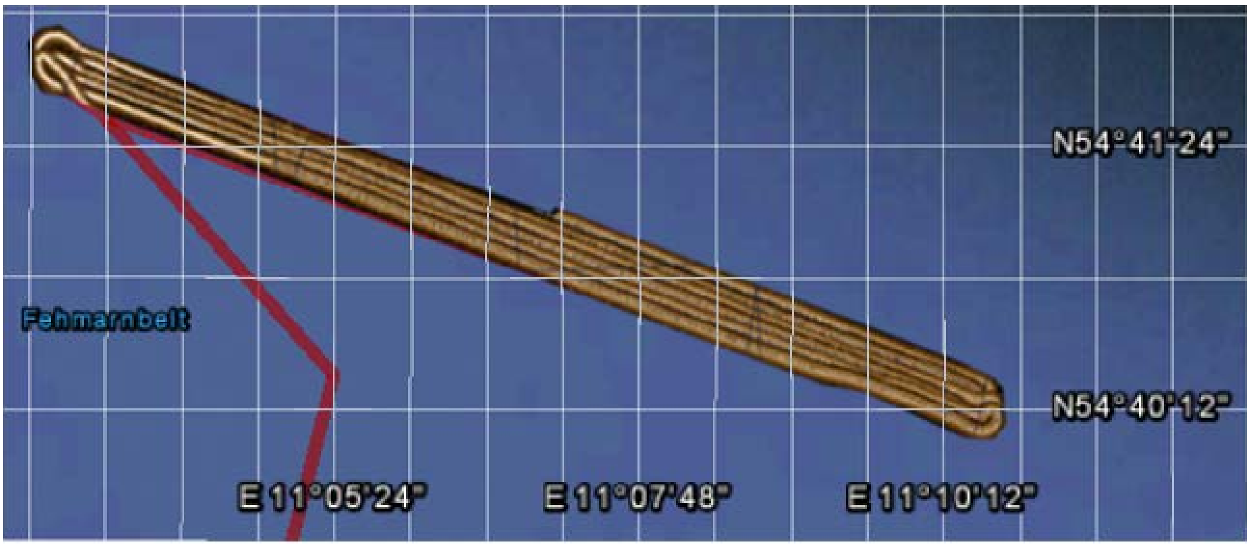


Figure 16: Danish side of the study area Fehmarnbelt

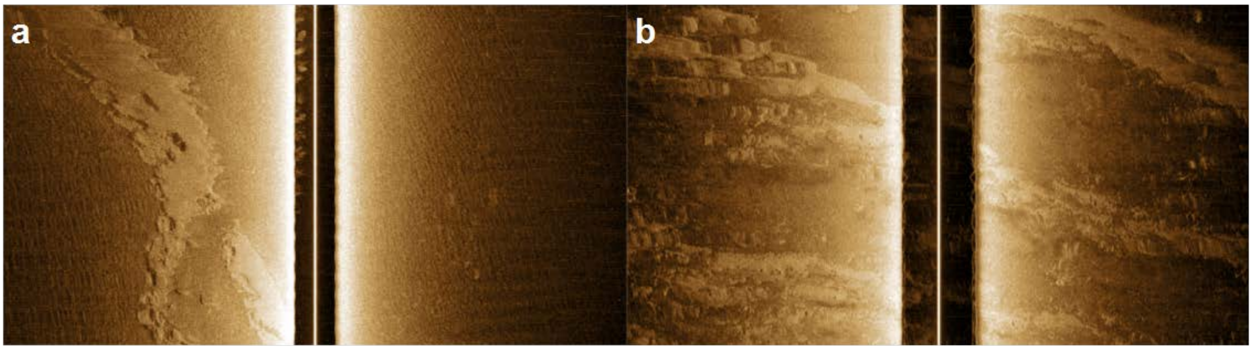


Figure 17: Backscatter of the seafloor off Danish side (water depth a: $5m$ water depth b: $9m$)

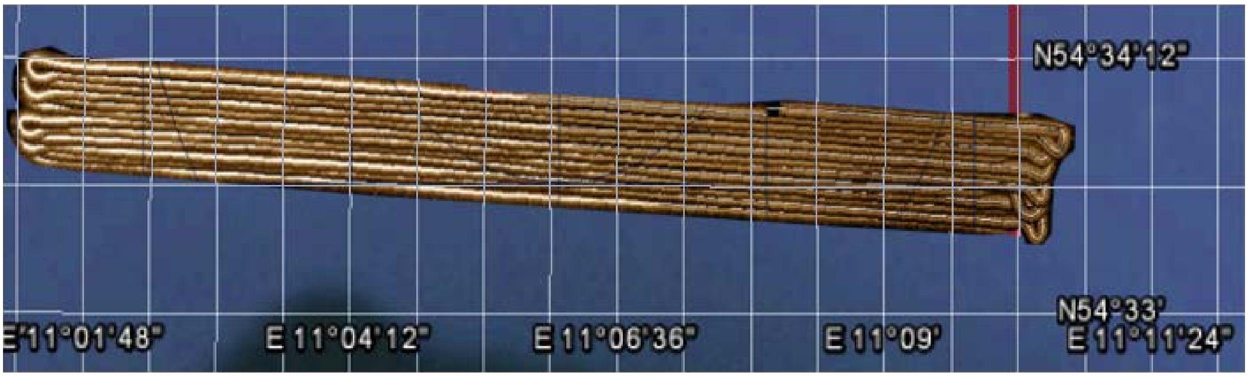


Figure 18: German side of the study area Fehmarnbelt

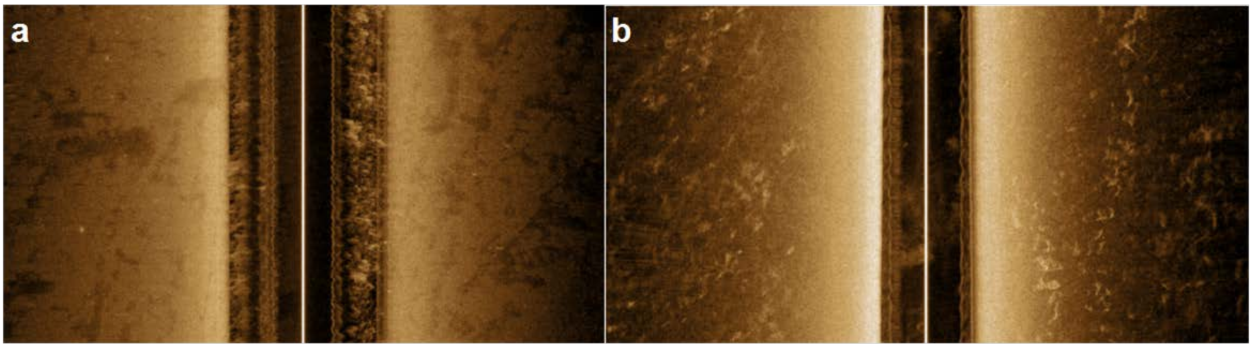
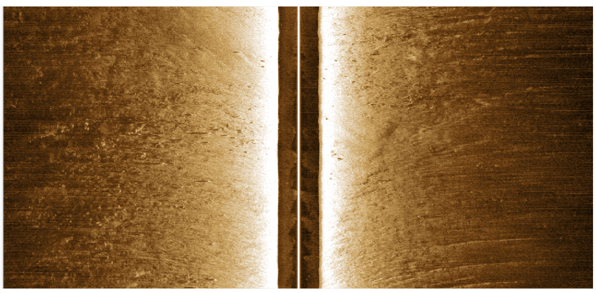
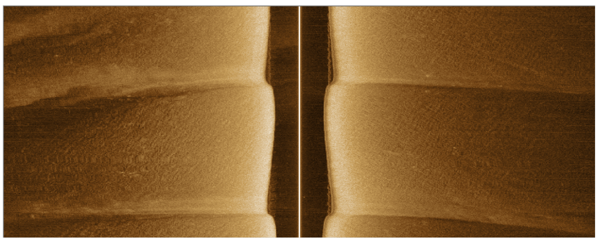


Figure 19: Backscatter of the seafloor off German side (water depth a: $17m$ water depth b: $9m$)



(a) Cobbles and rocks on the western seafloor of the profile (water depth: $5m$)



(b) Mega ripple marks (water depth: $6m$)

Figure 20: Structures on the seafloor

7.6 Sonic speed in the underground

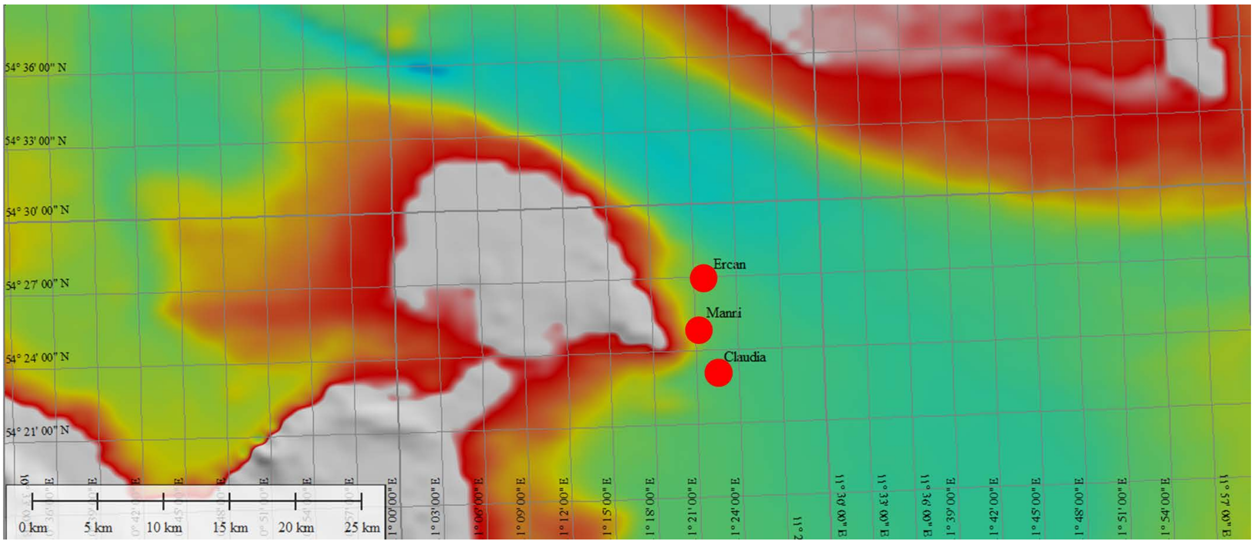


Figure 21: Overview of the position of the three OBS

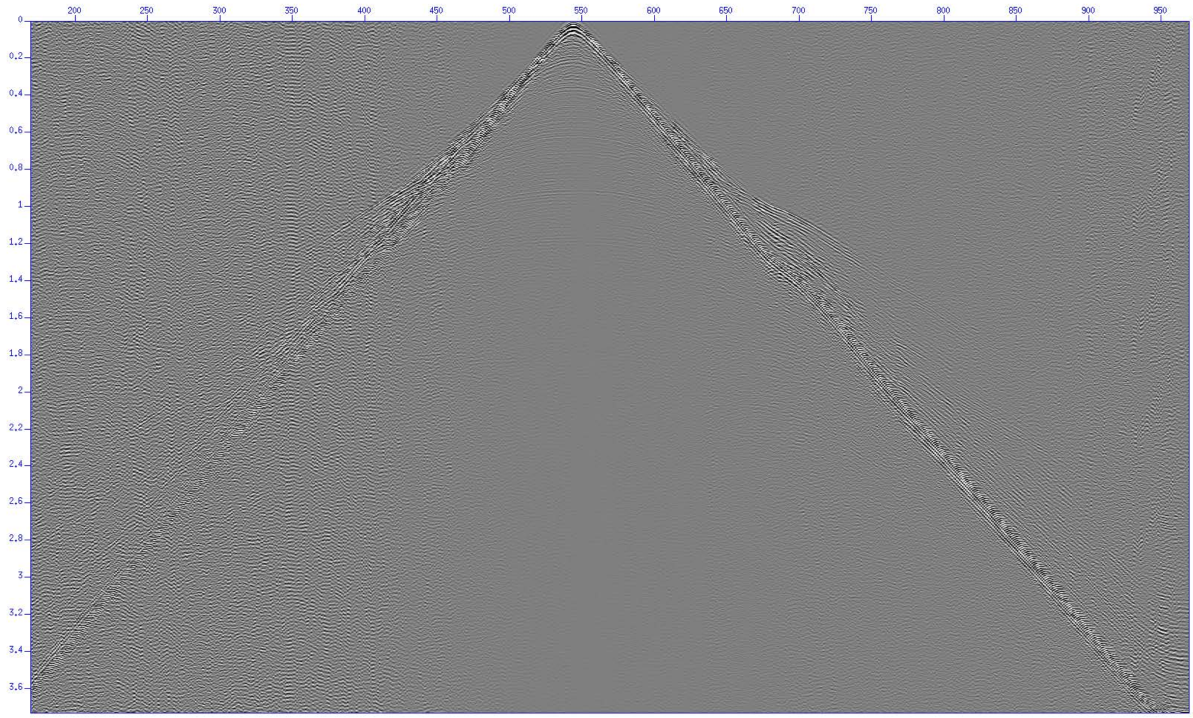


Figure 22: Full view on the profile of *Ercan*

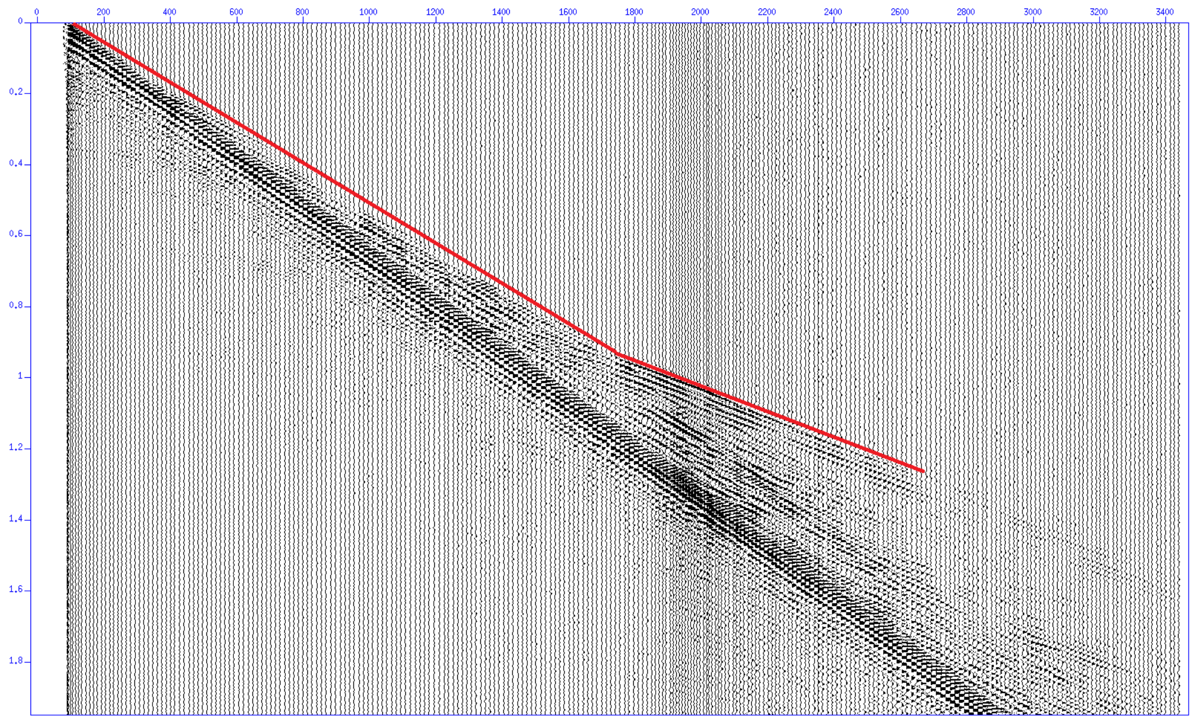


Figure 23: Right side view on the profile of *Ercan*. Layer 1: $1818m/s$, mightiness $60m$, moist sand. Layer 2: $2000m/s$, till

A Formation of the Baltic Sea

20,000 years ago the area of the Baltic Sea was covered with a several kilometre thick ice shield. This accumulated great masses of water as ice on land and consequently, the sea level worldwide was $130m$ lower. Center of the glaciation and therefore center of the glacial land subsidence was North Sweden. With the relief from the melting ice, the isostatic compensatory movement led to an uplifting motion of the before ice-covered area. This process and the eustatic sea level increase determined the formation of the Baltic Sea, which can be divided into four stages. The first stage 12,000 to 10,300 years ago, was coined by the formation of the Baltic Ice Lake (see figure 24). The slowly warming climate ended the glacial period and the melting ice formed a melt water lake in the Baltic Sea basin. Eventually, the lake overflowed, crossing the middle of Sweden. After some time, the isostatic uplift surpassed the climate induced sea level increase and the freshwater outflow came to a halt and salt water could enter the Baltic Sea basin. Named after a brackish water snail, the Yoldia Sea, describes this second stage (10,000 years ago). Due to the ongoing ice-melting and the associated sea level increase, approximately 9,500 years ago, the connection to the Skagerrak closed up and the Ancylus Lake developed. This freshwater lake covered a larger area than today's Baltic Sea. But the positive water balance and isostatic motion led to an outflow to the South. The end of the third stage and thus the beginning of the final fourth stage occurred 8,000 years ago, when salt water was able to enter the Ancylus Lake, forming the Litorina Sea. The continuous freshwater inflow from Scandinavian rivers , narrowing Danish gates and a slight isostatic uplift determine the state of the present day Baltic Sea.

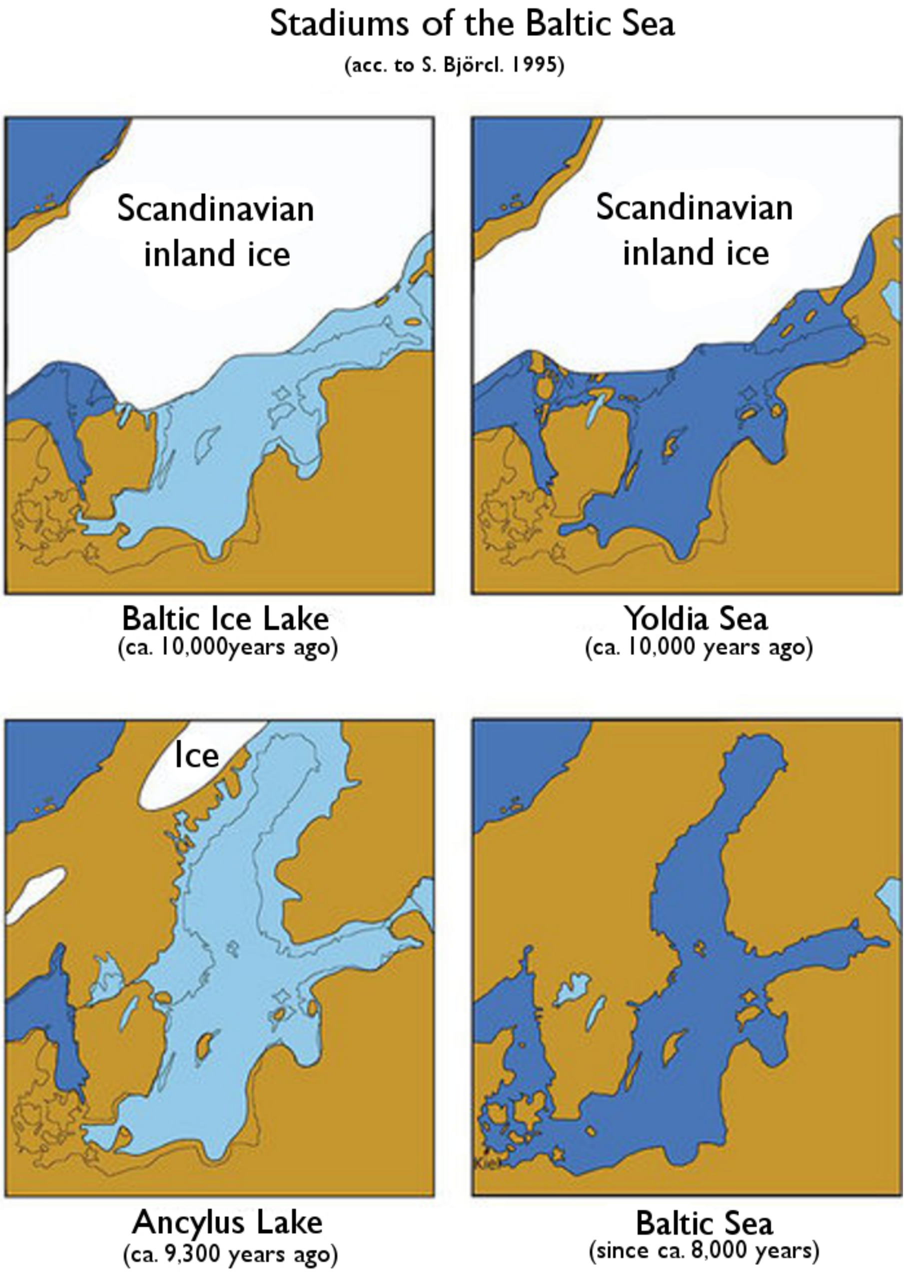


Figure 24: Stadiums of the Baltic Sea
(according to *http//www.geomar.de/de/entdecken/artikel/article/die-entstehung-der-ostsee/)*

B Station book

Attached is the station book as received from the bridge.
Abbreviations for the instruments are:

SSS	Sidescan Sonar
SEISREFL	Seismic reflection
OBS	Ocean Bottom Seismometer
BG	Box grab

Station	Time	PositionLat	PositionLon	Depth [m]	Wind [$\frac{m}{s}$]	Course [°]	Speed [kn]	Gear Abbr.	Action	Comment
9.10.2015										
POS491/643-1	11:06	54°32.00N	10°7.00E	17,9	SE 5	208,3	0,2	CTD	surface	Fortsetzung Forschungsarbeiten POS 491
POS491/643-1	11:08	54°31.98N	10°6.99E	17,9	SE 5	181,1	0,6	CTD	on deck	
POS491/644-1	11:30	54°31.79N	10°7.05E	17,6	SE 4	246,9	3,4	SSS	to water	
POS491/644-2	11:44	54°31.56N	10°6.05E	17,5	ESE 5	247,6	2,1	SEISREFL	airguns in the water	
POS491/644-2	11:46	54°31.53N	10°5.92E	16,5	SE 5	249,2	2,9	SEISREFL	Streamer into water	
POS491/644-2	11:48	54°31.49N	10°5.75E	15,2	ESE 5	248,3	3	SEISREFL	air gun array on deck	
POS491/644-2	12:39	54°30.62N	10°1.36E	23	ESE 5	242,4	2,8	SEISREFL	airguns in the water	
POS491/644-1	12:41	54°30.57N	10°1.22E	23	ESE 4	242,2	2,9	SSS	start profile	
POS491/644-2	12:42	54°30.55N	10°1.14E	24,1	ESE 5	241,9	3	SEISREFL	profile start	
POS491/644-1	13:19	54°29.13N	9°56.98E	23,5	E 4	239,8	4,5	SSS	alter course	
POS491/644-2	13:19	54°29.13N	9°56.98E	23,5	E 4	239,8	4,5	SEISREFL	alter course	
POS491/644-1	14:16	54°31.71N	10°1.83E	21,5	ESE 7	46,3	4,2	SSS	alter course	
POS491/644-2	14:16	54°31.71N	10°1.83E	21,5	ESE 7	46,3	4,2	SEISREFL	alter course	
POS491/644-1	14:36	54°32.38N	10°3.87E	22,5	ESE 8	61,3	4,3	SSS	alter course	
POS491/644-2	14:36	54°32.38N	10°3.87E	22,5	ESE 8	61,3	4,3	SEISREFL	alter course	
POS491/644-1	15:49	54°28.89N	9°57.48E	22,2	ESE 5	225	4,4	SSS	alter course	
POS491/644-2	15:49	54°28.89N	9°57.48E	22,2	ESE 5	225	4,4	SEISREFL	alter course	
POS491/644-1	16:58	54°32.15N	10°3.56E	23,1	SE 8	45,5	4	SSS	alter course	
POS491/644-2	16:58	54°32.15N	10°3.56E	23,1	SE 8	45,5	4	SEISREFL	alter course	
POS491/644-1	18:09	54°28.56N	9°57.89E	21	ESE 5	204,7	4	SSS	alter course	
POS491/644-2	18:09	54°28.56N	9°57.89E	21	ESE 5	204,7	4	SEISREFL	alter course	
POS491/644-1	19:19	54°31.83N	10°3.99E	23,6	SE 10	43,7	4,4	SSS	alter course	
POS491/644-2	19:19	54°31.83N	10°3.99E	23,6	SE 10	43,7	4,4	SEISREFL	alter course	
POS491/644-1	19:46	54°33.58N	10°5.64E	23	ESE 9	27,3	4,4	SSS	alter course	
POS491/644-2	19:46	54°33.58N	10°5.64E	23	ESE 9	27,3	4,4	SEISREFL	alter course	
POS491/644-2	22:06	54°33.14N	10°23.22E	13,1	SE 9	93,5	4,5	SEISREFL	air gun array on deck	neu Schwimmboje anbringen
POS491/644-2	22:17	54°33.12N	10°24.31E	14,7	SE 8	89	1,8	SEISREFL	airguns in the water	
10.10.2015										
POS491/644-1	04:12	54°34.89N	11°9.78E	24,2	SE 8	79	4,5	SSS	alter course	
POS491/644-2	04:12	54°34.89N	11°9.78E	24,2	SE 8	79	4,5	SEISREFL	alter course	
POS491/644-1	05:47	54°31.94N	11°20.94E	25	ESE 6	114,5	4,4	SSS	alter course	
POS491/644-2	05:47	54°31.94N	11°20.94E	25	ESE 6	114,5	4,4	SEISREFL	alter course	
POS491/644-1	07:01	54°26.46N	11°19.98E	13,6	ESE 8	188	4,5	SSS	end profile	
POS491/644-2	07:01	54°26.46N	11°19.98E	13,6	ESE 8	188	4,5	SEISREFL	end of profile	
POS491/644-1	07:03	54°26.40N	11°20.05E	14	ESE 7	95,3	1,6	SSS	on deck	
POS491/644-2	07:07	54°26.41N	11°20.17E	13,7	ESE 8	79,7	0,8	SEISREFL	air gun array on deck	
POS491/644-2	07:09	54°26.42N	11°20.22E	13,7	ESE 8	80,7	0,9	SEISREFL	streamer on deck	
POS491/645-1	07:36	54°24.79N	11°21.27E	15,5	ESE 9	76,6	0,2	OBS	surface	
POS491/645-1	07:39	54°24.79N	11°21.28E	15,6	ESE 8	219,6	0,3	OBS	at sea bottom	
POS491/646-1	08:04	54°26.80N	11°21.91E	16,1	ESE 9	205,8	0,5	OBS	surface	
POS491/646-1	08:07	54°26.78N	11°21.86E	16	ESE 8	246,6	0,7	OBS	at sea bottom	
POS491/647-1	08:35	54°28.99N	11°22.39E	23,1	ESE 9	147,9	0,1	OBS	surface	
POS491/647-1	08:37	54°28.99N	11°22.38E	23,1	ESE 9	251,6	0,5	OBS	at sea bottom	
POS491/648-1	08:38	54°28.99N	11°22.37E	23,2	ESE 9	205,3	0,3	SSS	to water	
POS491/648-2	09:05	54°30.85N	11°22.38E	26,1	ESE 9	116	2,4	SEISREFL	airguns in the water	
POS491/648-1	09:08	54°30.76N	11°22.53E	26,2	ESE 9	181,1	3,6	SSS	start profile	
POS491/648-2	09:08	54°30.76N	11°22.53E	26,2	ESE 9	181,1	3,6	SEISREFL	profile start	
POS491/648-1	10:14	54°25.76N	11°21.71E	17,4	ESE 10	192,5	3,6	SSS	end profile	
POS491/648-2	10:41	54°23.89N	11°21.20E	14,2	ESE 11	140,4	2,5	SEISREFL	end of profile	
POS491/648-2	10:46	54°23.85N	11°21.56E	15,9	ESE 10	94,5	2	SEISREFL	air gun array on deck	
POS491/648-3	10:49	54°23.84N	11°21.71E	16,5	ESE 10	94,2	2,8	SSS	to water	
POS491/648-3	11:09	54°24.63N	11°21.34E	15,2	ESE 10	3,4	3,1	SSS	start profile	
POS491/648-3	11:51	54°26.77N	11°22.07E	16,1	ESE 9	9	3,1	SSS	end profile	
POS491/648-3	11:55	54°26.84N	11°22.21E	16,4	ESE 9	112	1,3	SSS	on deck	
POS491/649-1	12:15	54°26.78N	11°21.86E	16	ESE 9	235,4	0,5	OBS	on deck	
POS491/650-1	12:44	54°28.99N	11°22.36E	23,2	E 8	81,2	0	OBS	on deck	
POS491/651-1	13:37	54°24.78N	11°20.89E	14,4	ESE 8	104,3	0,1	OBS	on deck	
POS491/652-1	13:56	54°23.84N	11°21.56E	16	E 8	61,8	0,4	BG	surface	
POS491/652-1	13:56	54°23.84N	11°21.56E	16	E 8	61,8	0,4	BG	at sea bottom	max SL: 17m
POS491/652-2	13:58	54°23.84N	11°21.57E	16,2	E 9	220,6	0,2	BG	surface	
POS491/652-1	13:58	54°23.84N	11°21.57E	16,2	E 9	220,6	0,2	BG	on deck	
POS491/652-2	13:59	54°23.84N	11°21.57E	15,9	E 9	233,9	0,4	BG	at sea bottom	max SL: 17m

Station	Time	PositionLat	PositionLon	Depth [m]	Wind [$\frac{m}{s}$]	Course [°]	Speed [kn]	Gear Abbr.	Action	Comment
POS491/652-2	13:59	54°23.84N	11°21.57E	15,9	E 8	233,9	0,4	BG	on deck	
POS491/653-1	14:12	54°23.96N	11°21.88E	16,6	E 8	294,6	0,4	BG	surface	
POS491/653-1	14:13	54°23.96N	11°21.88E	16,7	E 9	321,7	0,3	BG	at sea bottom	SL max 19 m
POS491/653-1	14:13	54°23.96N	11°21.88E	16,7	E 9	321,7	0,3	BG	on deck	
POS491/653-2	14:14	54°23.97N	11°21.86E	16,7	E 10	291	0,5	BG	surface	
POS491/653-2	14:16	54°23.98N	11°21.87E	16,6	E 9	64,2	0,6	BG	at sea bottom	SL max 18m
POS491/653-2	14:17	54°23.98N	11°21.89E	17	E 10	66,4	0,8	BG	on deck	
POS491/654-1	14:28	54°24.38N	11°21.38E	13,5	E 9	82,1	0,2	BG	surface	
POS491/654-1	14:29	54°24.38N	11°21.38E	13,6	E 8	188,6	0,3	BG	at sea bottom	SL max 14m
POS491/654-1	14:30	54°24.37N	11°21.38E	14,1	E 8	179,7	0,3	BG	on deck	
POS491/655-1	15:02	54°26.86N	11°22.00E	16,1	E 9	79,3	0,1	BG	surface	
POS491/655-1	15:03	54°26.86N	11°22.00E	16,1	E 9	275,5	0,3	BG	at sea bottom	SL max 17m
POS491/655-1	15:03	54°26.86N	11°22.00E	16,1	E 9	275,5	0,3	BG	on deck	
POS491/656-1	16:00	54°29.95N	11°22.48E	25,2	ESE 11	143	0,2	BG	surface	
POS491/656-1	16:01	54°29.95N	11°22.48E	25,5	E 11	339	0,2	BG	at sea bottom	SL max 25m
POS491/656-1	16:01	54°29.95N	11°22.48E	25,5	E 11	339	0,2	BG	on deck	
POS491/657-1	16:11	54°29.95N	11°22.52E	25,2	E 11	103,4	1,8	SSS	to water	
POS491/657-2	16:12	54°29.94N	11°22.56E	25,4	E 10	102,9	1,4	SEISREFL	airguns in the water	Bb-Seite
POS491/657-2	16:14	54°29.93N	11°22.63E	25,2	E 11	107,7	1,3	SEISREFL	Streamer into water	
POS491/657-1	16:30	54°30.70N	11°22.53E	25,7	E 11	295	5,9	SSS	start profile	
POS491/657-2	16:30	54°30.70N	11°22.53E	25,7	E 11	295	5,9	SEISREFL	profile start	
POS491/657-1	16:48	54°31.48N	11°20.29E	26,4	E 12	305,5	4,7	SSS	end profile	
POS491/657-2	16:48	54°31.48N	11°20.29E	26,4	E 12	305,5	4,7	SEISREFL	end of profile	
POS491/657-1	16:56	54°31.46N	11°20.12E	26,2	ESE 12	42,7	2,6	SSS	on deck	
POS491/657-2	17:00	54°31.72N	11°19.86E	26,6	ESE 11	298,8	5,6	SEISREFL	profile start	
POS491/657-2	19:20	54°37.94N	11°3.35E	18	ESE 12	305,9	4,8	SEISREFL	alter course	
POS491/657-2	20:21	54°33.84N	11°2.17E	9	ESE 14	196	4,4	SEISREFL	alter course	
POS491/657-2	21:02	54°32.87N	10°57.09E	8,7	ESE 11	254,9	4,5	SEISREFL	alter course	
POS491/657-2	22:22	54°38.00N	11°0.14E	15,9	SE 13	16,8	4,8	SEISREFL	alter course	
POS491/657-2	22:37	54°38.11N	10°58.66E	15,4	ESE 14	213,6	4,6	SEISREFL	alter course	
11.10.2015										
POS491/657-2	00:49	54°28.91N	10°51.77E	8,4	ESE 11	205,6	4,7	SEISREFL	alter course	
POS491/657-2	01:37	54°31.14N	10°48.57E	13,7	SE 9	320,2	4,5	SEISREFL	alter course	
POS491/657-2	03:37	54°38.01N	10°58.26E	16,7	SE 7	354,1	4,3	SEISREFL	alter course	
POS491/657-2	03:49	54°38.14N	10°56.73E	17,9	ESE 7	245,9	4	SEISREFL	alter course	
POS491/657-2	05:44	54°31.92N	10°46.64E	17	ESE 8	201,1	3,7	SEISREFL	alter course	
POS491/657-2	08:11	54°34.00N	10°57.58E	9,4	SE 8	21,8	4,5	SEISREFL	alter course	
POS491/657-2	09:04	54°33.50N	10°51.02E	16,1	SE 7	261,2	4,6	SEISREFL	alter course	
POS491/657-2	10:23	54°37.51N	10°57.55E	19,7	ESE 6	42,8	4,4	SEISREFL	alter course	
POS491/657-2	11:26	54°37.60N	11°5.58E	20,6	ESE 6	90,1	4,5	SEISREFL	end of profile	
POS491/657-2	11:34	54°37.60N	11°6.14E	20,6	ESE 5	96	1,9	SEISREFL	air gun array on deck	
POS491/657-2	11:39	54°37.56N	11°6.43E	20,9	E 6	107	2,4	SEISREFL	streamer on deck	
POS491/658-1	12:29	54°37.94N	10°57.31E	18	E 7	333,1	2,7	SSS	to water	
POS491/658-1	12:33	54°38.10N	10°57.22E	17,5	ESE 5	344,4	2,9	SSS	start profile	Mit Multibeam
POS491/658-1	13:02	54°39.45N	10°56.06E	17	ESE 6	332,8	2,6	SSS	on deck	Ausfall Scanfish, technische Probleme
POS491/658-1	16:06	54°41.74N	11°3.28E	7,9	ENE 7	58,2	2,9	SSS	alter course	Multibeam
POS491/658-1	16:16	54°41.66N	11°4.24E	8,5	ENE 6	110,8	3,8	SSS	alter course	Multibeam
POS491/658-1	17:00	54°41.03N	11°7.26E	14	ENE 5	109,9	2,3	SSS	to water	
POS491/658-1	17:37	54°40.36N	11°10.36E	14,7	ENE 5	110,4	3,1	SSS	alter course	
POS491/658-1	18:59	54°41.77N	11°3.58E	7,6	E 7	291,4	3,1	SSS	alter course	
POS491/658-1	20:32	54°40.29N	11°10.29E	15,1	ESE 10	111,1	3,2	SSS	alter course	
POS491/658-1	21:50	54°41.68N	11°3.58E	8,7	ESE 8	291,2	3,4	SSS	alter course	
POS491/658-1	23:24	54°40.21N	11°10.34E	15,2	ENE 7	110,2	2,9	SSS	alter course	
12.10.2015										
POS491/658-1	00:51	54°41.63N	11°3.43E	8,6	ENE 5	289	2,9	SSS	alter course	
POS491/658-1	01:36	54°40.31N	11°5.28E	12,7	ESE 7	204	3,6	SSS	alter course	
POS491/658-1	03:24	54°34.70N	11°3.05E	15,4	SSE 6	107,2	2,5	SSS	alter course	
POS491/658-1	04:02	54°34.48N	11°6.46E	21,1	SSE 8	97	3,2	SSS	alter course	
POS491/658-1	05:42	54°39.35N	11°9.58E	17,1	SE 9	18,3	3,2	SSS	alter course	
POS491/658-1	07:18	54°34.86N	11°10.25E	24,5	SE 10	176,6	3	SSS	alter course	
POS491/658-1	07:44	54°33.51N	11°10.20E	22,9	ESE 10	185,2	3,2	SSS	alter course	
POS491/658-1	09:12	54°33.70N	11°1.58E	7,7	SE 9	273	3,9	SSS	alter course	

Station	Time	PositionLat	PositionLon	Depth $[m]$	Wind $[\frac{m}{s}]$	Course $[°]$	Speed $[kn]$	Gear Abbr.	Action	Comment
POS491/658-1	10:57	$54°33.44N$	$11°10.16E$	22,4	ESE 10	91,6	3	SSS	alter course	
POS491/658-1	12:23	$54°33.77N$	$11°1.67E$	8,2	E 9	276,2	3,8	SSS	alter course	
POS491/658-1	14:15	$54°33.51N$	$11°10.41E$	23,4	E 10	84,8	1,8	SSS	alter course	
POS491/658-1	15:36	$54°33.85N$	$11°1.66E$	8,9	E 9	273,4	3,6	SSS	alter course	
POS491/658-1	17:36	$54°33.66N$	$11°9.81E$	22,6	ESE 10	274,7	4,4	SSS	alter course	
POS491/658-1	18:46	$54°33.93N$	$11°1.65E$	9,1	ESE 9	273,1	4,1	SSS	alter course	
POS491/658-1	20:30	$54°33.67N$	$11°10.20E$	23,2	ESE 9	94,5	3	SSS	alter course	
POS491/658-1	22:01	$54°34.00N$	$11°1.65E$	9,5	ESE 9	273	3,5	SSS	alter course	
POS491/658-1	23:51	$54°33.74N$	$11°10.23E$	23,5	ESE 8	94,7	3	SSS	alter course	
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POS491/658-1	01:26	$54°34.08N$	$11°1.68E$	10	ESE 6	273,8	3,3	SSS	alter course	
POS491/658-1	03:13	$54°33.76N$	$11°10.60E$	23,9	ESE 4	28,5	2,3	SSS	alter course	
POS491/658-1	03:30	$54°33.90N$	$11°8.89E$	21,5	ESE 4	274,1	4,1	SSS	end profile	
POS491/658-1	03:36	$54°33.92N$	$11°8.18E$	20	ESE 4	273,2	3,7	SSS	on deck	Ende der Forschungsarbeiten