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Centre for Arctic Gas Hydrate, Environment and Climate (CAGE)

Norwegian Centre of Excellence

R/V Kronprins Håkon.

22-October - 02 November 2018

Longyearbyen –Tromsø

CAGE18-5 Cruise report

Remotely-operated vehicle (ROV) investigations of active gas seepage sites in the Barents Sea

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Report prepared by: Bünz, Stefan with contributions by cruise participants

DOI:

Key words: gas seepage, gas hydrate pingo, blowout craters, Barents Sea

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NGU: Norwegian Geological Survey, Trondheim

UoA: University of Angers, France

OGS: Institute of Oceanography and Experimental Geophysics, Trieste, Italy

NPD: Norwegian Petroleum Directorate

NORMAR, UiB: Norwegian Marine Robotics Facility, University of Bergen

2 INTRODUCTION AND OBJECTIVES

Cruise CAGE18-5 is the first research expedition under the helm of UiT The Arctic University of Norway in Tromsø with the new ice-going research vessel R/V Kronprins Håkon (Figure 1). This new vessel provides new opportunities to collect cross-disciplinary data for addressing the objectives of the Norwegian Centre of Excellence for Arctic Gas Hydrate, Environment and Climate, CAGE. CAGE investigates Arctic gas hydrate and methane seepage systems in order to better understand the effects they may have on our oceans, ecosystems and global climate.

Figure 1: RV Kronprins Håkon at bykaia in Longyearbyen in the middle of October shortly before start of expedition CAGE18-5.

The new research vessel and its facilities allows CAGE access to a state-of-art remotely-operated vehicle, the ROV Ægir 6000 of the Norwegian Marine Robotics Laboratory at the University of Bergen. This vehicle provides a new domain for experimental work and acquisition of sample material from the seafloor.

The overall goal of cruise CAGE18-5 therefore is to utilize the ROV in order to provide guided video imagery and to study active gas seepage systems at the gas-hydrate pingo (GHP) site located in the outer Storfjord Trough, and at Storbanken in the northeastern part of the Barents Sea (Figure 2). Scientific problems that are to be addressed in these two key target areas include the structure, seafloor expression and geological setting of gas seepage features, quantification of methane concentrations in surface sediments and water column above, the occurrence of gas hydrates, benthic and microbial community studies, analyses of gas and pore water geochemistry and the periodicity and duration of gas seepage. All work packages of CAGE are involved in this cruise and represented on board. In addition to sampling work

from the ROV, we plan to carry out oceanographic (CTD, ADCP) studies and acoustic mapping (multi and single beam) from the ship.

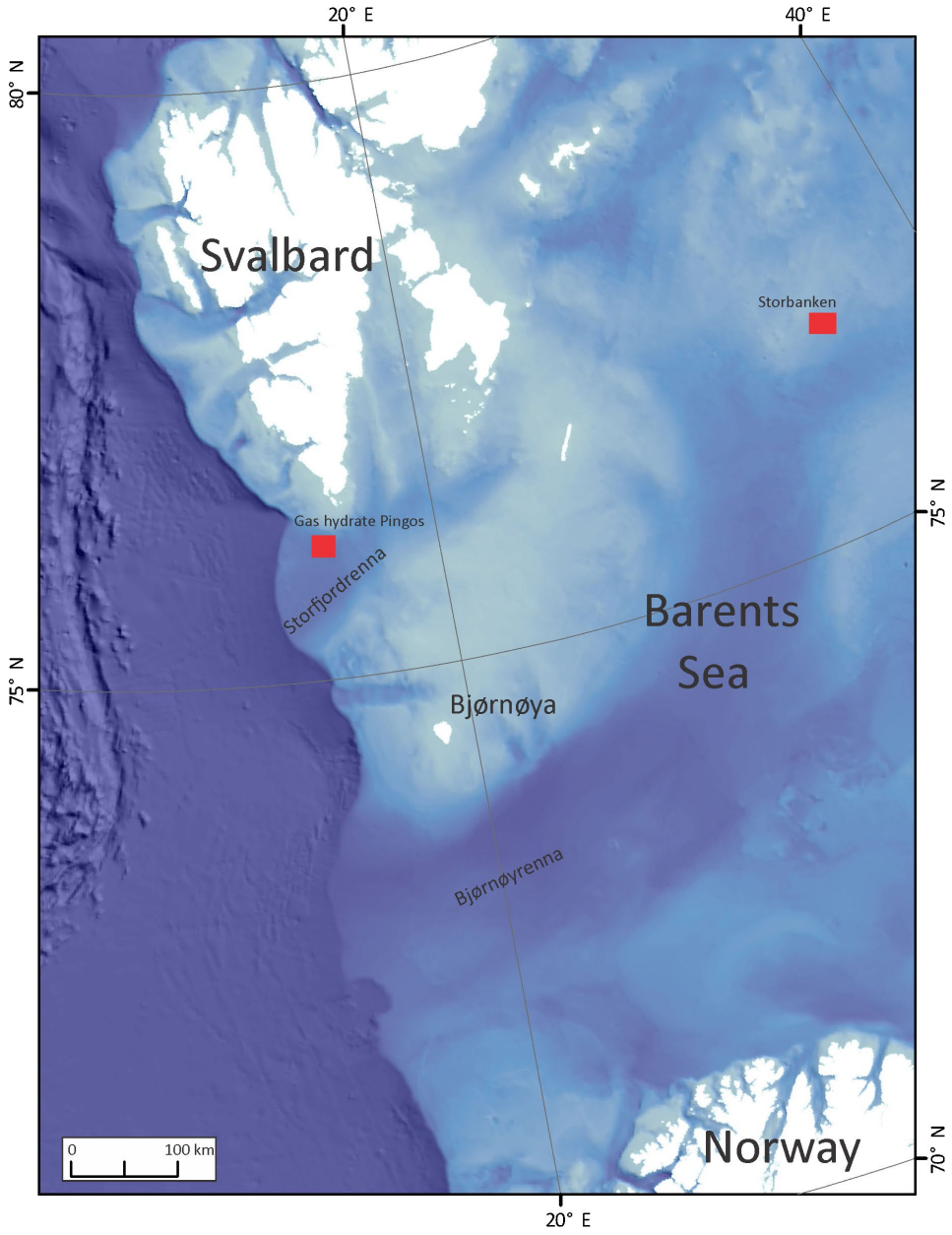


Figure 2: Overview map showing the two study areas: 1) Gas hydrate pingos in the Storfjord Trough, and 2) mound and crater structures at Storbanken. Active gas seepage has been identified in both areas on previous cruises.

3 GEOLOGICAL SETTING OF THE STUDY AREAS

3.1 Storfjord Trough gas hydrate pingos

In 2014, the discovery of seafloor mounds leaking methane gas into the water column in the north-western Barents Sea became the first to document the existence of non-permafrost related gas hydrate pingos (GHP) on the Eurasian Arctic shelf. The discovered site is given attention because the gas hydrates occur close to the upper limit of the gas hydrate stability zone, thus may be vulnerable to climatic forcing; furthermore, it belongs to the regional Hornsund Fault Zone marking a transition between the oceanic and continental crust. The Hornsund Fault Zone is known to coincide with an extensive seafloor gas seepage area; however, until now lack of seismic data prevented connecting deep structural elements to shallow seepage. The study area is located within a shear segment of the northern Hornsund Fault Zone, which is characterized by N-NW trending normal faults and E-W striking shear faults (Bergh & Grogan, 2003; Lasabuda et al., 2018). A group of 6 mound structures occure in close vicinity, with 5 of those structures actively seeping gas into the water column (Serov et al., 2017). From seafloor video transects, bottom samples, and shallow (<3 m) sediment cores, it is evident that the positive topographic features consist of gas hydrate-bearing soft cohesive muds.

3.2 Storbanken craters

The Storbanken craters are located on the southern part of Storbanken, a large fishing bank in the north-central Barents Sea (Figure 2). This bathymetrical high is also an underlying structural high, the Storbanken high (NPD, 2017). The seafloor in the study area is an area previously mapped to have several large “craters” and mounds. Several gas-flares, carbonate crusts and bacterial mats have previously been observed on the seafloor (CAGE17-2 and CAGE 18-1 Cruise reports). The area has a very thin quaternary cover, below seismic resolution and are very difficult to core, and rocks of uppermost Triassic and Jurassic are subcropping directly below. Some of the observed “craters” have very steep slopes, some places more than 45 degrees, and based on seismic data rocks of Jurassic age might outcrop in several of these localities.

4 NARRATIVE OF THE CRUISE

Most of the scientific team arrived in Longyearbyen on Sunday, 21st October and stayed overnight in a hotel. A pre-cruise meeting was held at UNIS. The chief scientist Stefan Bünz provided an overview of the cruise and each team gave an overview of their sampling plan. The ROV team was also present and was able to provide immediate feedback on the ROV operation. Times are given in local time.

Monday, 22 October

The scientific team embarked on FF Kronprins Håkon at 10:00 in the morning. Unfortunately and although notified, the ship was not expecting our team that early. The ROV team had started to mobilize the ROV earlier on Sunday but was hindered by the fact that the launching system over the moonpool in the hangar was not prepared by the crew. This was notified several weeks ago. In addition, several crew members were exchanged on Monday, although the crew change date officially was on Sunday 21st. So without a crew available work progressed very slowly on Monday. The departure from Longyearbyen needed to be delayed to Tuesday.

Tuesday, 23 October

Mobilization of the ROV continued in the morning. Departure from Longyearbyen at 18:00. We conducted a successful wet test of the ROV in Isfjorden and then left to Storfjorden. Weather is quite bad, partly up to 5m swell.

Wednesday, 24 October

On transit to Storfjorden. Swell is about 3-4 m. The balancing tanks of the ship do a great job of compensating sea swell. Arrival at Storfjorden at 15:00. We conduct a CTD transect of 5 stations prior to ROV deployment. Because the ship is so stable even in such weather we were able to launch the ROV on gas hydrate pingo (GHP) 1.

Thursday, 25 October

A visual survey of this site left all groups a bit disappointed and we moved the ROV over to GHP3. Here we found, a lot of carbonates, bacterial mats and two places with pretty heavy gas seepage from many small holes over a perimeter of ca. 3 m. Because of the bad weather, we could not deploy the basket with push corers from the A-frame at the stern of the ship. So we sampled some very nice carbonate rock pieces and ended the dive on Thursday morning. The ROV was refitted with a larger drawer in case we cannot deploy the basket and launched for dive no. 2 on Thursday afternoon at 14:45. In addition a basket with push cores, blade

corer and gas sampler was sent down from the A-frame of the hangar. We lost the NGU gas sampler when we put the basket in water. However, it immediately appeared on the sonar of the ROV and was found within 2 minutes. The basket was then deployed at the seafloor and the ROV started the push coring. In order to limit disturbance all 19 push cores and one blade core were initially push into sediment and not recovered. Unfortunately then at about 20:00, the ROV had a major failure and had to make an emergency recovery. It was fortunately brought back safely into the hangar. However, the failure search did not show any problems on the ROV but on the umbilical from the ship.

Friday, 26 October

The ROV team identified a squeeze on the umbilical about 300 m in. Work on the new termination of the cable lasted until the late afternoon hoping we can launch again at dinner tonight. We then have to recover all 19 push cores and redo all sampling, push cores have been closed off for too long, are potentially anoxic, and cannot be used for analysis. In the meantime, we completed another CTD and hydroacoustic transect across GHP 3. The ROV was launched again at 22:15. The basket was sent down and all cores were recovered and brought up on deck for cleaning.

Saturday, 27 October

The ROV took a blade core in an area with abundant bacterial mats. It then relocated to the position with intense gas flaring and use the NGU gas sampler to take 2 gas samples. With that, the ROV was brought back into the hangar. We conducted one CTD station before the ROV went back down for dive number 4 onto GHP3 after a short turnaround. Over a period of 8 hours it then took 28 push cores and one blade core. All those cores were brought back up in the basket for subsampling and analysis by the different science teams. The ROV took two more carbonate samples before it came back up in the hangar and concluded our work in the pingo area at about 18:00. The ship then headed towards the Hornsund Fjord and sheltered water in order to fix the garage port of the hangar.

Sunday, 28 October

Fixing the garage port was completed a 04:00 in the morning and the ship then headed towards our second study area at Storbanken /Olga Basin.

Monday, 29 October

We arrived at Storbanken at 10:00 in the morning and conducted one CTD station with water sampling. Thereafter the ROV went down for dive number 5 that was only committed to mulitbeam surveying an area where gas seepage had been detected on previous expeditions.

The multibeam data from the ROV were then used to identify possible targets for seafloor sampling. The ROV came back up into the hangar and was equipped with the gas sampler, a blade corer, a checkerboard for gas flux measurements and the hydrophone for listening to seepage. Dive 6 recovered carbonate samples, to gas samples and two blade cores. The remainder of the dive was spent on measuring the gas seepage using the checkerboard and hydrophone. The dive was completed and the ROV back in the hangar at around 23:00.

Tuesday, 30 October

We moved slightly further east to a relatively large mound structure that is clearly recognized on the seafloor. ROV dive 7 started at 01:00 and was dedicated to mapping the microbathymetry on the southern flank of the mound where gas seepage had been identified earlier. The dive was completed at 04:15. While the sampling tools for dive 8 were prepared, we acquired 11 CTD casts and a hydroacoustic line. ROV dive 8 started at 10:15 and acquired carbonate and rock samples, a gas sample, two blade cores and gas flux measurements. The dive was completed at 14:45. We continued further east to investigate two semi-evacuated depressions with associated mound (remobilized seafloor) focusing on the deepest part and steep northern sidewall where Jurassic strata is outcropping. Dive 9 started shortly before 16:00 and retrieved several rock samples. The dive was completed at 20:40 and rock samples were retrieved. The ROV immediately left again at 21:15 to investigate the second depression/mound structure.

Wednesday, 31 October

The last dive (no. 10) was completed at 02:15 and had also retrieved several rock samples from the outdrop strata at the northern sidewall. That completed all scientific experiments of the CAGE18-5 cruise and we started our transit to Tromsø.

Thursday, 1 November

On transit to Tromsø.

Friday, 2 November

Arrival at Tromsø at 08:00. End of cruise. Demobilization.

5 SCIENTIFIC EQUIPMENT ONBOARD RV KRONPRINS HÅKON

5.1 Hydroacoustic systems

The hydroacoustic systems onboard RV Kronprins Håkon can be operated simultaneously, where a dedicated software intelligently manages transducer pings to avoid interferences. In-ice operations only allow using acoustic systems that are mounted in the so-called Arctic tank, an ice window in the hull of the ship, where sea ice can slide along without damaging any transducers during ice breaking. However, ice operations make data acquisition more prone to noise.

Among the hydroacoustic systems, the following were used extensively during the HACON 19 cruise.

1. Simrad Kongsberg EA 600 – 12kHz single beam echosounder
2. Kongsberg EM 302 multibeam echosounder and SBP 300 Sub-Bottom Profiler

5.1.1 Kongsberg EA 600 –12kHz single beam ekkolodd

The EA 600 single beam echosounder operates up to four high power transceivers simultaneously. Available frequencies span from 12 to 710 kHz. A variety of highly efficient transducers is available to suit all your operational needs from extreme shallow water to a depth of 11.000 meters. Major applications of this echosounder is to identify the depth and finding high-reflective objects in the water column. During this cruise, we operated the echosounder at 12 kHz as this frequency provided best bottom detection. Higher frequencies were notably affected by sea ice under the hull and hence did often not detect bottom.

5.1.2 EM 710

The EM710 multibeam echosounder is a high to very high resolution seabed mapping system which operates at sonar frequencies in the 70-100 kHz range. The system is mounted on the port drop keel of Kronprins Haakon and is particularly suited for swath bathymetry surveys up to 800 m water depth. The system sends out 400 beams at an angle of upto 700 on each side (1400 coverage in total). In order to achieve a high-density of beams the system was used at an angle of 600 on each side. There are options to adjust the beam spacing, either equiangular or equidistant. There is an additional high-density mode to achieve higher sounding density by reducing the acoustic footprint. During the CAGE-18-5 cruise, the system was run on high-density equidistant mode. In addition, EM710 also allows recording of watercolumn backscatter data. This is particularly useful in identifying gas bubbles in the water column. The EM710 was primarily operational during the transits between study areas

of the CAGE-18-5 expedition. New CTD data were acquired at each study area to update the water velocity used by the EM710 system.

5.1.3 EM 302 and SBP 300

The EM 302 multibeam echo sounder has an operating frequency of 30 kHz and is designed to perform seabed mapping with high resolution and accuracy to a maximum depth of more than 7000 m. Beam focusing is applied both during reception and transmission. EM 302 is equipped with a function to reduce the transmission power in order to avoid hurting mammals if they are close by.

The system has up to 432 soundings per swath with pointing angles automatically adjusted according to achievable coverage or operator defined limits. With dual swath (two swaths per ping) the transmit fan is duplicated and transmitted with a small difference in along-track tilt. The applied tilt takes into account depth, coverage and vessel speed to give a constant sounding separation along track. In dual swath mode, 2 swaths are generated per ping cycle, with up to 864 soundings. The beam spacing is equidistant or equiangular.

The transmit fan is split in several individual sectors with independent active steering. This allows stabilization, which compensates for the vessel movements: yaw, pitch and roll. Each transmit sector has individual beam focusing.

In conjunction with a separate low frequency transmit transducer, the EM 302 may optionally be able to deliver sub-bottom profiling capabilities with a very narrow beamwidth. This system is known as the SBP 300 sub-bottom profiler. During this cruise, the SBP was operated constantly with a chirp pulse of 50 ms and frequency bandwidth of 2.5 – 6.5 kHz.

The EM 302 (including the SBP 300) is mounted in the ice window in the bottom hull of the vessel. During ice breaking, ice sliding beneath and along the ice window significantly affect the acquisition leading to high noise levels and false measurements.

During the cruise, the multibeam bathymetry data was processed and cleaned using QPS Qimera Software. An initial grid surface with a resolution of 15 m was produced for the perimeter of the Aurora Seamount. However, high noise levels merit further processing to improve map quality.

5.2 Oceanographic systems

Physical and chemical measurements are measured in the water column from a CTD/rosette. The CTD model is a Seabird 911 plus mounted on a 12 or 24 10-liters Niskin bottles carousel and was brought close to the seafloor. The CTD is coupled with different types of equipment such as oxygen sensor, transmissiometer and fluorimeter.

5.3 Attributed Sensors

5.3.1 GPS/Navigation, Motion Reference Unit

RV Kronprins Håkon uses a Kongsberg Seapath 330-5 system, an integrated global navigation satellite system (GNSS), using the GPS, GLONASS, Galileo or Beidou signals and inertial measurements to provide high quality results for applications including hydrographic surveying, dredging, oceanographic research, seismic work etc. This Seapath system includes a 5th generation MRU motion sensor package, providing up to 0.008° RMS roll and pitch accuracy. This accuracy is achieved by the use of accurate linear accelometers and unique MEMS type angular rate gyros.

5.3.2 USBL HiPaP

RV Kronprins Håkon is equipped with a HIPAP 501 Acoustic Underwater Positioning and Navigation System. ROV NUI, OFOBS, CTD and partly also coring equipment were outfitted with a HiPaP beacon for exact positioning information on the seafloor. The HiPAP 501 system operates with the transducer mounted on the hull to allow the transducer to be lowered some meters below the hull of the vessel. A transceiver unit containing transmitter, preamplifiers and beam forming electronics is mounted close to the hull unit. The HiPAP 501 system has a spherical transducer with several hundred elements covering the whole sphere under the vessel. The system will dynamically control the beam so it is always pointing towards the transponder. The transponder may be moving, and roll, pitch and yaw affect the vessel itself. Data from roll/pitch sensors are used to roll and pitch compensate the position.

The Super Short Base Line (SSBL) principle has the obvious advantage that it only requires installation of one hull mounted transducer and one subsea transponder to establish a three-dimensional position of the transponder. An SSBL system is measuring the horizontal and vertical angles together with the range to the transponder. An error in the angle measurement causes the position error to be a function of the range to the transponder. To obtain better position accuracy in deep water with an SSBL system it is necessary to increase the angle measurement accuracy. The frequency band of the HiPaP 501 is 21 - 31 kHz and the operating range is 1 - 5000 m. The range detection accuracy is given as 0.02 m assuming free sight between transducer and transponder, no or very little noise in the water column and no error from heading/roll/pitch sensor. We recognized interference between HiPaP and multibeam EM 302 systems due to usage of similar frequency bands. For most operations at the seafloor, EM 302 acquisition was stopped, leading to more stable positioning of the USBL transponder.

6 ROV ÆGIR6000

The ROV ÆGIR6000 is a SUPPORTER 2-type ROV from Kystdesign in Aksdal, Norway (Figure 3). The ROV has a total combined power of 115 Kw, a depth rating of 6000 m and is maneuvered by 7 thrusters. Its dimensions are (LxBxH) 2,75 m x 1,7 m x 1,65 m and it weighs 3600 kg in air. The ROV can carry a payload of 400 kg and has two strong manipulators arms. 8 HD and composite video camera inputs provide full vision of operation and partly have zoom and focus capability. The lighting capacity includes ten dimmable lights and has a maximum total load of 2300W. The SUPPORTER 2 can accommodate up to 24 additional hydraulic tooling functions, up to 21 additional survey sensors and 8 camera connectors. All hydraulic functions are proportionally controlled, and all electrical power supplies are ground fault monitored. The ROV control system offers a variety of auto-functions like AutoPOS and AutoTRACK capabilities. The control pod and telemetry system for survey operations works via up to 6 fibre optic cables. The umbilical able on RV Kronprins Hækon provides 4 fiber optic cables. In addition to the video feed, the system is capable of supporting several additional communication channels both serial and Ethernet.

Figure 3: The ROV Ægir6000 is a Kystdesign Supporter ROV rated to 6000 m water depth.

The ROV is equipped with an EM 2040 multibeam echo sounder for deep water multibeam mapping of the near bottom sounding environment in great detail. The basic EM 2040 has a transmit transducer, a receive transducer, a processing unit and a deck-side processing computer. The EM2040 operates at 200 - 400KHz, with 400 beams in single-swath mode

offering 0.4 x 0.7 degree angular resolution. A swath angle of up to 140 degrees can be reached providing a maximum coverage of 4 to 5 times the water depth. During the cruise, the maximum swath width was varied between 50 and 70 degrees on either side in order to improve data quality, reduce the amount of noisy data at the outer beams. The ROV flew approximately 8 – 10 m above seafloor in the Storfjorden pingo area and about 12 m above seafloor in the Storbanken area resulting an seafloor imaging resolutions of 10 cm and 15 cm respectively.

The ROV is equipped with a large drawer to store sample material during dives. A large basket was used to bring sample containers to the seafloor and back up using the A-Frame from the hangar at mid-ship position. That limits the times the ROV has to dive up and down and hence, saves considerable time. Aside from the manipulator arms providing the opportunity to take direct carbonate or rock samples, the ROV ÆGIR6000 provides a number of sampling tool, most prominently push coring device that can take up to 60 cm long sediment cores with a diameter of 8 cm. Another device is the blade corer that can sample a larger rectangular area of approximately 20x12 cm and has an automatic closing mechanism ensuring that sediments could not be lost during retrieval of the sediments. During one of the dives, the ROV also used a chainsaw to cut off a piece of carbonate material. And on another dive, a Niskin bottle was placed in the drawer but the rubber malfunctioned and did not close the bottle.

7 HULL-MOUNTED HYDROACOUSTIC SURVEYS

(Sunil Vadakkepuliyambatta, Manuel Moser, Benedicte Ferre,)

7.1 Singlebeam Echsounder EK80

During the cruise, the EK80 singlebeam echosounder was recording most of the time to identify active gas seepages from the seafloor. As this high frequency echosounder system is very sensitive to gas bubbles in the water column, the rising bubbles appear as high amplitude anomalies (acoustic flares) in the water column (see Figure 4). In addition to the "on-the-way-measurements", we conducted explicit EK80 surveys. Other acoustic systems which could interfere with the EK80 were turned off during these measurements.

The new flare data will be used: 1) to expand CAGE's flare data base, 2) for comparison with flares that were mapped in the Storbanken area during the CAGE 18-1 cruise in May 2018, 3) for comparison with benthic hydrophone measurements on specific flares at the pingo site and in the Storbanken crater area, 4) to determine volumetric flow rates at the above-mentioned flares and 5) to perform an experiment with the aim to determine the bubble size distribution (BSD) at these sites based on EK80 data and to compare the results with BSDs derived from optical checkerboard measurements on the aforementioned flares during the ROV dives.

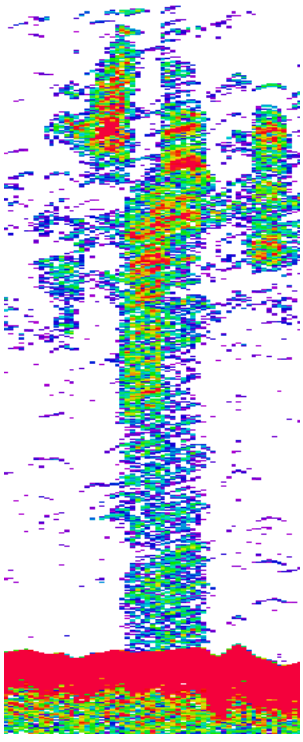


Figure 4: Acoustic gas flare rising from the 149 m deep seafloor to the water column. This ~91 m high flare is located in the Storbanken area and corresponds to a seep where we conducted hydrophone and checkerboard measurements. Brighter colours mean higher amplitudes.

7.2 Multibeam Echosounder EM710

Most of the multibeam data were acquired during the transit from Longyearbyen to Storfjordrenna Pingo area and to the Storbanken crater area. Except on the Storbanken mound, the EM710 was not logging at the study areas to avoid interferences with the ROV survey and to avoid low quality data, as the ship was stationary. The swath bathymetry from the EM710 is processed using QPS Qimera software. The Pingo area transit was gridded to 6m resolution, whereas the Storbanken transit and mound area were gridded to 3 m resolution. The bathymetry data show typical seafloor features of the Barents Sea, including glacial lineations and ploughmarks (Figure 5).

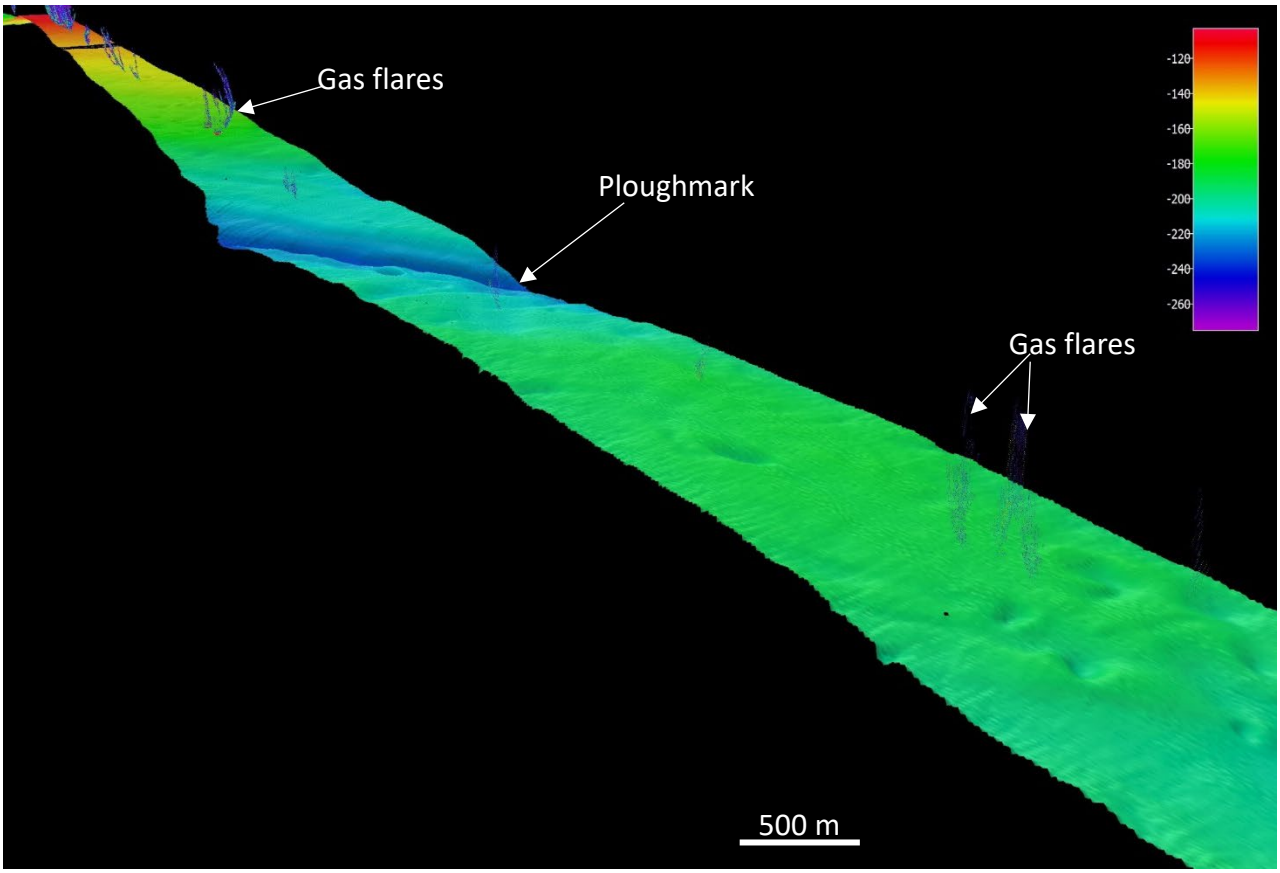


Figure 5: DTM map of the transit from Longyearbyen to Storfjordrenna. The mapped flares off the coast of Svalbard is plotted over the bathymetry. For location of the flares see Fig.yy

Water column data from the EM710 was logged and gas flares were extracted using QPS Midwater software (Figure 6). The transit from the Storfjordrenna Pingo area to Storbanken craters was planned to pass through potential gas leakage areas as interpreted from 2D seismic data.

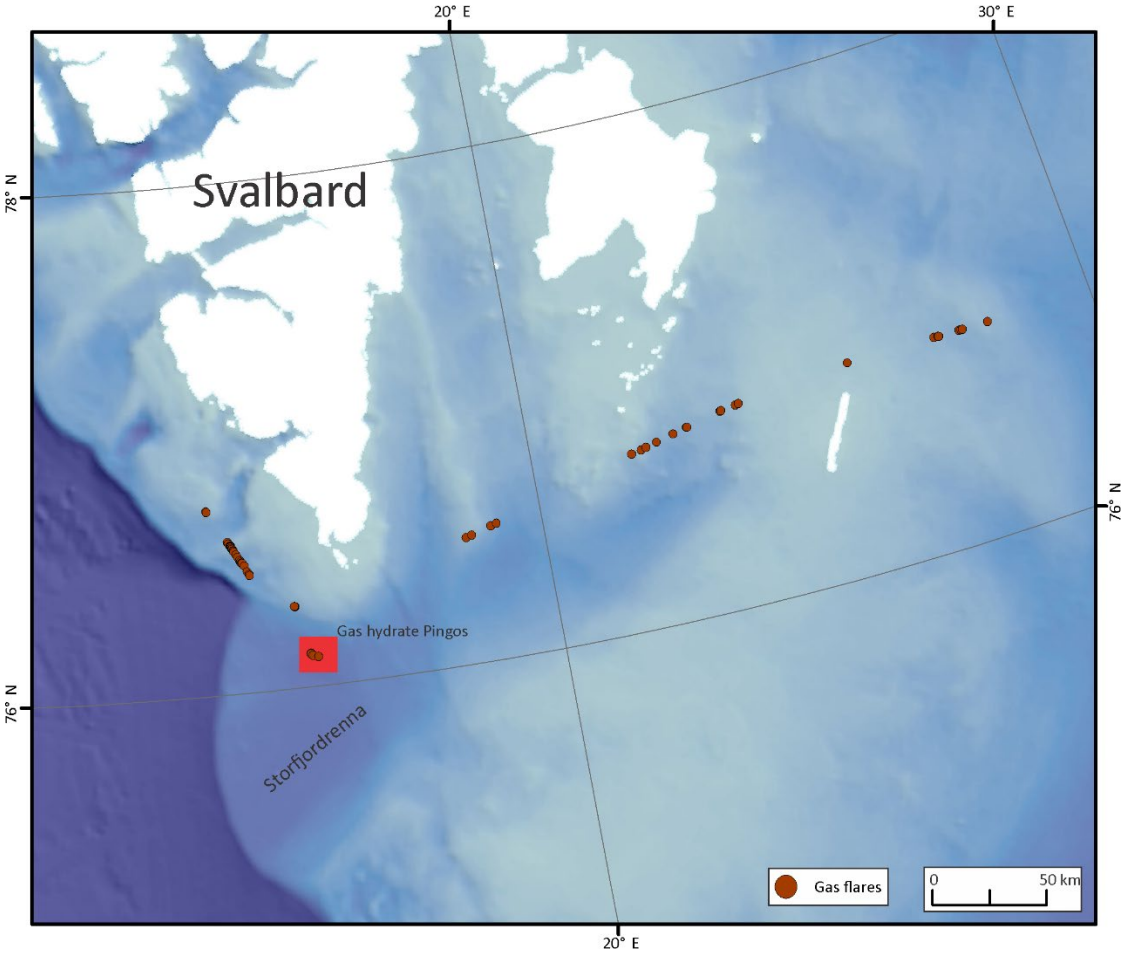


Figure 6: Mapped flares on the transit lines.

At the Storbanken mound area, four profiles were surveyed with full suite of hydro-acoustic systems onboard the Kronprins Haakon (Figure 7). Main aim of the survey was to study the response of gas bubbles in the water column to various acoustic frequencies and thereby extract more information about the properties of gas bubbles.

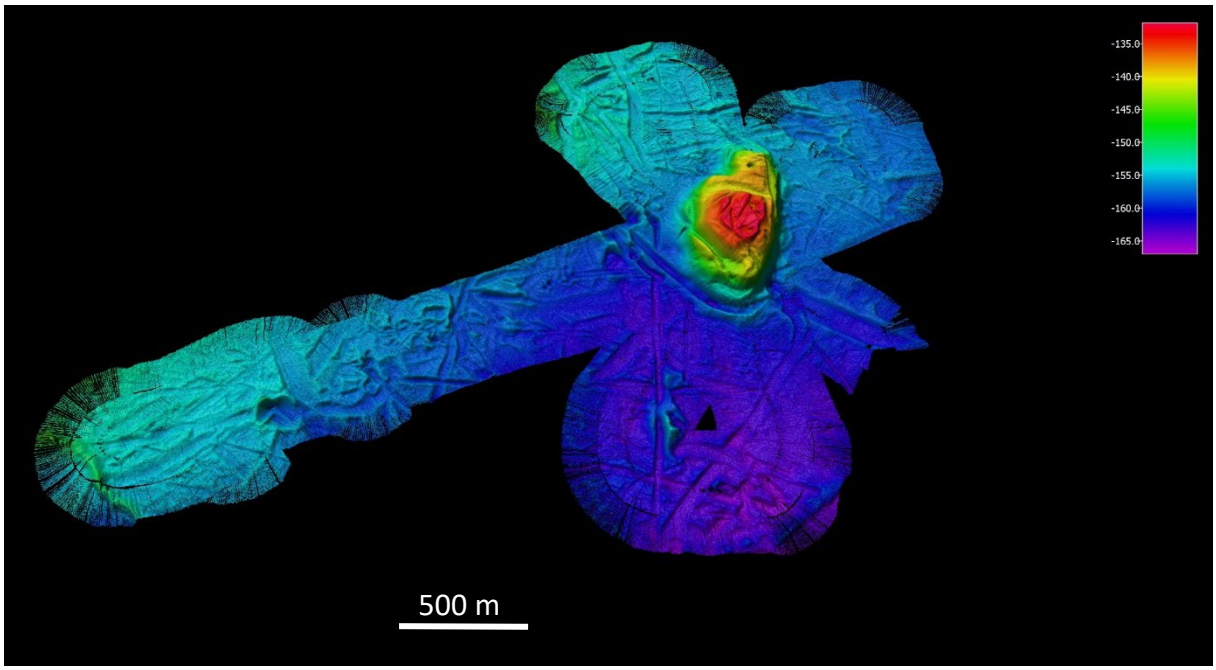


Figure 7: DTM map of the Storbanken mound highlighting the ploughmarks in the area. 3 m resolution & VEx6.

7.3 Acoustic Doppler Current Profiler (ADCP)

Current are measured in the water column from ADCPs (Acoustic Doppler Current Profilers). There are four ADCPs mounted on RV Kronprins Haakon: two 38 kHz and two 150 kHZ RDI Ocean Surveyors. One of each are located on a drop keel, the other ones are in the hull. During the cruise, only the ADCP 150Khz from the drop keel was on to prevent interferences with the echosounder EK80.

8 OCEANOGRAPHY

(Benedicte Ferre, Pär Jansson)

8.1 Methods

Temperature, salinity and oxygen measurements as well as water samples for further hydrocarbon analysis were collected from the CTD/rosette. The Niskin bottles were closed on the way up at various depth: 5, 10 and 25 meters above the seabed, 5 and 10 meters below the sea surface and the other bottles were spread out in the rest of the water column. Four CTD casts were performed across pingo 1 (182-185), six across pingo 3 (186-190) and six across the site in Storbanken (193-198) (Figure 8). Additional CTD data and water samples were obtained simultaneously with an ROV dive, during which the ROV was holding the rosette with its arm right above a seepage (CTD 191, Figure 9).

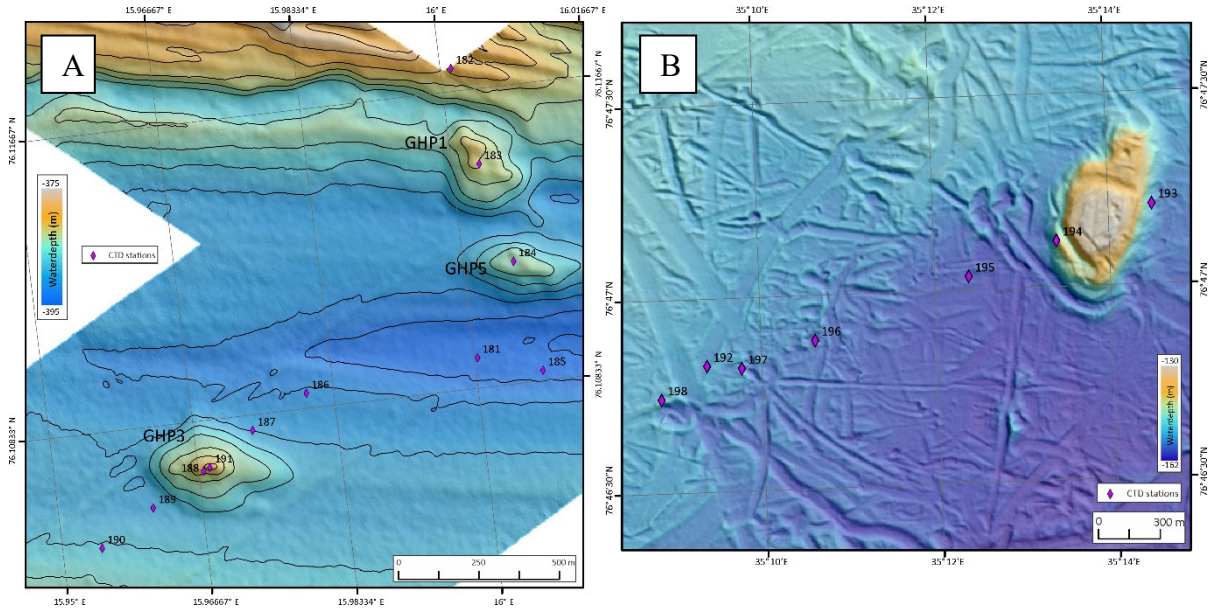


Figure 8: CTD casts performed in Storfjorden across A) pingos 1 and 3 and B) Storbanken.

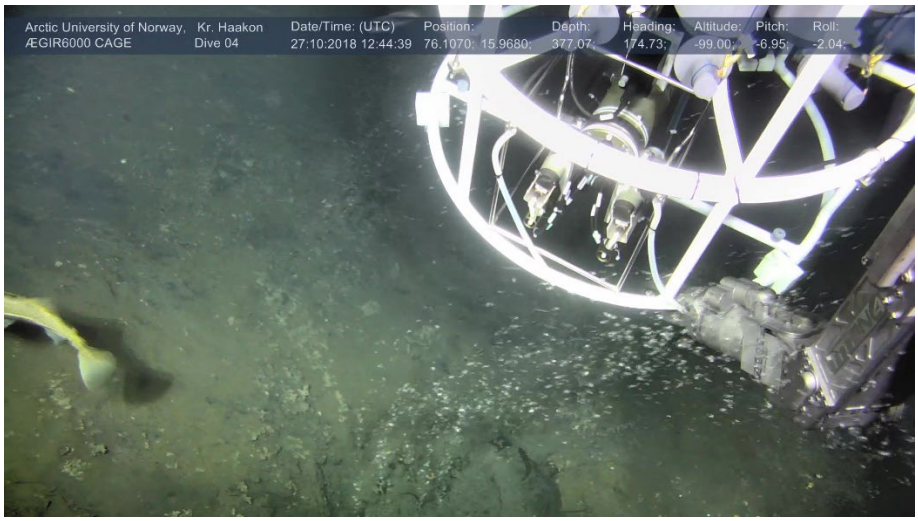


Figure 9: CTD cast with ROV arm holding the rosette above the flare for water sampling at the source.

Current was measured in the water column from the mounted ADCP 150kHz. The 38kHz ADCP was shut down to prevent interferences with the EK80. The ADCP was turned off during multibeam and EK80 surveys to prevent interferences. Data will be further analysed.

8.2 Preliminary Results

Water masses at the two study sites were very distinct but both strongly stratified. Storfjorden is characterized with surface water up to 100-200 m depth, Atlantic Water until ~300m depth and Polar Front signature (mixture of Atlantic water and Arctic Water) down to the sea floor (Harris et al., 1998) (Figure 10A). Storbanken water column is split between surface water down to 65m depth, Arctic water down to 90m depth and Polar Front down to the seafloor (Figure 10B) (Harris et al., 1998).

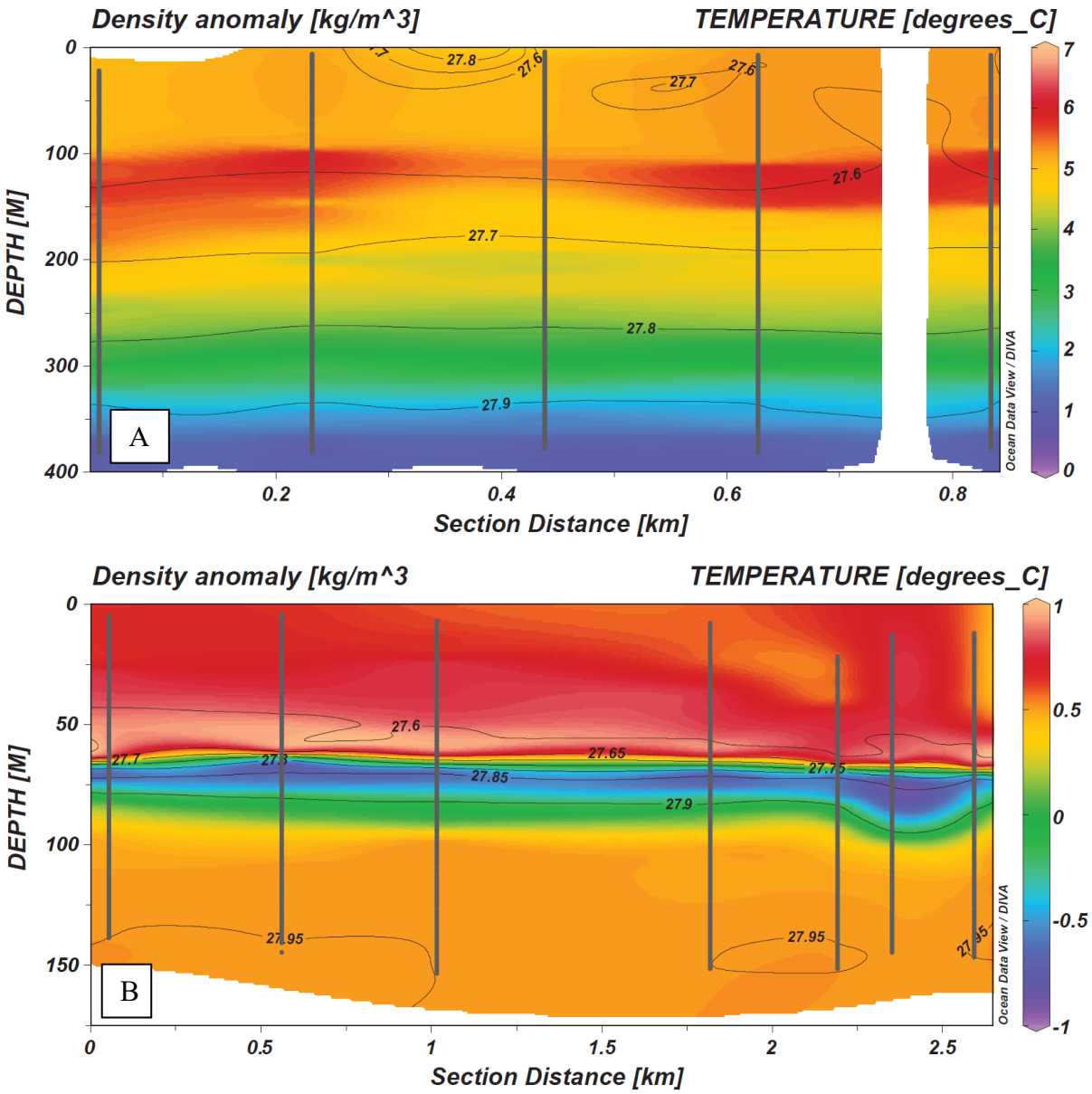


Figure 10: CTD transect with temperature (color scale) and density anomaly (contours) across A) Pingo 3 and B) Storbanken. CTD casts are represented by black lines.

9 ROV ÆGIR6000 DIVES

A total of 10 ROV dives were conducted during this expedition, 4 at the gas hydrate pingos (Figure 11) and 6 at three sites within the Storbanken crater and mound area. Each of the dives had different objectives ranging from simple seafloor inspection or microbathymetry mapping to integrated sampling missions using manipulator, coring devices and gas sampler.

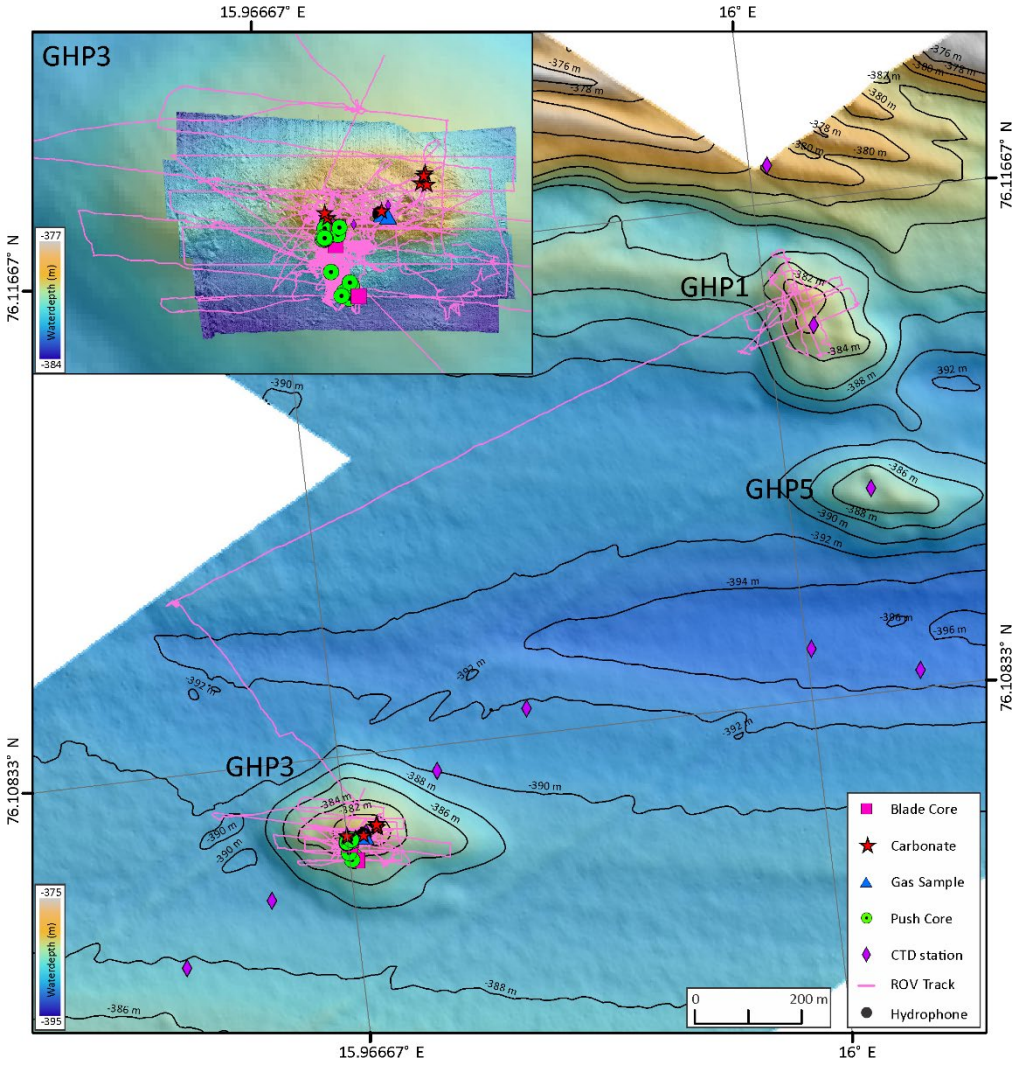


Figure 11: Overview of the 4 ROV dives conducted at the gas hydrate pingos in Storfjord Trough.

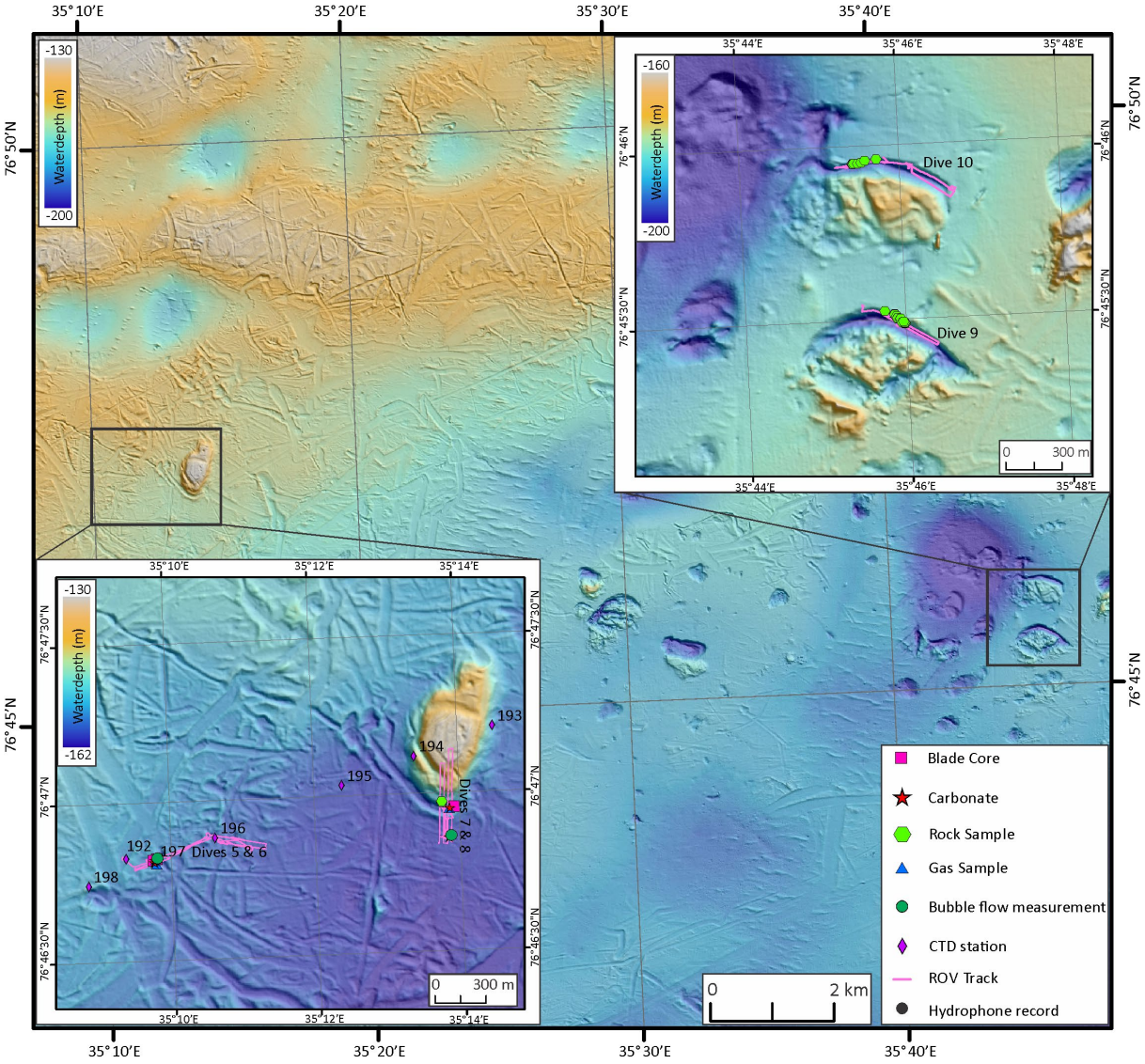


Figure 12: Overview of the 6 ROV dives conducted at Storbanken.

9.1 ROV dives at gas hydrate pingos (Dives 1, 2, 3 & 4)

ROV dive 1 started at GHP 1. A systematic survey of this pingo structure did not show signs of high activity, so the dive continued over to GHP3 (Figure 13). This GHP had been well studied using deep-tow camera and sampling equipment operated from a vessel (Serov et al., 2017; Hong et al., 2017; Sen et al., 2018), but the visual inspection of the seafloor showed an environment much more active and affected by the active gas seepage than expected. Many places were rich in biota, several areas covered with bacterial mats and carbonate crust, and we found two places with very intensive gas seepage (Figure 14). Several pieces of carbonate crust from two different locations were taken during dive 1.

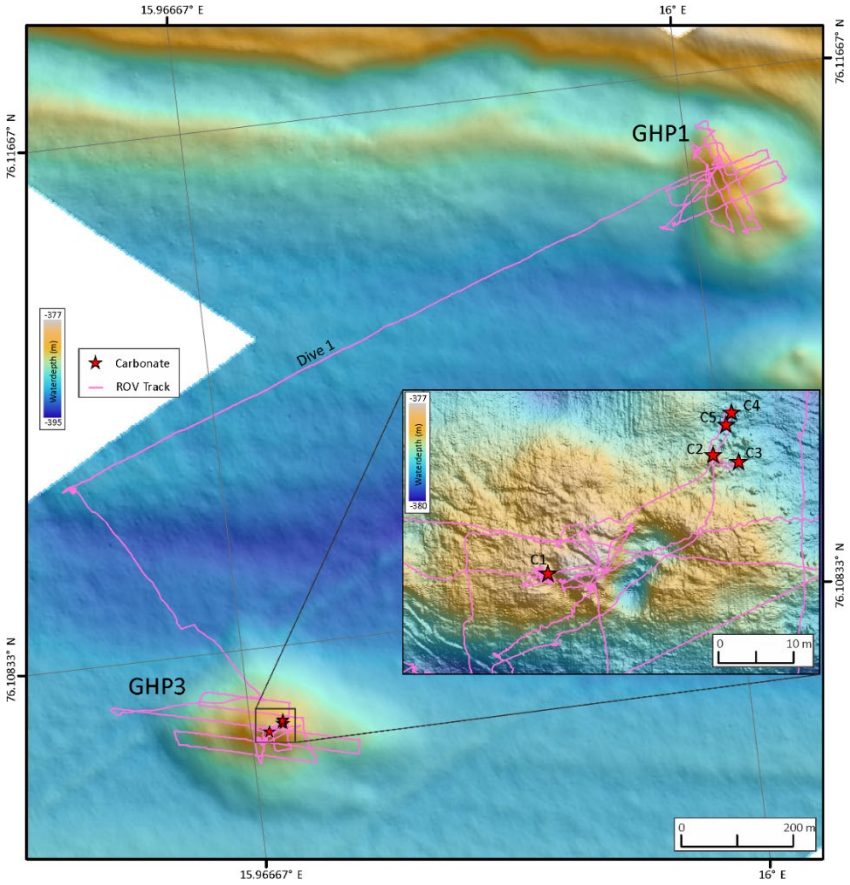


Figure 13: Track and sample locations of ROV dive no. 1.

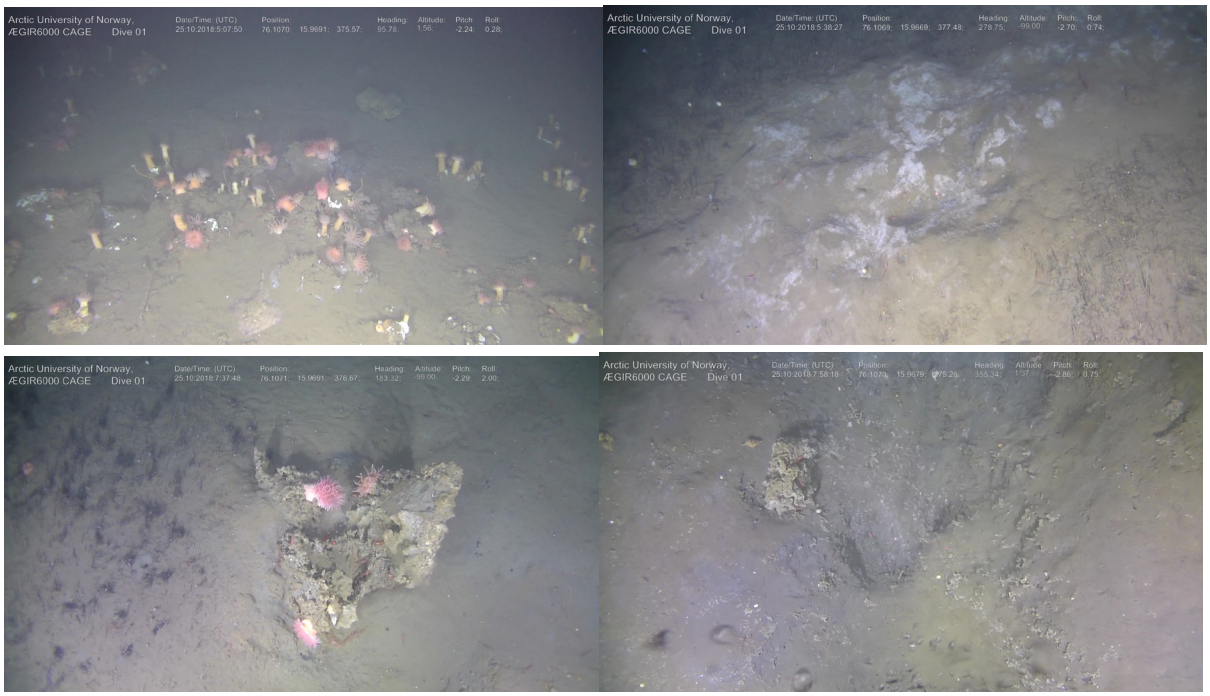


Figure 14: Seafloor observations at GHP3 showed abundant biota (top left), abundant bacterial mats (top right), large carbonate accretions (lower left) and intensive gas seepage (lower right).

Dive no. 2 was dedicated to an intensive coring program using 20+ push corers and a blade corer (Figure 15 and Figure 16). Many push cores were deployed with close spacing over bacterial mats in order investigate small scale changes in geochemical conditions and microbiological activity. A number of possible sites were inspected before all of the push cores were deployed successfully at a site on the southern flank of GHP3 (Figure 15). However, directly after deployment, the ROV had an umbilical problem and had to make an emergency recovery. All push cores were left on the seafloor.

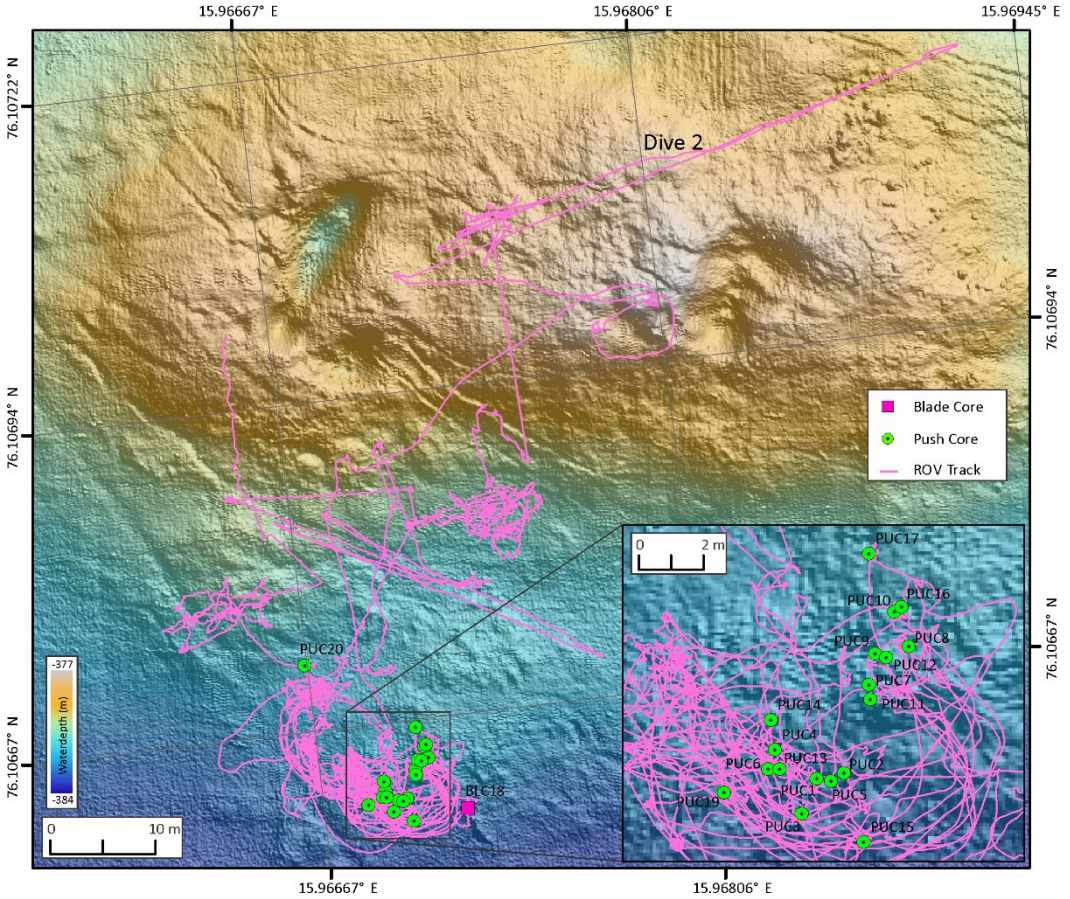


Figure 15: Track and sample locations of ROV dive no. 2.

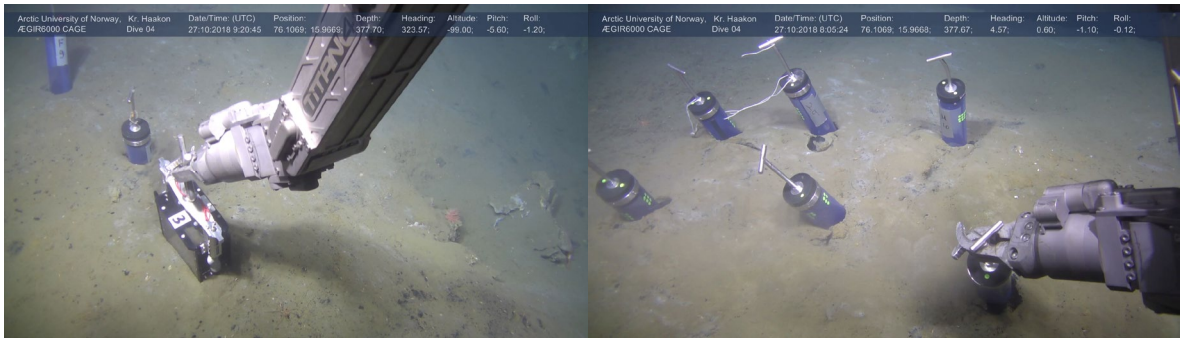


Figure 16: Dive 2 was dedicated to an intensive coring program with 20+ push cores for geochemical, sedimentological and microbiological investigations. Many push cores were closely spaced in areas with bacterial mats. A blade corer (left) can take a larger sample of the upper few cm of the seafloor and much better preserve the surface.

After the ROV umbilical was fixed, the first goal of dive 3 was to recover all coring devices that were stuck at the seafloor. Those were brought up to the ship using a basket through the A-frame of the hangar (Figure 18). While the push corer were prepared onboard for another deployment, the ROV used its Kongsberg multibeam system to map the GHP in high detail (Figure 17 and Figure 19). The high-resolution map shows two depressions at the top of the pingo, of which the eastern depressions is associated with intensive gas seepage, carbonate crusts and a multitude of biota. No gas seepage was identified at the western depression during this expedition. A gas sampler from NGU twice sampled gas from two different gas seepages associated with the eastern depression (Figure 18). Here we also used a hydrophone to listen to the gas seepage.

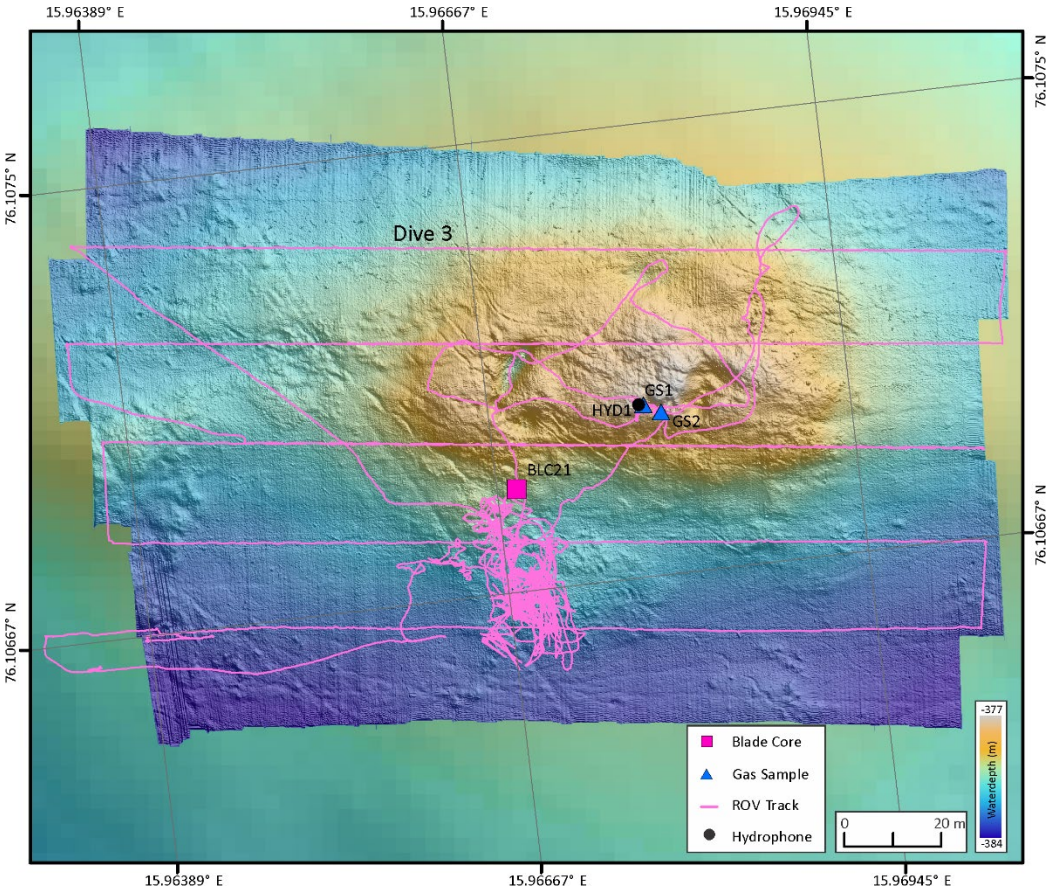


Figure 17: Track and sample locations of ROV dive no. 3. The microbathymetry data shown in the other dive maps was acquired during this dive.

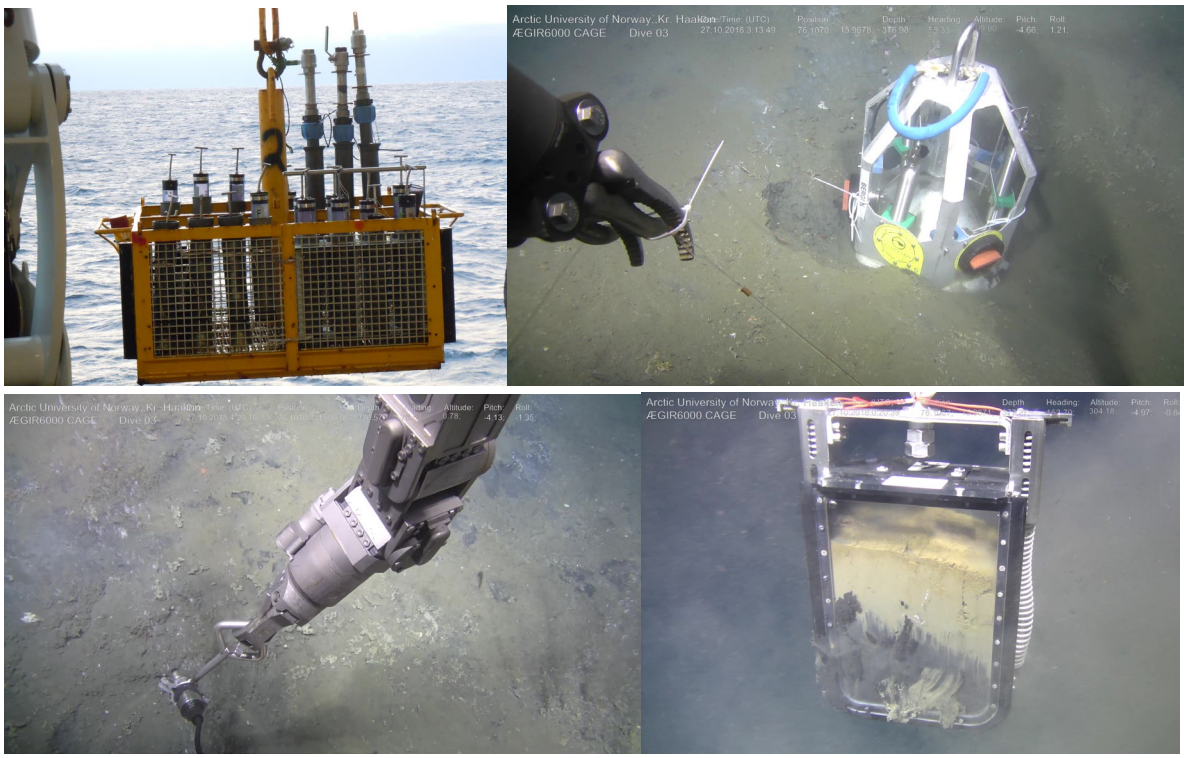


Figure 18: A basket was used to bring sampling tools down to and up from the seafloor (upper left). A gas sampler sampled gas twice over the most intensive gas seepage locations (upper right). We used a hydrophone to listen to the gas seepage (lower left). The blade corer is an excellent tool for obtaining an undisturbed seafloor sample (lower right).

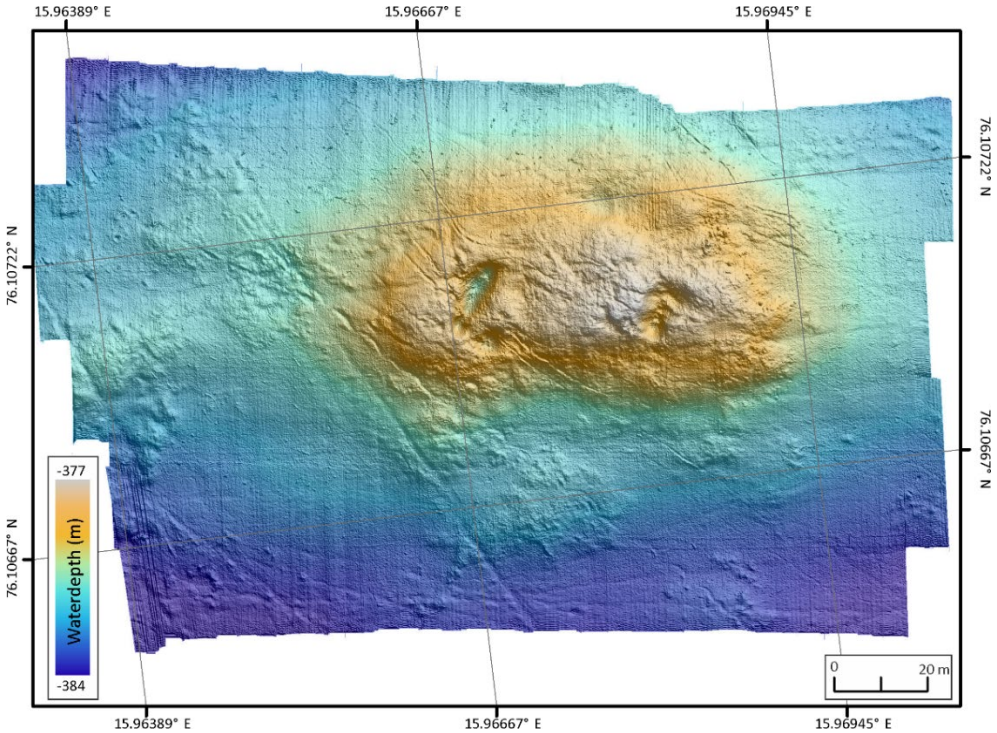


Figure 19: Microbathymetry data acquired during ROV dive 3. The data has a resolution of 20 cm and shows the structure and morphology of GHP3 in great detail.

ROV dive 4 repeated the experiment with 20+ push cores at another site with bacterial mats that was still undisturbed (Figure 20). First, all push cores were taken but not recovered immediately as that would have caused a lot of disturbance and dust in the water impairing visibility. After that, all of the push cores were recovered and returned to the ship in the basket.

An overview of all samples taken at the gas hydrate pingo site in Storfjord Trough is shown in Figure 21.

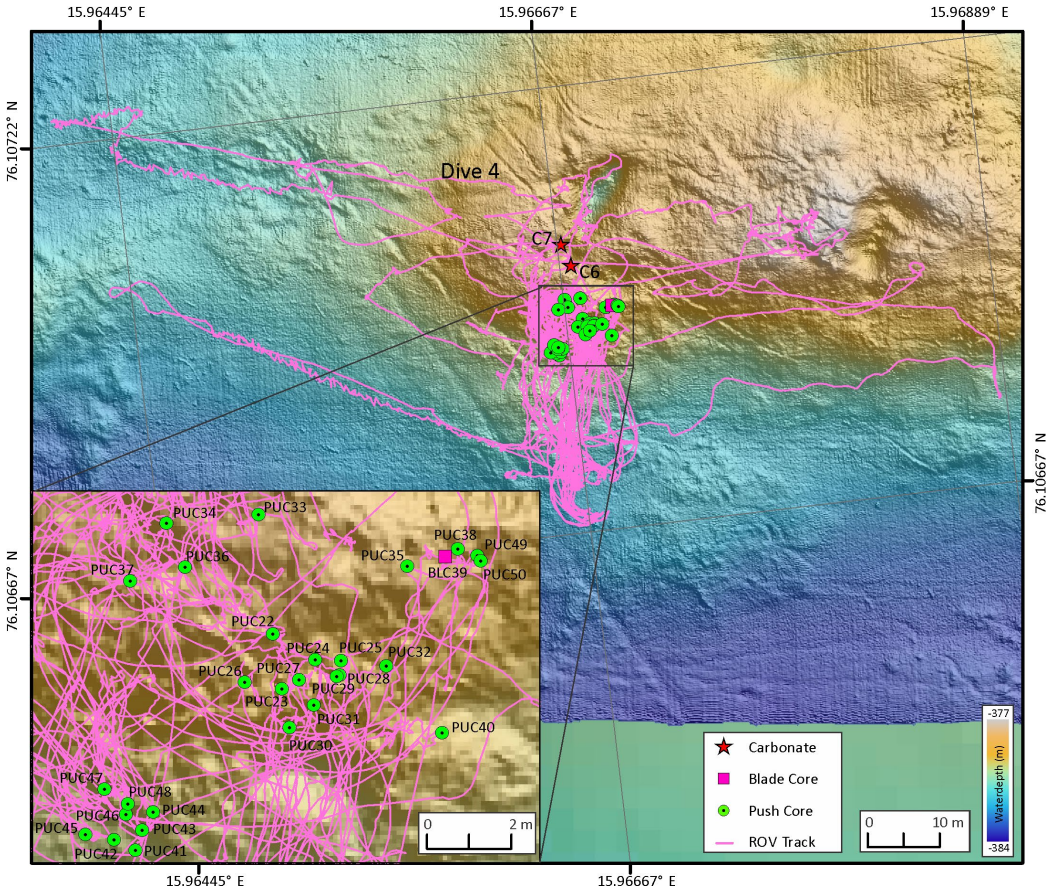


Figure 20: Track and sample locations of ROV dive no. 4.

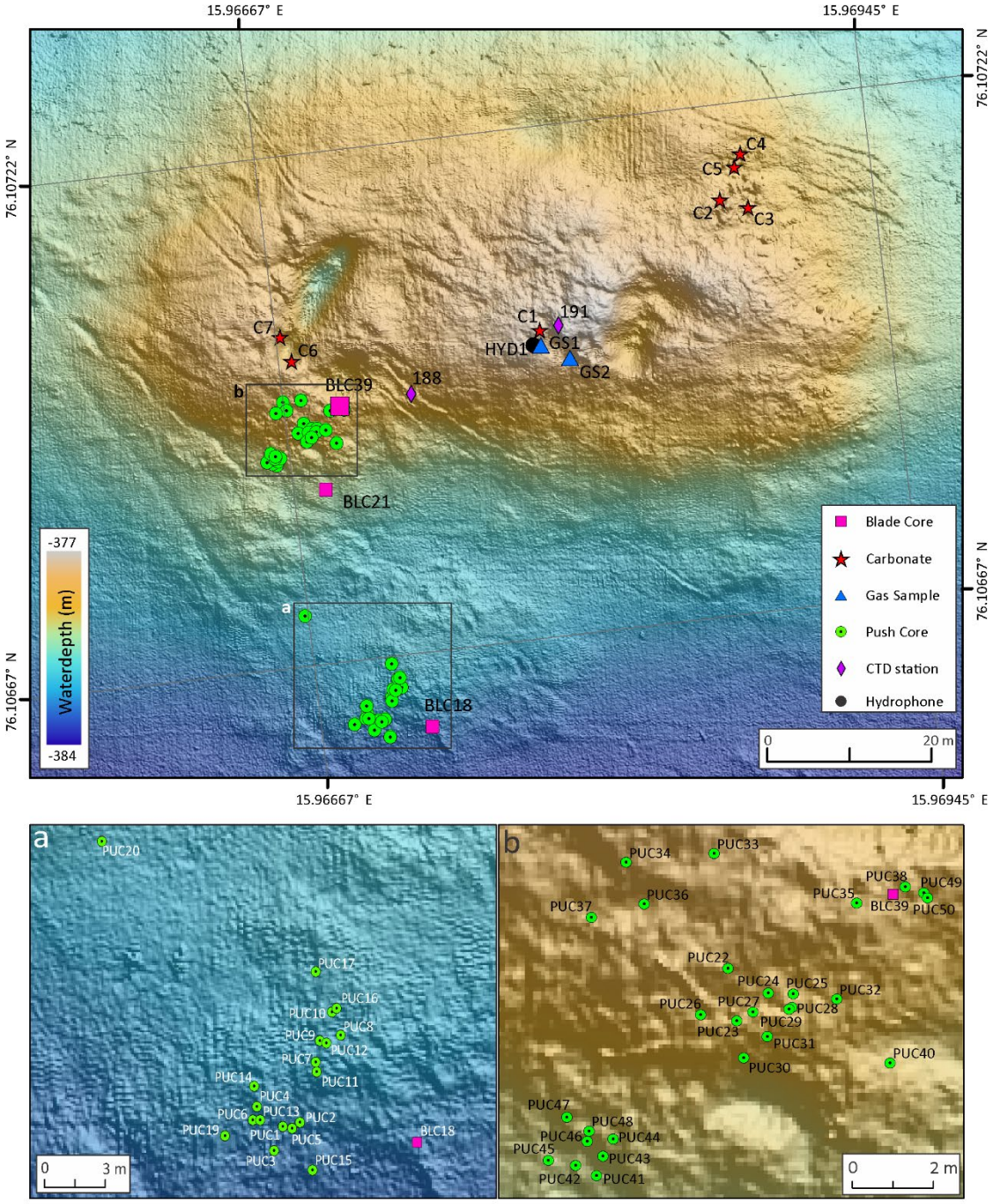


Figure 21: Overview of all samples taken by the ROV at GHP3.

9.2 ROV dives at Storbanken (dives 6-10)

Limited time constrained our work in the Storbanken area. ROV dives at Storbanken were planned to be shorter and effective targeting potential known seepage locations. Two of the dives (5 and 7) were only for mapping the seafloor in high resolution and identifying potential targets for sampling. The mapping focused on areas where gas seepage had been identified on previous expedition using hull-mounted acoustic systems. The ROV dives 6 and 8 in this area

provided the first visual confirmation of gas seepage from the seafloor. The dives were dedicated to sampling of carbonate crusts, rocks and gas, in addition, bubble flux measurements were conducted (Figure 22 and Figure 23 and Figure 24).

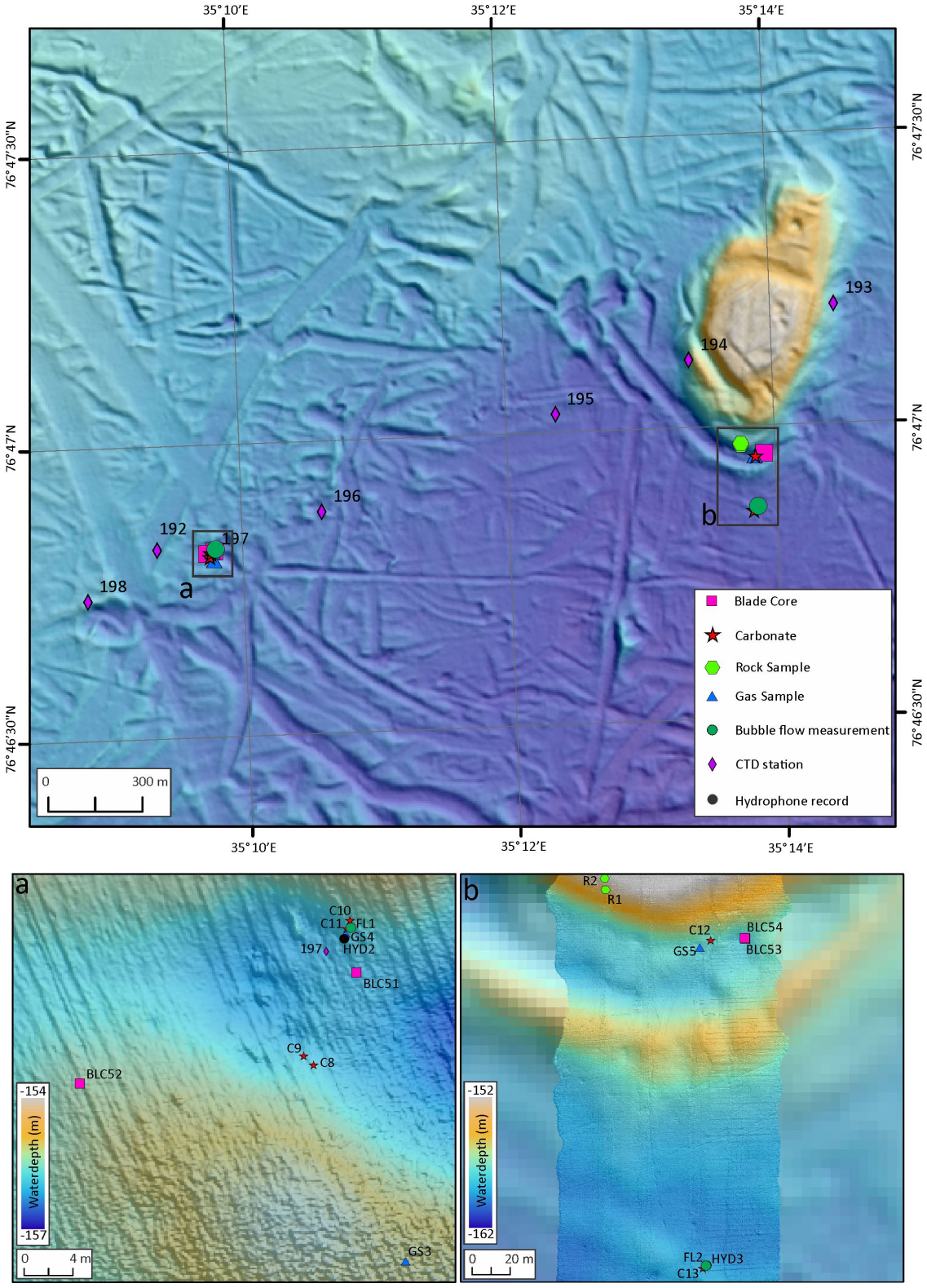


Figure 22: Overview of samples taken during dives 6 and 8 at Storbanken focusing on two known locations of gas seepage.

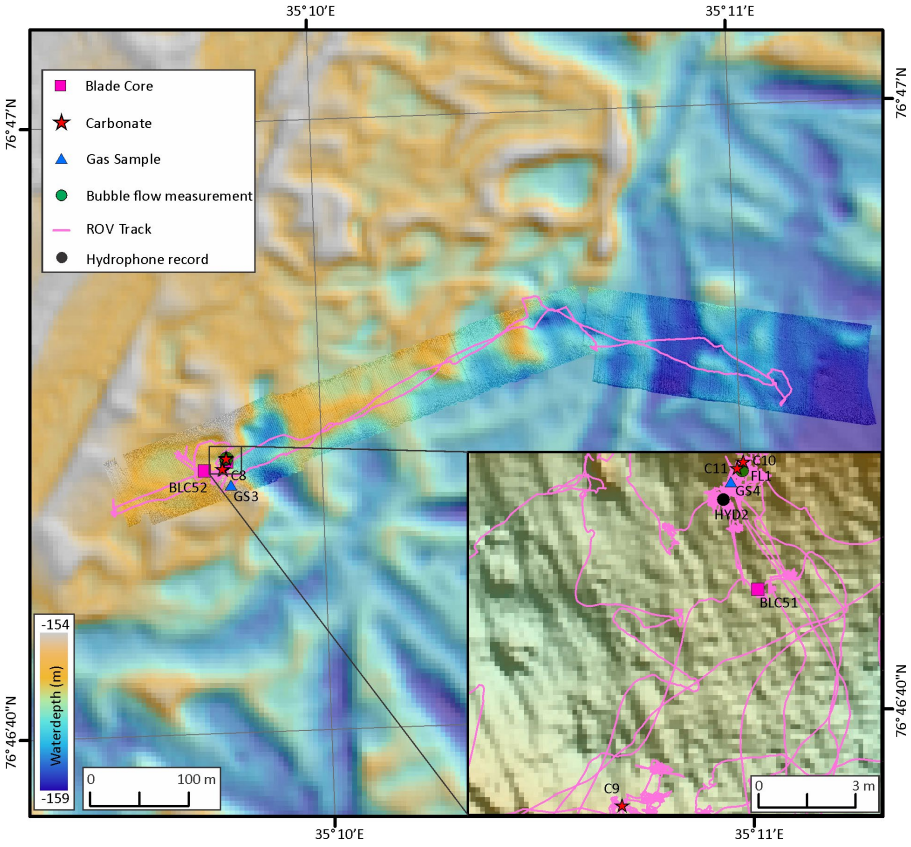


Figure 23: Dive track and samples taken during dive 6.

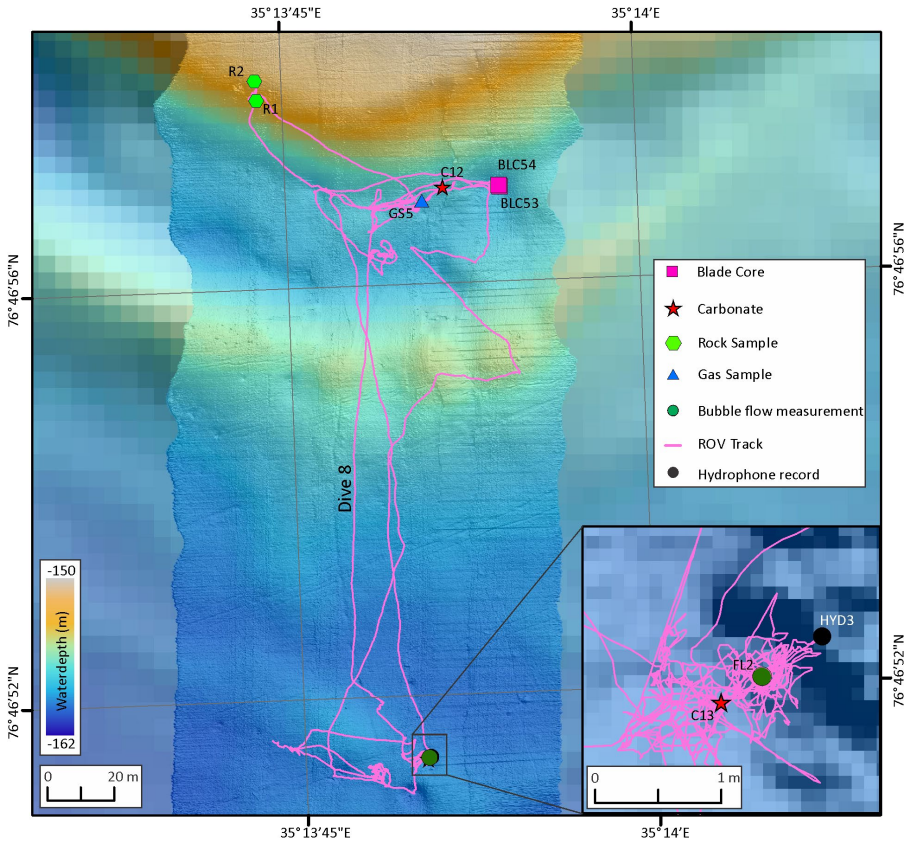


Figure 24: Dive track and samples taken during dive 8.

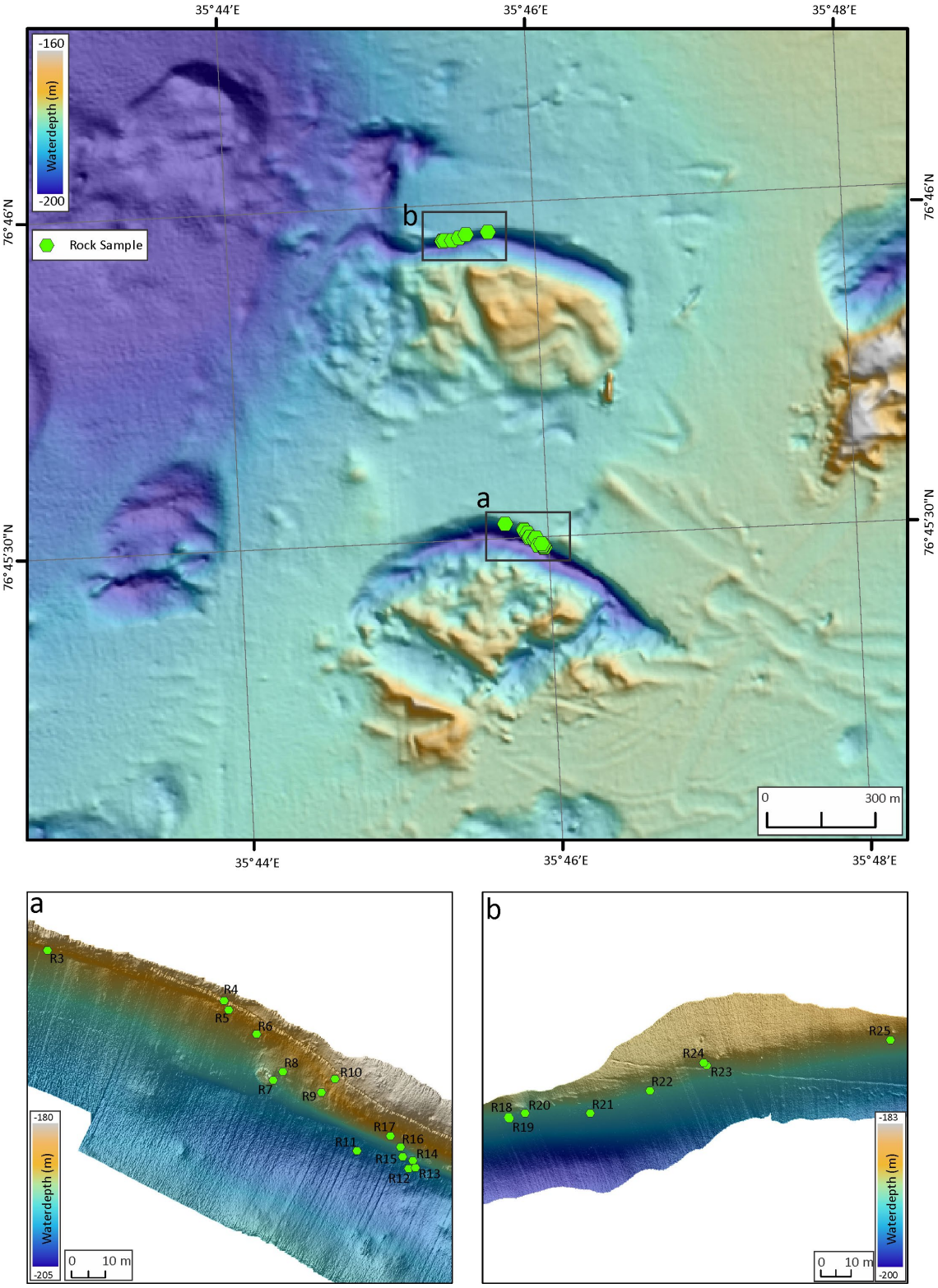


Figure 25: The Storbanken area contains many semi-evacuated crater structures. Many show a sharp northern sidewall and mounded features to the south. Two of those crater/mound structures were investigated during dives 9 and 10.

ROV dives 9 and 10 focussed on two semi-evacuated crater structures in the eastern part of the Storbanken area (Figure 25). These structures have a very sharp and steep northern sidewall (Figure 25 and Figure 26). Sedimentary rocks of Jurassic age have been mobilized southward forming a subtle mound structure partly covering the crater. The steep headwall exposed sediments of the very prominent Stø and Hekking formations, the former a well-known reservoir rock and the latter a well-known cap rock in the Barents Sea. Dive 9 targeted the southern crater/mound structure and samples sedimentary rocks likely from the Stø formation (Figure 27 and Figure 28). The steep sidewall effectively forms an outcrop known from land, which can be mapped from bottom to top. Gas seepage was absent as expected, however, the sidewall still was rich and abundant in biota and few occurrences of bacterial mats. Dive 10 mapped a similar headwall in a crater/mound structure to the north (Figure 29) where sedimentary rocks likely of the Hekkingen formation outcrop.

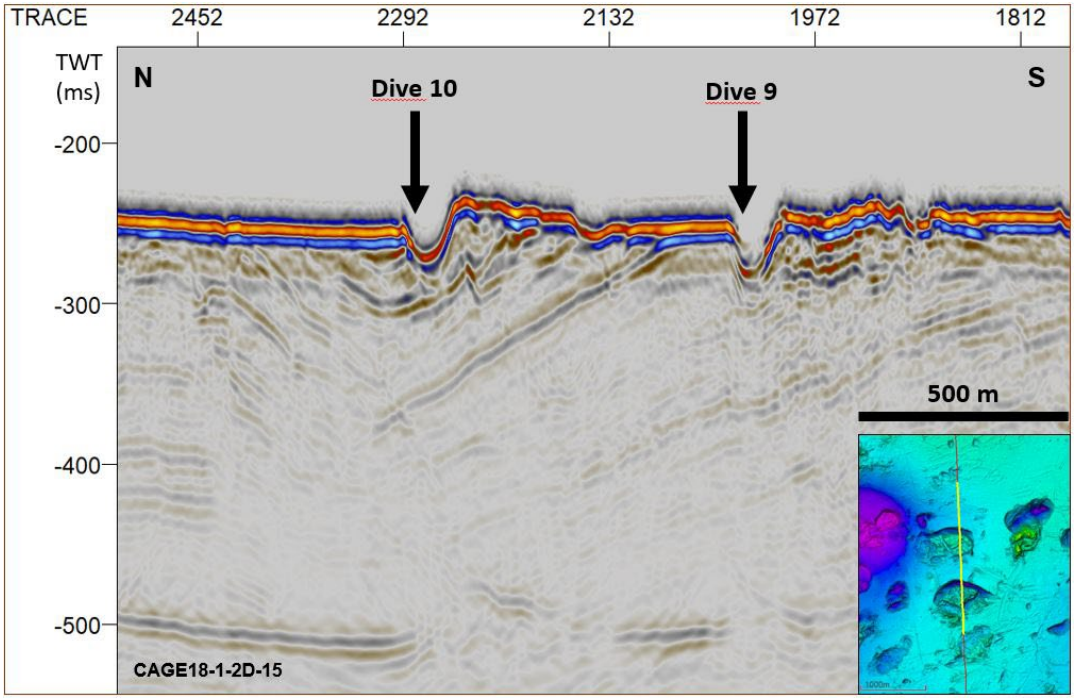


Figure 26: High-resolution 2D seismic line across the crater/mound structures that were investigated during dives 9 and 10 (see also Figure 25).

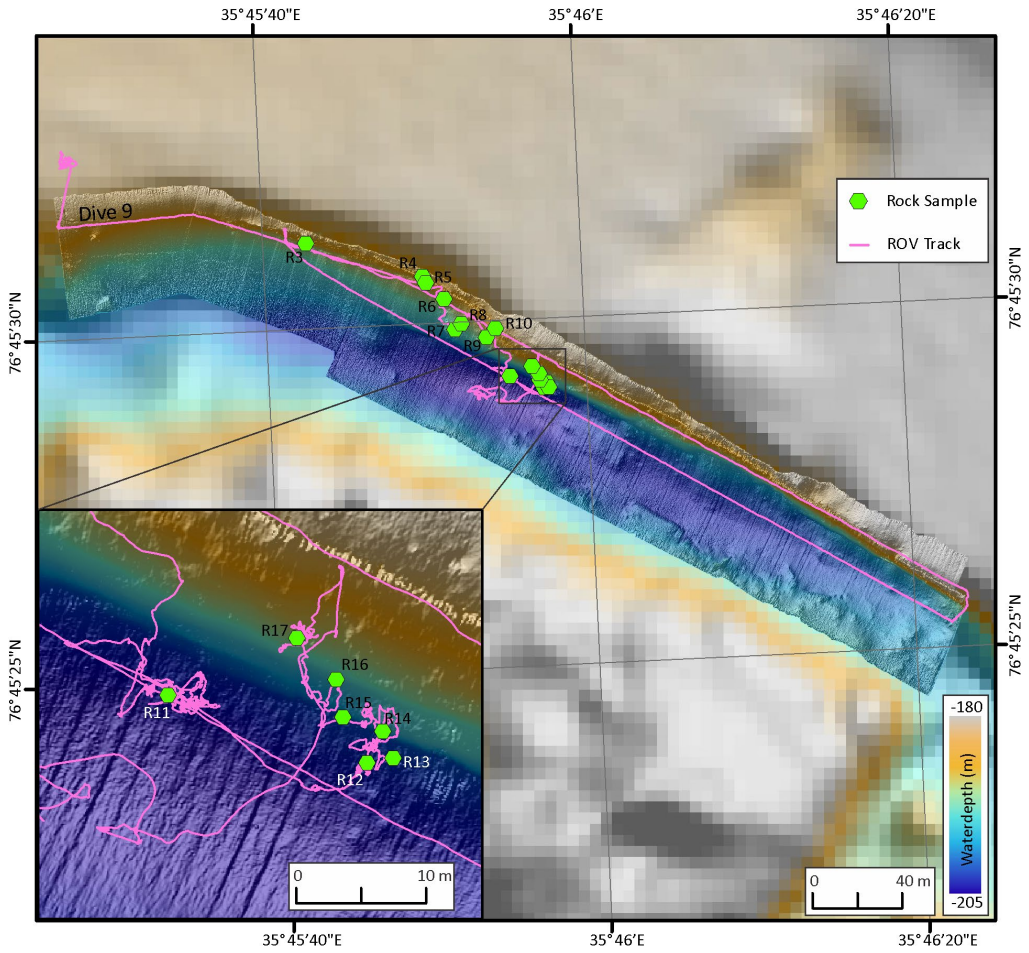


Figure 27: Dive track and samples taken during dive 9.

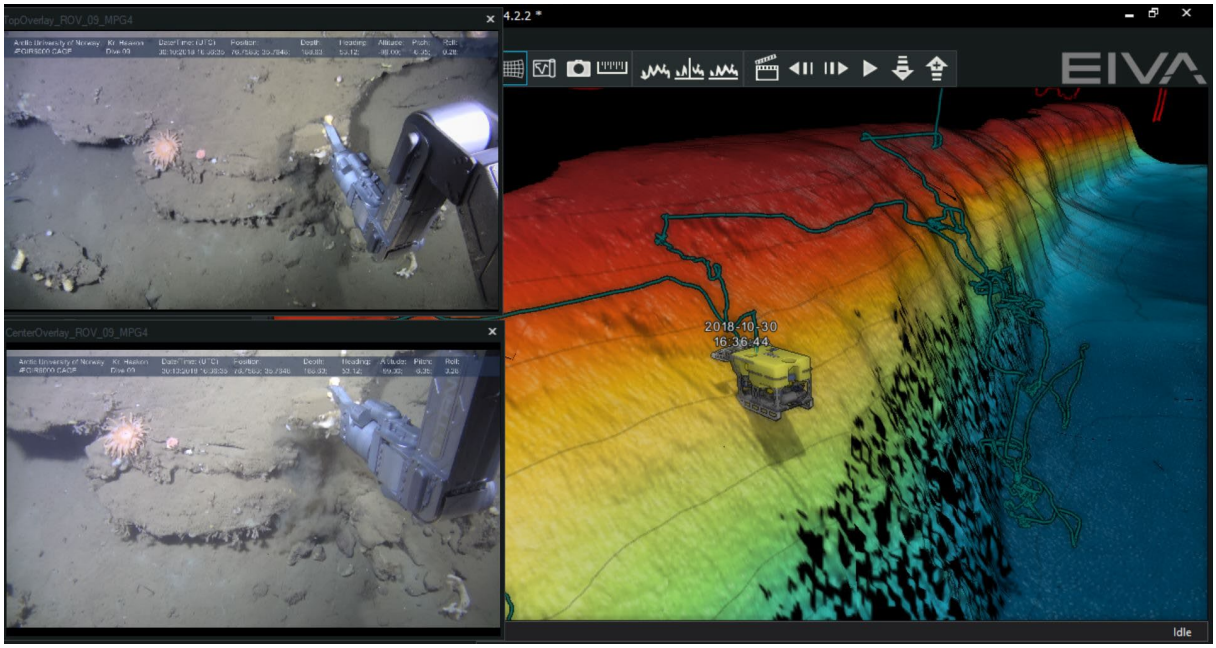


Figure 28: The steep northern sidewall of the crater provided an ideal target for mapping a cross section of several outcropping sedimentary rocks of Jurassic age. The sidewall was up to 25 m high.

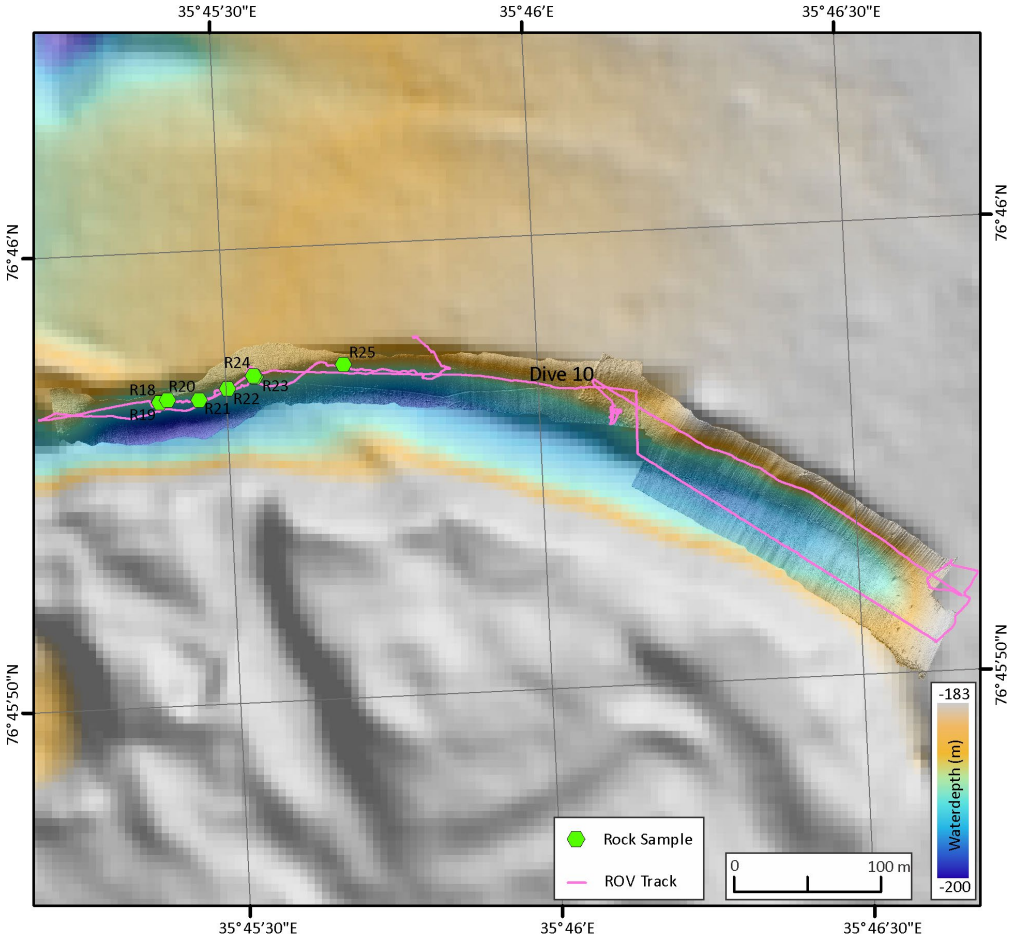


Figure 29: Dive track and samples taken during dive 10.

10 SEDIMENTOLOGY

(Renata Lucchi)

1-m long plastic liners were used to sample surface sediments for sedimentological investigation. The penetration and recovery of the plastic liners have been operated through the ROV arm (push cores) in the same areas selected for the other type of investigation (geochemistry, micropaleontology and microbiology). A total of 3 push cores were attempted at the Storfjorden Pingo site (Table 1)

Table 1:-Push cores for sedimentology

ID core (sampling ID)	date dd/mm/yy	time UTC	depth m	Lat N	Long E	recovery cm
CAGE 18-5-KH-Dive 2-PC19 (L1)	25/10/18	18:19	382.3	76.106599	15.9667907	31
CAGE 18-5-KH-Dive 2-PC20 (L2)	25/10/18	18:29	381.7	76.106723	15.9666237	19
CAGE 18-5-KH-Dive 3-PC40 (L3)	27/10/18	09:30	379.2	76.1069063	15.966859	34

The cores have been sealed and left in the cool room at +4°C for shore-based analyses at CAGE laboratories. Shore based analyses will include: multi-sensor core scan (magnetic susceptibility, wet bulk density, P-wave velocity) and X-ray radiographs on the whole cores, and XRF core scan, colour scan, HD photography, and visual logging on the open cores. The analytical results from the subsurface sediments will be compared with the longer record already retrieved from the same area.

11 METHANE-DERIVED AUTHIGENIC CARBONATES (MDAC)

(Aivo Lepland and Tobias Himmler)

Authigenic seep carbonates are distinct geological features of methane seeps (Suess, 2014). At seeps, increased alkalinity resulting from the microbial-mediated sulfate-dependent anaerobic oxidation of methane (AOM) facilitates carbonate precipitation, following the chemical equations:

$$CH_4 + SO_4^{2-} \rightarrow HCO_3^- + HS^- + H_2O \text{ (AOM)}$$
$$Ca^{2+} + 2HCO_3^- \rightarrow CaCO_3 + CO_2 + H_2O \text{ (carbonate precipitation)}$$

Seep carbonates are valuable geological archives, recording the geochemical composition of the seepage fluids, preserving molecular fossils of the AOM-mediating microbes, and allow to reconstruct the seepage timing through uranium – thorium dating (e.g., Himmler et al., 2015; Crémière et al., 2016).

11.1 Methods and onboard analyses

Overall, a total of 13 carbonates were sampled, including seven samples form site GHP3 (samples C1 – C7) and six (C8 – C13) from the Storbanken seeps (see APPENDIX; Figure 30). The seep carbonates were sampled from the seafloor using the ROV manipulator arm. One sample (C12) was chopped off using a hydraulic chain saw mounted on the ROV. The samples are irregular shaped and range in size from ~15 cm to more than 100 cm in diameter. After sampling, loose sediment was removed from the rock surface using a brush and the carbonates were wrapped in bubble wrap and stored in a pallet on deck.

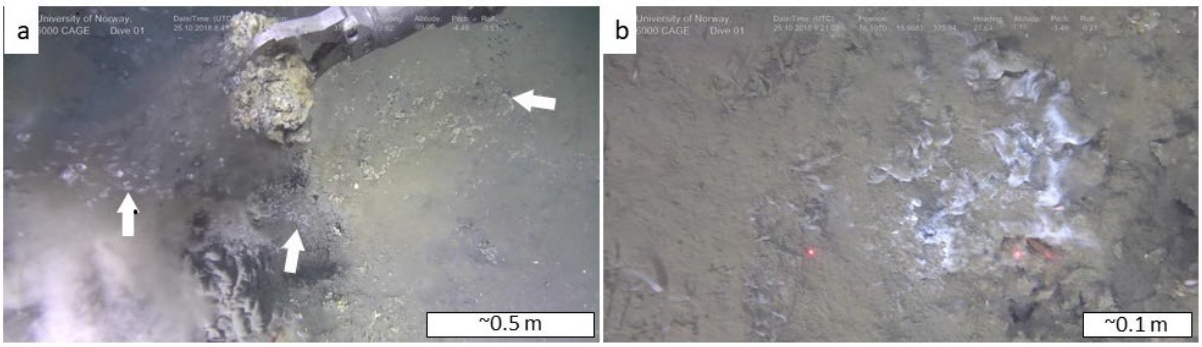


Figure 30: (a) Sample C1 taken with the ROV manipulator arm from an active seep at GHP3; gas bubbles (arrows) escaped from underneath and within the carbonate during sampling, and from unsampled crusts cropping out nearby, indicating that free gas migrates through the cavernous crusts. (b) White filamentous microbes, partly covered by soft sediment, on the surface of a partly sediment covered seep carbonate crusts.

11.2 Preliminary results

The sampled seep carbonates are strongly lithified and have a high cavernous porosity. Gas bubbles were frequently observed escaping from seep carbonates on the seafloor through the cavernous pores. White, filamentous microbes were attached to some carbonates on the surface exposed on the seafloor (e.g., sample C3). Usually, the carbonates protruded up to tens of cm above the surrounding seafloor. When the carbonates have been partly buried in the seafloor the buried part was covered with black sediment (Figure 30, Figure 31).

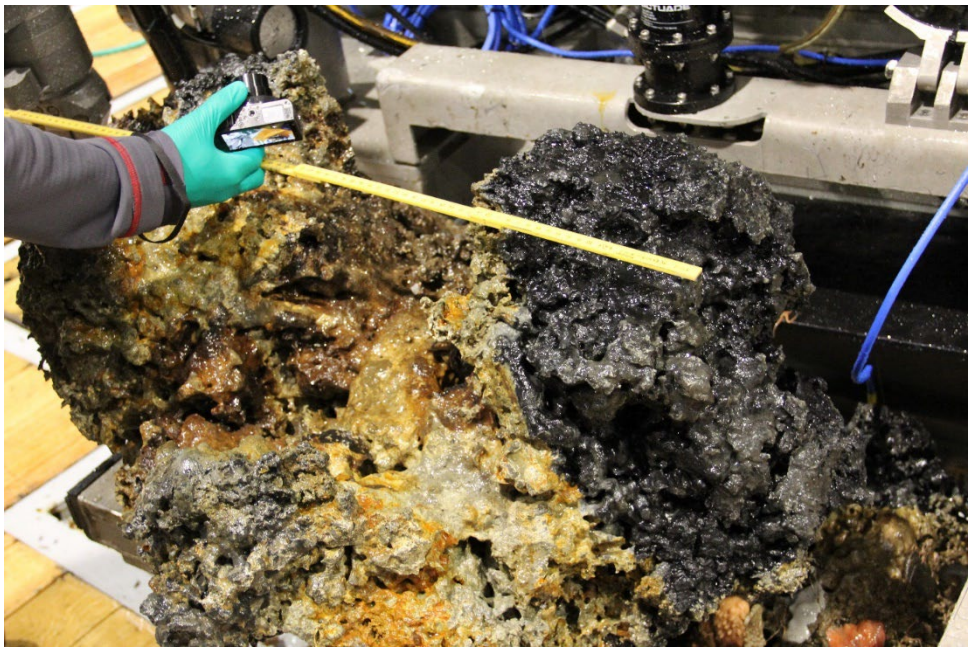


Figure 31: Carbonate sample C5 in the drawer of the ROV. Note the black sediment attached at the bottom, indicating the part of the carbonate that was buried in the sediment. Also, note the brownish and yellowish cover (biofilm?)

The cut surface of sample C12 reveals a high cavernous porosity of the sample. C12 is comprised of two authigenic carbonate cement generations: (i) relatively older, microcrystalline cement cementing the background sediment matrix, and (ii) relatively younger, fibrous cement filling remaining open pore space. Likewise, a freshly broken sample (C2) similarly reveals the two generations of authigenic cement (Figure 32).

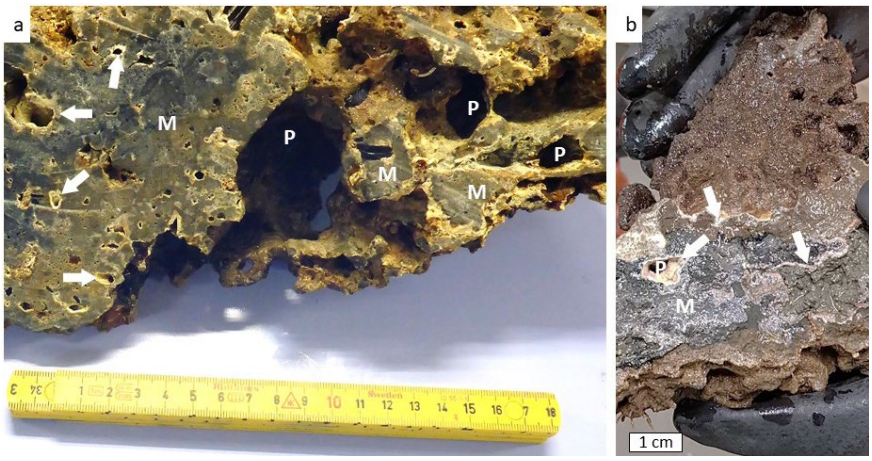


Figure 32: (a) Cut surface of sample C12, showing grey to brownish cemented sediment comprising the rock matrix (M), and abundant pores (P) partly filled with white fibrous cement (arrows). (b) Freshly broken surface of sample C11, showing grey microcrystalline carbonate cemented sediment matrix (M), and thin layers of white, fibrous cement filling pore space (arrows).

11.3 Future work

The seep carbonates will be studied at NGU. Standard petrographic (e.g. thin section and scanning electron microscopy, XRD) and geochemical ($\delta^{13}C$, $\delta^{18}O$) analyses will be used to characterize the carbonate microfacies and seepage fluid composition. Uranium–thorium dating of the seep carbonates will allow reconstructing the timing of seepage (e.g., Himmler et al., 2015; Crémière et al., 2016).

12 MICROPALEONTOLOGY

(Emmanuelle Geslin, Christiane Schmidt, (Giuliana Panieri off-board))

12.1 Methods and onboard analyses

Sediment chemistry

Four cores, labelled F6, F7, F9, F10 (Table 2 and Appendix) were sampled every centimeter for the first 20 centimeters for porewater, by using rhizon filters connected to 5 mL syringes. The extracted porewater for every sample was split into 2 vials - for analysis of d13C and concentration of DIC as well as concentration of sulfate. 10uL of a concentrated HgCl2 solution was added to the DIC vials in order to stop any microbial activity.

Micropaleontology

For the characterization of the foraminiferal associations, sediment samples were collected from 8 multicore stations and 1 grab station. At each multicore station, one multicore was sliced every 0.5 cm from the top to 2 cm, from 2 to 10 cm. Half of sediment was fixed with Cell Tracker Green (CTG) and the other half with Rose Bengal (RB). The rest of the core was sampled every cm for investigation of fossil foraminifera.

Below the two staining methods described.

Cell Tracker Green - CTG labelling

On board, sediment cores collected using a ROC were sliced into 0.5 cm intervals until 2 cm depth and into 1 cm intervals until 5 cm depth. A method based on enzymatic reactions was used to distinguish living foraminifera (Bernhard et al., 2006; Pucci et al., 2009; Langlet et al., 2013). One milligram of Cell-Tracker™ Green (CTG 5 CMFDA: 5-chloromethylfluorescein diacetate) was dissolved in 1 mL of dimethylsulfoxide (DMSO) and diluted by 10 in in situ sea water. Samples were incubated for 12 h to 20 h at in situ temperature without light in a solution of seawater, with a CTG final concentration of 1 mmol L-1, as described by Bernhard et al. (2006). During this time, CTG passes through the cellular membrane of living organisms, and reaches the cytoplasm where hydrolysis with nonspecific esterases creates fluorogenic elements. After the death of the cell, esterases are decomposed in a few hours to some days at maximum, depending on environmental conditions (Bernhard et al., 2006), making the CTG method highly accurate to discriminate between living and dead organisms. After incubation, the samples were fixed in 96% ethanol and stored at room temperature.

Table 2: Sediment cores for micropaleontological analyses

Area	Date	Dive	entional name	own name	type of samples	Time (link to position)	pore water extraction	phylogeny	Environmental DNA	me (DNA of forams)	TEM fixation	isotopes (d13C;d18O)	Ox profiling	Experiment	CTG	alive sampl	fossil	
Pingo 1	25.10.2018	1	) sample															roughly 2 hours of monitoring, Sediment was disturbed and very few bacterial mats were observed
Pingo 3 (fixed poi	25.10.2018	2	Crust 1		carbonate crust	08:50												Peace of crust collected on the area which was on the water, Observation and picking of 3 dead cibice)idoides (slid
Pingo 3 (fixed poi	25.10.2018	2	Crust 2		carbonate crust	09:34												Samples of a peace of crust lying on the sea water and an other peace lying on the sediment, sediment was samples
Pingo 3 (fixed poi	25.10.2018	2	BLC_18	B 1	Blade	17:58		yes	yes		yes			yes			yes below 2 cı	The blade was collected on the 25th Oktober and the basket was retrieved few hours later on the 26th. BLC was sampled on a reference site
Pingo 3 (fixed poi	25.10.2018	2	PUC 1	F6	Push core	16:11	yes				yes						below 1 cm	About the PC, treatment of the PC was performed 24 hours later sampling. The PC were lying closed on the seafloor during more than 24 hours (O2 may change). PC 1 was
Pingo 3 (fixed poi	25.10.2018	2	PUC 2	F7	Push core	16:16	yes				yes					yes	below 1 cm	PC2 was colleted on a patchy part near the mat
Pingo 3 (fixed poi	25.10.2018	2	PUC3	F8	Push core	16:24	no						yes		yes		below 5 cm	PC3 was sampled on the mat
Pingo 3 (fixed poi	25.10.2018	2	PUC14	H2	Push core		Yes By Wei Li										yes	We took the rest of the samples that Wei Li collected for the water geochemistry
Pingo 3 (fixed poi	25.10.2018	2	PUC17	H5	Push core		Yes By Wei Li										yes	We took the rest of the samples that Wei Li collected for the water geochemistry
Pingo 3 (fixed poi	27.10.2018	3	BLC21	B2	Blade	00:18	no									yes	yes	it was collected at 380 m depth
Pingo 3 (fixed poi	27.10.2018	4	PUC33	F9	Push core	08:30:54	yes				yes					yes	hive below 1 cm	
Pingo 3 (fixed poi	27.10.2018	4	PUC34	F10	Push core	08:35:30	yes											
Pingo 3 (fixed poi	27.10.2018	4	PUC35	F11	Push core	08:41:40			yes (Met	yes (Mette group)							Archive below 3	in the mat - Brownish until 1 cm and then dark sediment
Pingo 3 (fixed poi	27.10.2018	4	PUC36	F12	Push core	08:47:47			yes (Met	yes (Mette group)							Archive below 3	Reference core - Brownish until 3 cm
Pingo 3 (fixed poi	27.10.2018	4	PUC37	F14	Push core	08:42:40							yes		yes		yes	Reference core
Pingo 3 (fixed poi	27.10.2018	4	PUC38	F13	Push core	08:48:29							yes		yes		yes	core in the mat
Pingo 3 (fixed poi	27.10.2018	4	BLC39	Blade 3	Blade	09:21:19										yes	yes	
Storbanken	29.10.2018	6	BLC51		Blade	18:33:05											x	not well preserved, few sediment, very soft, brown and thin sediment on the surface, grey deeper
Storbanken	29.10.2018	6	BLC52		Blade	18:53:38											x	not well preserved, few sediment, very soft, brown and thin sediment on the surface, grey deeper
Storbanken	30.10.2018	8	BLC53		Blade	09:48:14	yes by Wei Ly				yes							roughly 8 cm3 of superficial sediment has been sampled immediatly on board and fixed with gluta

Phylogeny

On board freshly collected sediment was sieved using 125, 250 and 500 µm mesh with in situ bottom water (T°C 2°C, Salinity 35). Living foraminiferal specimens with colored cytoplasm and/or encysted with sediment (occurrence of vitality) were picked using a binocular microscope, washed with micro filtrated seawater (2µm) and stored in an Eppendorf vial.

Environmental DNA

Fresh sediments from multicore were sampled to determine the biodiversity of foraminifera using environmental DNA. Roughly 10 cm^3 of the 3 first cm (0-1, 1-2, 2-3 cm) was sampled using a sterilized spoon in a sterilized plastic bag and stored to the freezer (-80°C).

Fixation for TEM observation

On board freshly collected sediment was sieved using 125, 250 and 500 µm µm mesh with in situ bottom water (T°C 2°C, Salinity 35). Foraminiferal specimens with colored cytoplasm located in all the chambers except in the last one (occurrence of vitality) were picked and put in an Eppendorf. Living foraminifera were chemically fixed with the fixative solution contained 4% glutaraldehyde and 2% paraformaldehyde (LeKieffre et al., 2018). Samples were then keep at cool temperature, transported to Angers laboratory (France) in order to perform imbedding and ultra-thin section and TEM observation. TEM observation of the foraminiferal cell may detect symbiosis or cytological adaptation.

Fixation for TEM observation

On board freshly collected sediment was sieved using 125 µm mesh with in situ bottom water (T°C 2°C, Salinity 35). Foraminiferal specimens with colored cytoplams located in all the chambers except in the last one (occurrence of vitality) were picked and put in an Eppendorf with in situ sediment. On August 7th, at Longyearbyen, sediment samples containing living foraminifera were chemically fixed with the fixative solution contained 4% glutaraldehyde and 2% paraformaldehyde (LeKieffre et al., 2018). Samples were then keep at cool temperature, transported to Angers laboratory (France) in order to perform imbedding and utra-thin section and TEM observation. TEM observation of the foraminiferal cell may detect symbiosis or cytological adaptation.

Oxygen profiles

Three cores was selected and immediately brought in a temperature-controlled room at 2°C which is the situ temperature. Depth profiles of O_2 were measured using a Clark-type microelectrode with a 50 µm thick tip (OX50, Unisense, Denmark) connected to a multimeter (Unisense). Microelectrodes were calibrated at two points (O_2 saturation was obtained bubbling seawater at in situ temperature and salinity and zero oxygen concentration was obtained by measuring deeper part of the sediment core).

Experiments on board

Living foraminifera were collected in Pingo 3 site. The top centimeters of the sediment was sampled, sieved over a mesh of 125, 250 and 500 µm with *in situ* seawater. Two experiments were perfomed, one with *N. labradorica,* and one with *Globobulimina* spp.

N. labradorica experiment : alive specimens were selected in the surface layer of sediment collected with a blade core (BLC 18). The 250-500 µm fraction was used to healthy living individuals of *N. labradorica* under a binocular microscope based on their cytoplasm color and the occurrence of a kyste. The selected specimens were placed into Petri dishes (5 to 6 specimens per Petridish) filled with artificial seawater (ASW, Red Sea Salt, salinity = 35, pH = 8.0). Three of the Petri dishes contained ASW enriched with 15 µM $^{15}NH^4Cl$. And 25 µM $^{34}SO_4^{2-}$ and three Petri dish contained enriched with marine methanotrophic bacteria, 15 µM $^{15}NH^4Cl$. And 25 µM $^{34}SO_4^{2-}$. Five specimens were fixed at T0 (beginning of the experiment) and served as controls for NanoSIMS analysis. All other Petri dishes were placed in an incubator (temperature: 2 °C in the dark). At each time point, i.e., after 4, 8, and 20 hours, two Petri dishes were removed from the incubator and the specimens contained in this Petri dish were immediately chemically fixed with the fixative solution contained 4% glutaraldehyde and 2% paraformaldehyde (LeKieffre et al., 2018).

Globobulimina experiment : alive specimens were selected in the 0.5 to 2 cm sediment layer collected with a blade core (BLC 21). The 250-500 µm fraction was used to healthy living individuals of *Globobulimina* under a binocular microscope based on their cytoplasm color. The selected specimens were placed into Petri dishes (5 to 6 specimens per Petridish) filled with artificial seawater (ASW, Red Sea Salt, salinity = 35, pH = 8.0). Three of the Petri dishes contained ASW enriched with 15 µM $^{15}NH^4Cl$. And 25 µM $^{34}SO_4^{2-}$. Five specimens were fixed at T0 (beginning of the experiment) and served as controls for NanoSIMS analysis . All other Petri dishes were placed in an incubator (temperature: 2 °C in the dark). At each time point, i.e., after 4, 8, and 20 hours, two Petri dishes were removed from the incubator and the specimens contained in this Petri dish were immediately chemically fixed with the fixative solution contained 4% glutaraldehyde and 2% paraformaldehyde (LeKieffre et al., 2018).

12.2 Preliminary results

Sediment

Sediments collected with push cores and blade cores using the ROV are mostly clay, silty clay. The multicores collected at bacterial mats exhibit a dark/black sediment near the surface (few mm) and strong H_2S odor.

Cores from the dive 2 stayed more than 24 h on the sea floor (because of technical problem of the ROV). Some of the cores collected on the bacterial mat have shown a dark surface layer of 1 to 5 mm (probably due to the decomposition of the bacterial mats) and a thin brownish

layer above (roughly 0.5-1cm). The cores collected around the mats on a brownish sediment did not show such dark layer on the surface.

The cores collected in the mat show thinner brownish layer than out of the mat.

Micropaleontology

Micropaleontological observations were made on the surficial sediment (0-0.5 or 0.5-2 cm) of many stations, although the number of living foraminifera is low compared to coastal environments. Some living calcareous foraminifera appear to have a cist surrounding the shell (*N. labradorica*), or all the chambers occupied by the cell except the last one. Also, porcellaneous, agglutinated, and allogromids forams were found alive.

The color of the cell is green in *Cassidulina* sp, brown to red in *Nonionella labradorica*, *Hoeglundina elegans, Robertinoides* sp. and *Stainforthia*. *Globocassidulina* has orange cytoplasm.

Globocassidulina and *Stainforthia* were found only on the fraction 125-250 µm whereas *N. labradorica, Globobulimina, H. elegans* and *Robertinoides* were found in the fraction 250-500 µm.

Few *Trifarina angulosa* were observed with a green cytoplasm. 3 specimens of *Nonionella* sp. exhibiting a last chamber with fingers were found alive with a brown to red cytoplasm.

Few dead shells were observed. Agglutinated species were quite abundant and diverse. Very few planktonic foraminifera were observed.

After a qualitative observation of fresh sediment, it appears that the surface sediment from the mat is inhabiting by mainly *Globocassidulina* sp. (small specimens slower than 250 µm) whereas the sediment collected out the mat are more diverse containing *N. labradorica, Globobulimina, H. elegans* and *Robertinoides* (higher size of the specimens) (Figure 33).

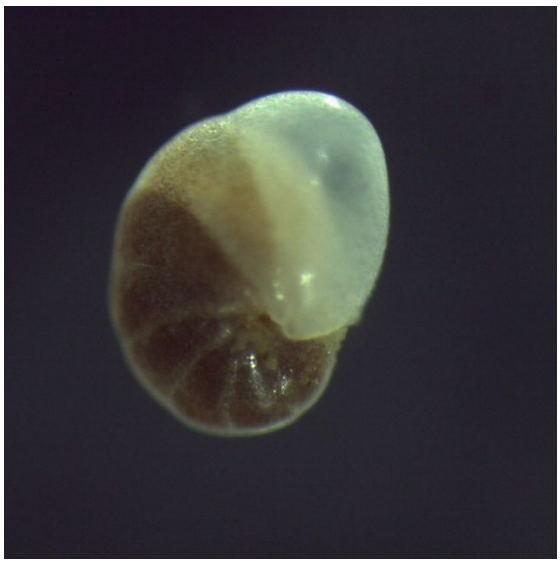
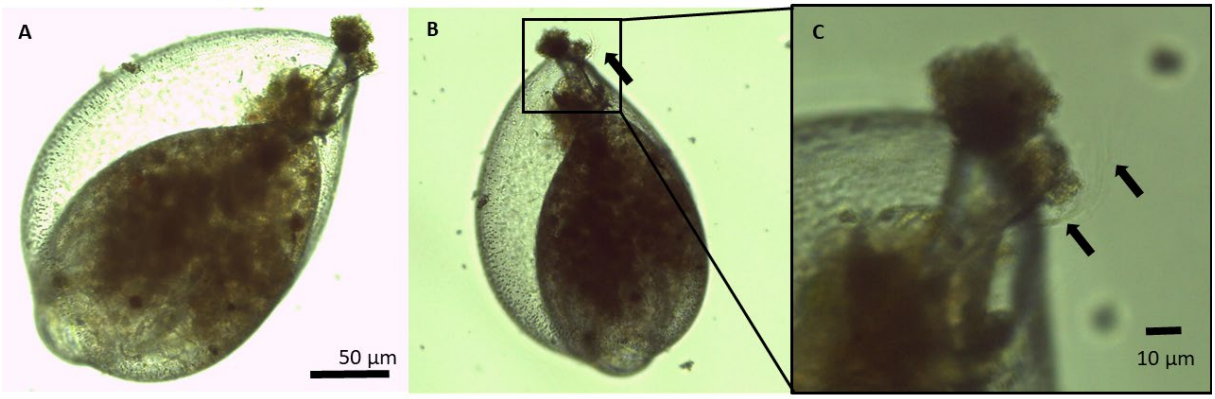


Figure 33: Picture of alive N. labradorica.



Globobulima spp. sampled from blade core CAGE-18-05-Dive3_BLC21 on 27.10.2018 was used for isotopic experiments on the incorporation of ammonium and sulfate short-term experiments. Image B shows foraminfera actively feeding with extended pseudopods at the aperture, which indicated actively feeding

13 PORE WATER GEOCHEMISTRY

(Wei-Li Hong, Matteus Lindgren)

The primary objectives are taking porewater samples for the clumped isotopes of DIC from the Storfjordrenna gas hydrate mounds (GHMs) and to survey the new cold seeps in Storbanken area.

13.1 Methods and onboard analyses

In the Storfjordrenna GHMs area, we targeted the GHM #3 for push coring. Porewater samples were taken from six cores: three from bacterial mats, one from worm tuff, and two from area without visible seafloor biology. A total number of 112 samples were taken from the six cores (Table 3), preserved for onshore analyses, and analyzed onboard for total alkalinity (TA).

Table 3: Subsamples of pore water analyses. For full core name and location, refer to Appendix.

Core	TA	Nutrients	Cations	Anions	δ^{13}C-DIC	O/H	Clumped isotope of DIC	ΣHS
H2	25	20	17	25	0	0	25	0
H3	20							0
H5	20	15	15	20	0	0	17	0
F8	14	14	14	14	13	0	0	14
F13	13	13	13	13	9	0	0	13
F14	6	6	6	6	6	0	0	6
Barents Sea craters	8	8	8	8	8	8	0	8

Porewater samples from core H2, H3, H5 were extracted through centrifuging (3200 rpm and 15-20 minutes) under room temperature while samples from F8, F13, and F14 were extracted through rhizons in the cold room. All syringes and rhizons used for porewater sampling were acid wash onshore. For the three cores with centrifuging, sediments were sliced every 1 cm in the cold room (with parallel sampling for Emmanuelle Geslin, Micropaleontology) and brought to lab for centrifuging. In general, 2-20 ml of porewater was extracted through

centrifuging. The water was filtered with 25 mm syringe filters with 0.2 μM Cellulose acetate membranes. The plan for porewater distribution of these three cores is given in Table 3. For the three cores sampled with rhizons, 3-20 ml of water was extracted in 3-4 hours. Rhizons were wetted with MilliQ water before using. The first half to one ml of porewater was discarded to avoid dilution from the MilliQ. The sampling plan for these three cores was given in Table 3.

I perform TA titration onboard using the The pH electrode was calibrated against pH 4, 7 and 10 Metrohm Instrument buffers before the cruise. HCl titrant (12M Sigma-Aldrich TraceSELECT HCl diluted to 0.012M with MilliQ) was prepared onboard and calibrated against both a 0.01M borax standard. The same borax standard was titrated daily during the cruise to ensure the quality of the titrant. Depending on the amount of porewater recovered and the expected TA, we titrated 0.2 to 0.5 ml of sample aliquot. About 10 ml of MilliQ was added to each sample to ensure that the pH electrode was fully submerged. Titrant acid was added while constantly stirring in an open 50 ml beaker. The amount of acid and pH was manually recorded during each addition. Alkalinity was calculated from the Gran function plots, which were made by plotting Gran functions against the titrant volume. Gran function is defined as:

$$(V_0+V_t)\times 10^{-pH}$$

where V_0 is the initial volume of sample and V_t is the volume of titrant added. The concentration of alkalinity was then estimated from the slope and intercept of the regression line from the Gran function plot. Four to five points were used for regression. All titrations were done less than six hours after the syringe disconnected from the rhizons and were stored under 4 ^{o}C condition while in the queue of analyses to prevent carbonate precipitation.

13.2 Preliminary results

During the coupling between anaerobic oxidation of methane and sulfate reduction (AOM-SR), bicarbonate and hydrogen sulfide ions were produced:

$CH_4 + SO_4^{2-} \rightarrow HCO_3^- + HS^- + H_2O$

Both the bicarbonate (HCO_3^-) and hydrogen sulfide (HS^-) ions contribute to TA. Reactions that consume these two ions, such as carbonate precipitation and pyrite formation, decrease TA. By measuring TA, one could have a preliminary guess of the depth of sulfate-methane-transition-zone in each core, which can usually be defined by the highest TA measured in the sediments and TA values higher than ca. 30 mM.

The TA results from the six push cores obtained during this cruise together with the results obtained from the previous two cruises (CAGE16-5 and CAGE15-2) were shown together to demonstrate how TA can vary from the different seafloor habitats (Figure 34).

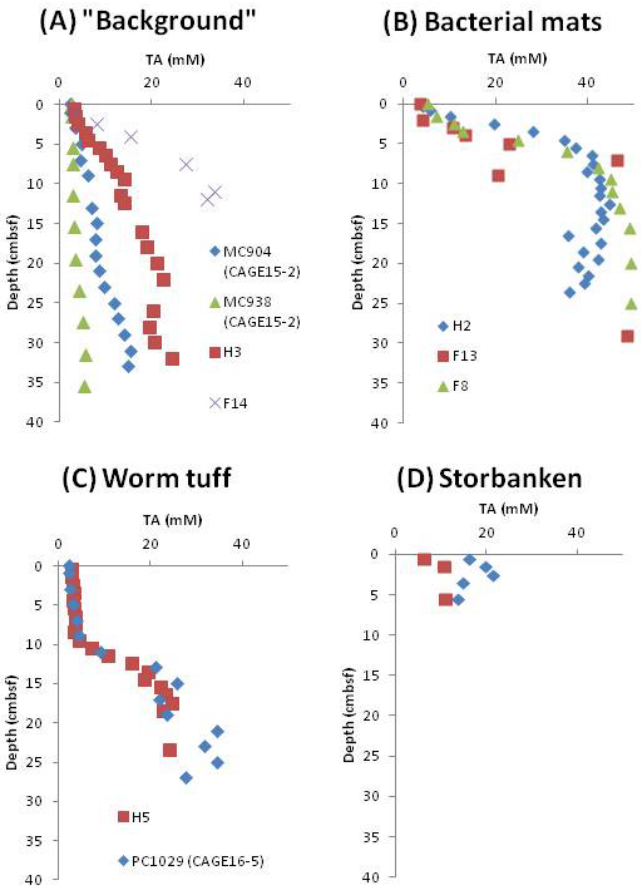


Figure 34: Results for total alkalinity (TA) for this cruise compared with previous findings in the GHM area.

The TA gradients are smaller from the four Storfjordrenna cores without bacterial mats and worms (Figure 34), inferring slower sulfate reduction as the result of lower methane supply. The three cores taken from the bacterial mats (Figure 34B) have much larger TA gradients, and higher methane flux, with sulfate-methane-transition-zone as shallow as 5-10 cm below seafloor (cmbsf). The two TA profiles from worm tuff are very similar to each other despite they were taken from different cruises two years apart. Such TA profiles suggest contrasting sulfur cycle between the shallow sediments (<10 cmbsf) and deeper sediments (>10 cmbsf) which may relate to the disturbance from the burrowing activities of the worms, that can be as long as the push cores (Figure 35).

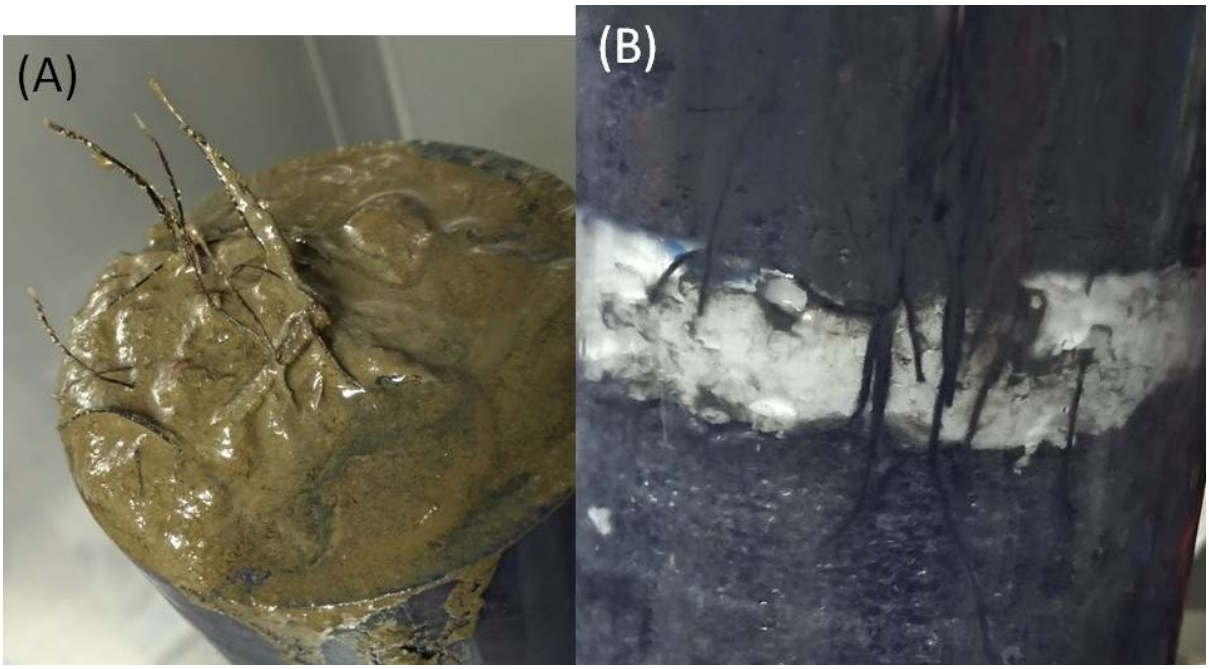


Figure 35: Example of push core with worms that may burrow to depth greater than the push core.

14 GAS GEOCHEMISTRY

(Pavel Serov)

We collected the headspace gas samples from push-cores with 3-5 cm resolution. Using a cut-off plastic syringe, we took 3 ml of bulk sediment and placed in a 20 ml chromatographic vial containing 7 ml of 1-molar NaOH solution. In push-cores taken by pore-water group we increased volume of sampled sediment to 5 ml and decreased volume of NaOH solution to 5 ml to obtain more concentrated samples. After a sample is placed in a vial we closed it with a rubber septum and sealed with an alumina cap. The sealed vials were stored in a cool room at a temperature of approx. 10 C.

In addition to headspace gas samples we collected samples for estimating sediment porosity from the same push-core intervals. Porosity samples were taken with 5 ml cut-off syringes and placed in Falcon tubes for centrifugation. Porosity measurements will be used to convert headspace gas concentrations to gas concentrations in pore space of sediments.

The headspace gas samples will be used for analyzing molecular composition of hydrocarbon gas and may be used for analyzing isotope composition of carbon and hydrogen in methane molecules. These analyses will provide information about the source of gas.

15 MICROBIOLOGY

(Mette Svenning, Dimitri Kalenitchenko and Vincent Carrier)

15.1 Methods and onboard analyses

Cold seeps environments are characterized by methane fluxes from reservoirs below the seabed to the water column. This source of carbon can be converted by bacterial/archaeal consortium into hydrogen sulfide. Thereafter, hydrogen sulfide become a source of energy for free living or symbiotic bacteria. However, this methane flux (and hydrogen sulfide) is not homogeneous over an area and therefore cold seeps are always described as a patchy habitat. Here we focused on one patch to try to understand how the microbial community is structured. We have selected an area (Fix point 9) where both free living and symbiotic bacteria occurs. Free living bacteria are building white biofilms covering the sediment surface whereas symbiotic bacteria lives inside siboglinids worms.

To get a precise knowledge and be able to understand which members of the microbial community are key players in the pingo arctic cold seep, we emphasized our sampling efforts on a small area of interest (Figure 36). Using this sampling approach, we hope to be able to characterize microbial variations within meters and then understand the drivers of the community structure.

Four types of habitats were targeted: Biofilm and at its edge in addition to a worm-dominated surface and its edge. Sediment were sampled (50% success rate) using push cores deployed from the ROV and brought back to the ship in less than 30-40 min using a basket.

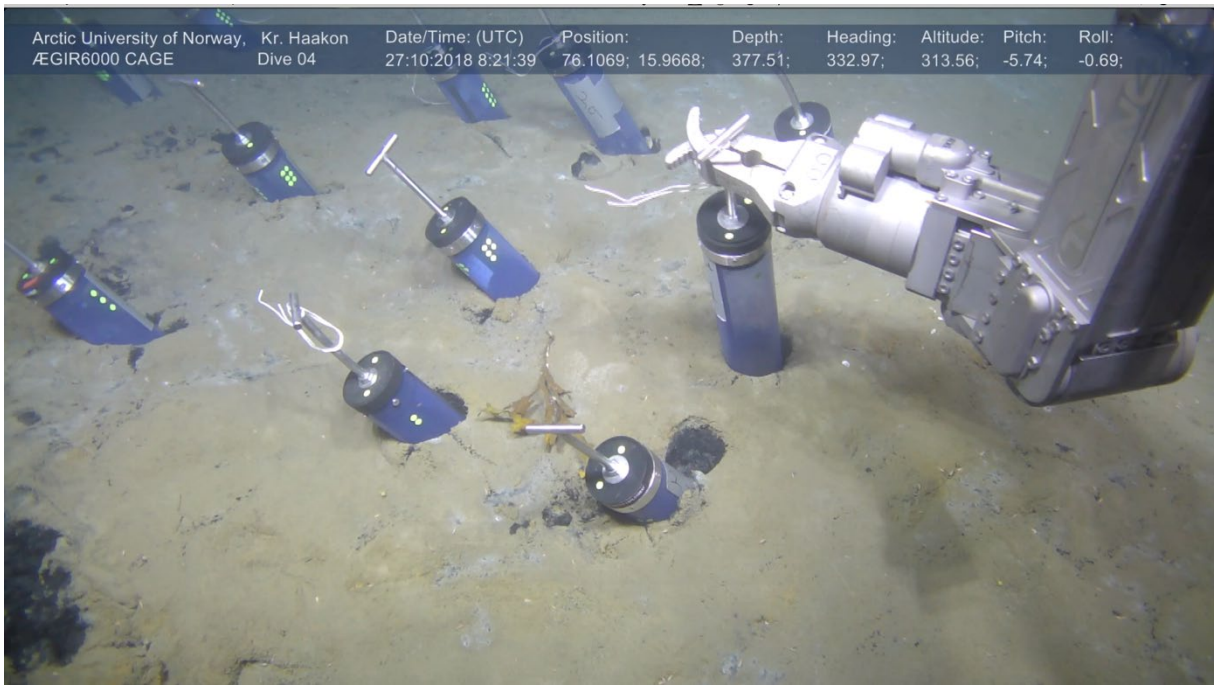


Figure 36: Sampling of densely spaced push cores with the ROV on gas hydrate pingo 3 site.

On 10 cores, we measured the oxygen, the hydrogen sulfide and the pH using electrochemical probes from Unisense (Aarhus, DK). These three parameters allowed us to define 3 to 4 target depths within each core. For example, on the core CAGE18-5_KH_Dive4_C22 (Figure 37) we have selected the first centimeter as the "oxic layer", 8 cm depth in the H_2S gradient and 12 cm depth as the H_2S maximum.

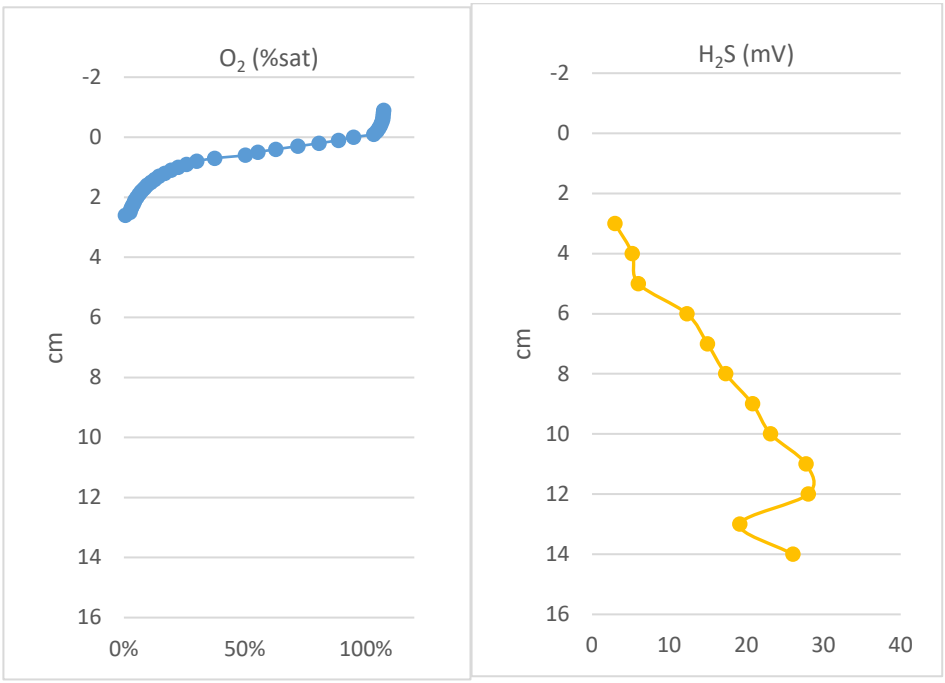


Figure 37: Oxygen (O_2) and hydrogen sulfide (H_2S) profiles from core CAGE18-5_KH_Dive4_C22.

Furthermore, profiled cores were sliced and sediments were sampled for DNA/RNA and Fluorescent *In Situ* Hybridization (FISH) at targeted depth and for methane and porosity analyses every 4 cm. DNA/ RNA and FISH will tell us who is present based on both bacterial and archaeal molecular signatures. To understand the ecophysiology of a microorganism mitigating methane emission, we also collected samples for cultivation in lab. We took 14 sediment samples in multiple cores in the oxic and anoxic zones (Table 4). The sample was transferred to a 100 ml bottle filled with 70 ml of filtered seawater and 5 ml of methane. Incubation of enrichment cultures were started on board at 4°C in the dark. We expect that some of the methanotrophs present will proliferate in the bottles to deepen our knowledge on the key actors in the area.

Table 4: Sediment and Biofilm sampled on CAGE-18-5 cruise.

			Electrochemical	Number of samples taken for				
Internal ID	CAGE ID	Feature	profile	Porosity	Methane	DNA/RNA	FISH	Enrichment
Carboncrust #3	CAGE18-5_KH_Dive1_C3	Biofilm	No	X	X	1	5	1
µ1	CAGE18-5_KH_Dive4_C47	Matt-edge	Yes	6	6	3	3	X
µ2	CAGE18-5_KH_Dive4_C31	Matt-edge	Yes	6	6	3	3	X
µ3	CAGE18-5_KH_Dive4_C45	Worm-edge	Yes	4	4	3	3	X
µ4	CAGE18-5_KH_Dive4_C29	Matt	Yes	9	9	4	4	2
µ6	CAGE18-5_KH_Dive4_C27	Worm-edge	Yes	5	5	4	4	X
µ7	CAGE18-5_KH_Dive4_C22	Worm	Yes	4	4	3	3	2
µ8	CAGE18-5_KH_Dive4_C44	Worm	Yes	5	5	3	3	X
µ10	CAGE18-5_KH_Dive4_C25	Matt	Yes	7	7	3	3	X
µ11	CAGE18-5_KH_Dive4_C26	Worm	No	6	6	3	3	2
µ12	CAGE18-5_KH_Dive4_C49	Bubbles	No	4	4	2	2	2
µ14	CAGE18-5_KH_Dive4_C50	Bubbles	Yes	2	2	4	4	2
µ15	CAGE18-5_KH_Dive4_C41	Worm-edge	Yes	7	7	5	4	2
Blade Core #1	CAGE18-5_KH_Dive8_BLC53	Matt	Yes	2	2	2	2	X
Rock #20	CAGE18-5_KH_Dive10_R20	Biofilm	No	X	X	2	3	X

In addition, we performed sampling on bubbling sites, rocks, carbon crust and blade cores from mats, when opportunities were given (Table 1). These samples will be used to verify for the presence of a specific arctic microbial community and eventually to define new sampling sites of interest.

Water samples

Collecting water samples will allow us to study the microbial community that is interconnected with methane fluxes that went through the sediment´s microbial filters. On this cruise we sampled three rosettes on Pingo 3 site (Table 5): one above a gas flare (CAGE_18_5_KH_188_CTD), one at a reference site (CAGE_18_5_KH_190_CTD) and one guided by the ROV camera into a gas flare (CAGE_18_5_KH_191_CTD).

Seawater was filtered through Sterivex cartridge (0.2 µm pore size, Millipore) and stored at -80°C until further analyses in our laboratory. Seven water samples were used as individual inoculum for enrichments of methanotrophs where 80 ml of water were transferred to a 100 ml bottle filled with 20 ml of methane.

Table 5: Water sampled on CAGE-18-5 cruise.

Internal ID	CAGE ID	Depth	Enrichment	Vol (mL)
184_379	CAGE_18_5_KH_184_CTD	379	x	1000
188_btl-1-2	CAGE_18_5_KH_188_CTD	381.319	x	500
188_btl-3-4	CAGE_18_5_KH_188_CTD	371.067		200
188_btl-5	CAGE_18_5_KH_188_CTD	355.944		200
188_btl-6	CAGE_18_5_KH_188_CTD	268.09		200
188_btl-7	CAGE_18_5_KH_188_CTD	182.39		200
188_btl-8	CAGE_18_5_KH_188_CTD	95.148		200
188_btl-9	CAGE_18_5_KH_188_CTD	25.223		200
188_btl-10	CAGE_18_5_KH_188_CTD	10.295	x	200
188_btl-12	CAGE_18_5_KH_188_CTD	4.183		500
190_btl_1	CAGE_18_5_KH_190_CTD	380.939		200
190_btl_3	CAGE_18_5_KH_190_CTD	370.47		200
190_btl_4	CAGE_18_5_KH_190_CTD	370.497		200
190_btl_5	CAGE_18_5_KH_190_CTD	356.306		200
190_btl_6	CAGE_18_5_KH_190_CTD	269.391		200
190_btl_7	CAGE_18_5_KH_190_CTD	181.93		200
190_btl_8	CAGE_18_5_KH_190_CTD	94.914		200
190_btl_9	CAGE_18_5_KH_190_CTD	24.889		200
190_btl_12	CAGE_18_5_KH_190_CTD	5.549		200
Flare_btl_2	CAGE_18_5_KH_191_CTD	381.102	x	200
Flare_btl_5	CAGE_18_5_KH_191_CTD	380.149	x	200
Flare_btl_8	CAGE_18_5_KH_191_CTD	374.898	x	200
Flare_btl_11	CAGE_18_5_KH_191_CTD	368.174	x	200

15.2 Future work

Molecular samples will be processed rapidly to acquire a precise molecular diversity “picture” of the arctic cold seep community. Based on this result we will be able to define key players and to observe them under the microscope using the FISH samples.

In parallel, we will try to cultivate some of the methanotroph microbes from the enrichments to move from the observation of the microbial diversity to the comprehension at the cellular level of the lifestyle of these arctic methanotrophs.

By combing these three approaches we might be able to conclude whereas the pingo site microbial community has unique characteristics related to its arctic location (cold adaptation, ice algae carbon input…) and discuss our results in the context of the Baas Becking hypothesis “Everything is everywhere but the environment select”.

16 IN-SITU BUBBLE MEASUREMENTS

(Benedicte Ferre)

Marine seeps produce underwater sounds, and frequency and sound levels are related to bubble size and gas emission flux. We will determine this information using a hydrophone mounted on the ROV and placed directly above the source (Figure 38).

Figure 38: Hydrophone placed by the ROV manipulator just above a seepage.

We will compare our calculation with a checkerboard-like calibrated grid, place at a minimum distance from the seep, in order to observe, count and measure the bubbles passing in front of the board (Figure 39). This equipment will also allow us to estimate the bubbles rising speed.

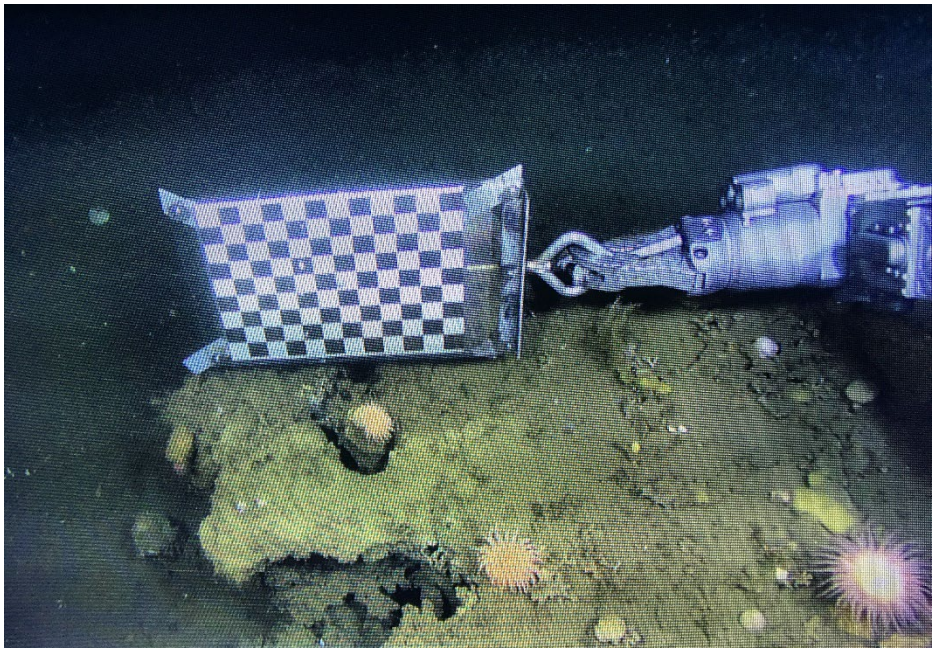


Figure 39: Checkerboard placed behind the methane seepage at pingo 3.

17 HARD ROCK SAMPLING

(Rune Mattingsdal)

Dive 9 and 10 focused on trying to sample outcropping sedimentary rocks in the walls of two of the craters on Storbanken (Figure 26). The outcropping sedimentary rocks in the Dive 9 location was, based on seismic interpretations, believed to be sandstones of Middle Jurassic age, and in the Dive 10 location shales of Upper Jurassic age.

The recovered sedimentary rocks from Dive 9 (samples R3-R17) and Dive 10 (samples R18-R26) in the Storbanken craters were when onboard confirmed to be respectively sandstones and shales, as assumed before the dives and observed on video during the dives. The sandstones from Dive 9 are light grey in color and seems visually to be massive fine sand with little finer material, only one sample (R17) seems to have what is interpreted to be thin black strings of possible more finer material (shale?). The shales from Dive 10 vary in composition and color, but are mostly dark in color. Some of the shale samples include macrofossils (mussels?).

The recovery of sandstones from Dive 9 and shales from Dive 10 confirms what was assumed before the cruise based on seismic interpretations.

The sedimentary rock samples from Dive 9 and 10 will first be described in Tromsø and then analysed for biostratigraphy by NPD in Stavanger.

18 SCIENTIFIC DATA MANAGEMENT AND AVAILABILITY

Scientific data from this cruise is managed and archived at the UiT data repository and can be accessed by contacting any of the team leaders at CAGE. Extensive tables and spreadsheets following the sampling and subsampling program are available through CAGE Sharepoint at UiT.

19 ACKNOWLEDGEMENT

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21 APPENDIX

Below are shortened tables of the stations of CAGE18-5. More extended spreadsheets are available in the CAGE sharepoint folder.

1) CTD Stations
2) Push and blade cores
3) Carbonate samples
4) Rock samples
5) Gas samples
6) Other activities

21.1 CTD Stations

Site/Area	Ship Station	Activity	Station Id	Date (UTC)	Time (UTC)	Latitude	North/ South	Longitude	East /West	Water Depth [m]	Bottles fired	Notes
Storfjordrenna Pingo1	181	CTD	CAGE_18_5_KH_181_CTD	24.10.2018	14:03	76.10920	N	16.00030	E	395	4	
Storfjordrenna Pingo1	182	CTD	CAGE_18_5_KH_182_CTD	24.10.2018	15:34	76.11732	N	16.00121	E	378	12	
Storfjordrenna Pingo1	183	CTD	CAGE_18_5_KH_183_CTD	24.10.2018	16:40	76.11457	N	16.00315	E	381	12	last two bottles were fired on the fly. Winch couldnt be stopped at 5 m due to bad weather.
Storfjordrenna Pingo1	184	CTD	CAGE_18_5_KH_184_CTD	24.10.2018	17:27	76.11175	N	16.00577	E	384	12	11th bottle fired at 10 m
Storfjordrenna Pingo1	185	CTD	CAGE_18_5_KH_185_CTD	24.10.2018	18:16	76.10863	N	16.00767	E	394	12	11th bottle fired at 10 m
Storfjordrenna Pingo3	186	CTD	CAGE_18_5_KH_186_CTD	26.10.2018	09:40	76.10877	N	15.98013	E	391	12	11th bottle fired near 10 r
Storfjordrenna Pingo3	187	CTD	CAGE_18_5_KH_187_CTD	26.10.2018	11:22	76.10791	N	15.97343	E	390	12	11th bottle fired at 10 m
Storfjordrenna Pingo3	188	CTD	CAGE_18_5_KH_188_CTD	26.10.2018	12:25	76.10695	N	15.96722	E	386	12	11th bottle fired at 10 m a
Storfjordrenna Pingo3	189	CTD	CAGE_18_5_KH_189_CTD	26.10.2018	14:03	76.10608	N	15.96093	E	388	12	
Storfjordrenna Pingo3	190	CTD	CAGE_18_5_KH_190_CTD	26.10.2018	14:56	76.10513	N	15.95452	E	386	12	
Storfjordrenna Pingo3	191	CTD	CAGE_18_5_KH_191_CTD	27.10.2018	12:41:34	76.10702	N	15.96798	E	379	12	ROV guided water sampli
Storbanken	192	CTD	CAGE_18_5_KH_192_CTD	29.10.2018	08:17:30	76.78041	N	35.15610	E	158		
Storbanken	193	CTD	CAGE_18_5_KH_193_CTD	30.10.2018	02:37	76.78676	N	35.24142	E	145	12	11th bottle at 10m
Storbanken	194	CTD	CAGE_18_5_KH_194_CTD	30.10.2018	03:18	76.78529	N	35.22314	E	151	12	
Storbanken	195	CTD	CAGE_18_5_KH_195_CTD	30.10.2018	03:59:23	76.78388	N	35.20629	E	160	12	
Storbanken	196	CTD	CAGE_18_5_KH_196_CTD	30.10.2018	04:45:34	76.78137	N	35.17679	E	158	12	
Storbanken	197	CTD	CAGE_18_5_KH_197_CTD	30.10.2018	05:19:18	76.78026	N	35.16271	E	156	12	
Storbanken	198	CTD	CAGE_18_5_KH_198_CTD	30.10.2018	05:48:48	76.77902	N	35.14726	E	153	12	

21.2 Push and blade core stations

Site/Area	push core label in basket	Activity (PUC or BladeC)	Station Id	Date (UTC)	Time (UTC)	Latitude	North/ South	Longitude	East/ West	Recovery	Water Depth [m]
GHP3	F6	PUC	CAGE18-5_KH_Dive2_PUC1	25.10.2018	16:12:12	76.1066	N	15.9668982	E		382
GHP3	F7	PUC	CAGE18-5_KH_Dive2_PUC2	25.10.2018	16:20:13	76.1066007	N	15.9669303	E		382
GHP3	F8	PUC	CAGE18-5_KH_Dive2_PUC3	25.10.2018	16:24:08	76.1065908	N	15.9668768	E		382
GHP3	F9	PUC	CAGE18-5_KH_Dive2_PUC4	25.10.2018	16:29:00	76.1066093	N	15.9668547	E	no recovery	382
GHP3	F10	PUC	CAGE18-5_KH_Dive2_PUC5	25.10.2018	16:34:53	76.1065988	N	15.9669148	E	no recovery	382
GHP3	F11	PUC	CAGE18-5_KH_Dive2_PUC6	25.10.2018	16:38:24	76.1066042	N	15.9668445	E	no recovery	382
GHP3	M6	PUC	CAGE18-5_KH_Dive2_PUC7	25.10.2018	16:46:26	76.106624	N	15.9669708	E	no recovery	382
GHP3	M5	PUC	CAGE18-5_KH_Dive2_PUC8	25.10.2018	16:53:41	76.1066333	N	15.9668445		no recovery	382
GHP3	M4	PUC	CAGE18-5_KH_Dive2_PUC9	25.10.2018	17:00:28	76.1066323	N	15.9669825	E		382
GHP3	M3	PUC	CAGE18-5_KH_Dive2_PUC10	25.10.2018	17:07:29	76.1066432	N	15.9670102	E		382
GHP3	M2	PUC	CAGE18-5_KH_Dive2_PUC11	25.10.2018	17:13:44	76.10662	N	15.9669707	E	no recovery	382
GHP3	M1	PUC	CAGE18-5_KH_Dive2_PUC12	25.10.2018	17:20:24	76.106631	N	15.9669942	E	no recovery	382
GHP3	H1	PUC	CAGE18-5_KH_Dive2_PUC13	25.10.2018	17:26:03	76.1066038	N	15.9668575	E	no recovery	382
GHP3	H2	PUC	CAGE18-5_KH_Dive2_PUC14	25.10.2018	17:29:55	76.1066175	N	15.966854	E		382
GHP3	H3	PUC	CAGE18-5_KH_Dive2_PUC15	25.10.2018	17:34:41	76.106581	N	15.9669435	E		383
GHP3	H4	PUC	CAGE18-5_KH_Dive2_PUC16	25.10.2018	17:41:23	76.1066443	N	15.967019	E	no recovery	382

GHP3	H5	PUC	CAGE18-5_KH_Dive2_PUC17	25.10.2018	17:49:10	76.10666	N	15.9669885	E		382
GHP3	B1	BLC	CAGE18-5_KH_Dive2_BLC18	25.10.2018	17:58:45	76.1065867	N	15.96714	E		382
GHP3	L1	PUC	CAGE18-5_KH_Dive2_PUC19	25.10.2018	18:19:17	76.1065992	N	15.9667907	E		382
GHP3	L2	PUC	CAGE18-5_KH_Dive2_PUC20	25.10.2018	18:29:41	76.106723	N	15.9666237	E		382
GHP3	B2	BLC	CAGE18-5_KH_Dive3_BLC21	27.10.2018	00:19:13	76.106857	N	15.966786	E		380
GHP3	M7	PUC	CAGE18-5_KH_Dive4_PUC22	27.10.2018	07:26:39	76.1069313	N	15.9667208	E		379
GHP3	M8	PUC	CAGE18-5_KH_Dive4_PUC23	27.10.2018	07:32:52	76.1069195	N	15.966723	E		379
GHP3	M9	PUC	CAGE18-5_KH_Dive4_PUC24	27.10.2018	07:36:43	76.1069248	N	15.9667552	E		379
GHP3	M10	PUC	CAGE18-5_KH_Dive4_PUC25	27.10.2018	07:42:16	76.106924	N	15.966778	E		379
GHP3	M11	PUC	CAGE18-5_KH_Dive4_PUC26	27.10.2018	07:47:26	76.1069218	N	15.966691	E		379
GHP3	M6	PUC	CAGE18-5_KH_Dive4_PUC27	27.10.2018	07:55:10	76.106921	N	15.966739	E		379
GHP3	M5	PUC	CAGE18-5_KH_Dive4_PUC28	27.10.2018	08:01:17	76.106921	N	15.9667752	E		379
GHP3	M4	PUC	CAGE18-5_KH_Dive4_PUC29	27.10.2018	08:05:58	76.1069207	N	15.9667725	E		379
GHP3	M3	PUC	CAGE18-5_KH_Dive4_PUC30	27.10.2018	08:11:32	76.1069112	N	15.9667258	E		379
GHP3	M2	PUC	CAGE18-5_KH_Dive4_PUC31	27.10.2018	08:16:38	76.1069153	N	15.9667495	E		379
GHP3	M1	PUC	CAGE18-5_KH_Dive4_PUC32	27.10.2018	08:22:17	76.1069217	N	15.966817	E		379
GHP3	F9	PUC	CAGE18-5_KH_Dive4_PUC33	27.10.2018	08:30:02	76.1069568	N	15.9667205	E		378
GHP3	F10	PUC	CAGE18-5_KH_Dive4_PUC34	27.10.2018	08:35:44	76.1069572	N	15.9666392	E		378
GHP3	F11	PUC	CAGE18-5_KH_Dive4_PUC35	27.10.2018	08:41:50	76.1069422	N	15.9668458	E		379
GHP3	F12	PUC	CAGE18-5_KH_Dive4_PUC36	27.10.2018	08:47:56	76.1069475	N	15.966651	E		379
GHP3	F14	PUC	CAGE18-5_KH_Dive4_PUC37	27.10.2018	08:52:57	76.106946	N	15.9666013	E		379

GHP3	F13	PUC	CAGE18-5_KH_Dive4_PUC38	27.10.2018	08:58:38	76.1069445	N	15.9668918	E		379
GHP3	B3	BLC	CAGE18-5_KH_Dive4_BLC39	27.10.2018	09:21:21	76.1069432	N	15.96688	E		379
GHP3	L1	PUC	CAGE18-5_KH_Dive4_PUC40	27.10.2018	09:30:06	76.1069063	N	15.966859	E		379
GHP3	M15	PUC	CAGE18-5_KH_Dive4_PUC41	27.10.2018	14:13:17	76.1068892	N	15.966578	E		380
GHP3	M13	PUC	CAGE18-5_KH_Dive4_PUC42	27.10.2018	14:15:57	76.106892	N	15.96656	E		380
GHP3	M5	PUC	CAGE18-5_KH_Dive4_PUC43	27.10.2018	14:17:54	76.1068933	N	15.966586	E		379
GHP3	M9	PUC	CAGE18-5_KH_Dive4_PUC44	27.10.2018	14:19:50	76.1068968	N	15.9665972	E		379
GHP3	M3	PUC	CAGE18-5_KH_Dive4_PUC45	27.10.2018	14:23:56	76.1068938	N	15.9665358	E		380
GHP3	M8	PUC	CAGE18-5_KH_Dive4_PUC46	27.10.2018	14:26:33	76.106897	N	15.9665733	E		379
GHP3	M1	PUC	CAGE18-5_KH_Dive4_PUC47	27.10.2018	14:29:05	76.1069028	N	15.9665572	E		379
GHP3	M16	PUC	CAGE18-5_KH_Dive4_PUC48	27.10.2018	14:31:39	76.1068992	N	15.966576	E		379
GHP3	M12	PUC	CAGE18-5_KH_Dive4_PUC49	27.10.2018	14:52:40	76.1069427	N	15.9669082	E		379
GHP3	M14	PUC	CAGE18-5_KH_Dive4_PUC50	27.10.2018	14:55:30	76.1069415	N	15.9669107	E		379
Storbanken	B3	BLC	CAGE18-5_KH_Dive6_BLC51	29.10.2018	18:33:05	76.7802457	N	35.1627945	E		156
Storbanken	B1	BLC	CAGE18-5_KH_Dive6_BLC52	29.10.2018	18:53:38	76.7801717	N	35.1618932	E		155
Storbanken	B4	BLC	CAGE18-5_KH_Dive8_BLC53	30.10.2018	09:48:14	76.7824735	N	35.2316183	E	blades worked	158
Storbanken	B1	BLC	CAGE18-5_KH_Dive8_BLC54	30.10.2018	09:56:24	76.7824772	N	35.2316103	E	blades worked	158

21.3 Carbonate samples

Site/ Area	Activity	Station Id	Date (UTC)	Time (UTC)	Latitude	North/ South	Longitude	East/ West	Water Depth [m]	Notes
GHP3	Carbonate	CAGE18-5_KH_Dive1_C1	25.10.2018	08:50:01	76.107001	N	15.967832	E	377	sampled from a small depression at bubbling site; cavernous crust, partly filled with free gas(! See ROV video); half buried in black sediment
GHP3	Carbonate	CAGE18-5_KH_Dive1_C2	25.10.2018	09:34:24	76.1071188	N	15.968715	E	378	cavernous crust; massive sample
GHP3	Carbonate	CAGE18-5_KH_Dive1_C3	25.10.2018	09:37:12	76.107107	N	15.968837	E	379	with white filamentous (ca. 5 cm long) bacteria attached on surface;ca 20 cm diamter
GHP3	Carbonate	CAGE18-5_KH_Dive1_C4	25.10.2018	09:40:28	76.1071663	N	15.968831	E	379	flat, elongated crust
GHP3	Carbonate	CAGE18-5_KH_Dive1_C5	25.10.2018	09:46:06	76.1071528	N	15.968797	E	379	massive sample; cavernous crust; with black sediment and yellowish and white cover (microbial mat? Sulphur?cement?) on the bottom
GHP3	Carbonate	CAGE18-5_KH_Dive4_C6	27.10.2018	15:33:46	76.1069995	N	15.966695	E	379	cavernous crust, W flank mound top

GHP3	Carbonate	CAGE18-5_KH_Dive4_C7	27.10.2018	15:39:48	76.107027	N	15.966656	E	379	cavernous crust, W flank mound top; C7 slightly larger than C6
Storb anken	Carbonate	CAGE18-5_KH_Dive6_C8	29.10.2018	17:57:03	76.7801803	N	35.162651	E	156	
Storb anken	Carbonate	CAGE18-5_KH_Dive6_C9	29.10.2018	18:08:09	76.7801873	N	35.162621	E	156	
Storb anken	Carbonate	CAGE18-5_KH_Dive6_C10	29.10.2018	19:37:56	76.7802855	N	35.162786	E	156	
Storb anken	Carbonate	CAGE18-5_KH_Dive6_C11	29.10.2018	19:44:34	76.7802797	N	35.162775	E	156	
Storb anken	Carbonate	CAGE18-5_KH_Dive8_C12	30.10.2018	10:34:24	76.7824795	N	35.230945	E	157	carbonate sample cut with a chain saw
Storb anken	Carbonate	CAGE18-5_KH_Dive8_C13	30.10.2018	12:09:51	76.7809358	N	35.230526	E	160	

21.4 Rock samples

Site/Area	Activity	Station Id	Date (UTC)	Time (UTC)	Latitude	North/South	Longitude	East/West	Water Depth [m}
Storbanken	Rock	CAGE18-5_KH_Dive8_R1	30.10.2018	09:31:06	76.78273	N	35.22878	E	153
Storbanken	Rock	CAGE18-5_KH_Dive8_R2	30.10.2018	09:33:25	76.78278	N	35.22877	E	152
Storbanken	Rock	CAGE18-5_KH_Dive9_R3	30.10.2018	15:39:17	76.75867	N	35.76175	E	190
Storbanken	Rock	CAGE18-5_KH_Dive9_R4	30.10.2018	15:56:16	76.75852	N	35.76376	E	187
Storbanken	Rock	CAGE18-5_KH_Dive9_R5	30.10.2018	16:01:22	76.75849	N	35.76381	E	187
Storbanken	Rock	CAGE18-5_KH_Dive9_R6	30.10.2018	16:06:20	76.75842	N	35.76412	E	189
Storbanken	Rock	CAGE18-5_KH_Dive9_R7	30.10.2018	16:22:41	76.7583	N	35.76429	E	193
Storbanken	Rock	CAGE18-5_KH_Dive9_R8	30.10.2018	16:28:37	76.75832	N	35.7644	E	192
Storbanken	Rock	CAGE18-5_KH_Dive9_R9	30.10.2018	16:36:43	76.75826	N	35.76483	E	190
Storbanken	Rock	CAGE18-5_KH_Dive9_R10	30.10.2018	16:42:33	76.7583	N	35.765	E	186
Storbanken	Rock	CAGE18-5_KH_Dive9_R11	30.10.2018	17:16:49	76.7581	N	35.76521	E	204
Storbanken	Rock	CAGE18-5_KH_Dive9_R12	30.10.2018	17:38:55	76.75805	N	35.7658	E	203
Storbanken	Rock	CAGE18-5_KH_Dive9_R13	30.10.2018	17:44:25	76.75807	N	35.76585	E	200
Storbanken	Rock	CAGE18-5_KH_Dive9_R14	30.10.2018	17:46:03	76.75805	N	35.76588	E	202
Storbanken	Rock	CAGE18-5_KH_Dive9_R15	30.10.2018	17:55:38	76.75808	N	35.76573	E	201
Storbanken	Rock	CAGE18-5_KH_Dive9_R16	30.10.2018	17:58:01	76.75811	N	35.76572	E	196
Storbanken	Rock	CAGE18-5_KH_Dive9_R17	30.10.2018	18:07:32	76.75814	N	35.76561	E	191
Storbanken	Rock	CAGE18-5_KH_Dive10_R18	30.10.2018	21:46:05	76.76575	N	35.7564	E	192
Storbanken	Rock	CAGE18-5_KH_Dive10_R19	30.10.2018	21:53:37	76.76574	N	35.75641	E	193
Storbanken	Rock	CAGE18-5_KH_Dive10_R20	30.10.2018	22:06:49	76.76576	N	35.75661	E	192
Storbanken	Rock	CAGE18-5_KH_Dive10_R21	30.10.2018	22:31:11	76.76575	N	35.75745	E	193
Storbanken	Rock	CAGE18-5_KH_Dive10_R22	30.10.2018	22:45:31	76.76581	N	35.75823	E	191
Storbanken	Rock	CAGE18-5_KH_Dive10_R23	30.10.2018	22:55:16	76.76587	N	35.75898	E	190
Storbanken	Rock	CAGE18-5_KH_Dive10_R24	30.10.2018	22:59:17	76.76588	N	35.75894	E	190
Storbanken	Rock	CAGE18-5_KH_Dive10_R25	30.10.2018	23:21:54	76.76592	N	35.76135	E	189

21.5 Gas samples

Site/Area	Handle no.	Station Id	Date (UTC)	Time (UTC)	Latitude	North/ South	Longitude	East/ West	Water Depth [m]	Notes
GHP3		CAGE18-5_KH_Dive3_GS1	27.10.2018	03:14:02	76.1069843	N	15.967828	E	378	
GHP3		CAGE18-5_KH_Dive3_GS2	27.10.2018	03:56:28	76.1069672	N	15.967953	E	378	
Storbanken	5	CAGE18-5_KH_Dive6_GS3	29.10.2018	16:10:12	76.780033	N	35.162921	E	155	sampling from 16:10:12 to 17:38:54
Storbanken	3	CAGE18-5_KH_Dive6_GS4	29.10.2018	17:48:49	76.7802758	N	35.162766	E	156	sampling from 17:48:49 to
Storbanken	5	CAGE18-5_KH_Dive8_GS5	30.10.2018	09:24:10	76.7824437	N	35.230693	E	158	sampling from 09:24:10 to 11:05:35

21.6 Other activities

Site/Area	Activity	Station Id	Date (UTC)	Time (UTC)	Latitude	North/South	Longitude	East/West	Equipment	Water Depth [m]
Storfjordrenna Pingo 3	Hydrophone record	CAGE_18_5_KH_Dive3_HYD1	27.10.2018	04:25:48	76.10699	N	15.9677912	E	Hydrophone	378
Storbanken	Hydrophone record	CAGE_18_5_KH_Dive6_HYD2	29.10.2018	16:45:14	76.78027	N	35.1627568	E	Hydrophone	156
Storbanken	Bubble flow rate measurement	CAGE_18_5_KH_Dive6_FL1	29.10.2018	16:23:46	76.78028	N	35.1627803	E	ROV	156
Storbanken	Hydrophone record	CAGE_18_5_KH_Dive8_HYD3	30.10.2018	11:46:36	76.78094	N	35.2305582	E	Hydrophone	160
Storbanken	Bubble flow rate measurement	CAGE_18_5_KH_Dive8_FL2	30.10.2018	11:53:33	76.78094	N	35.230539	E	ROV	160