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R/V Helmer Hanssen

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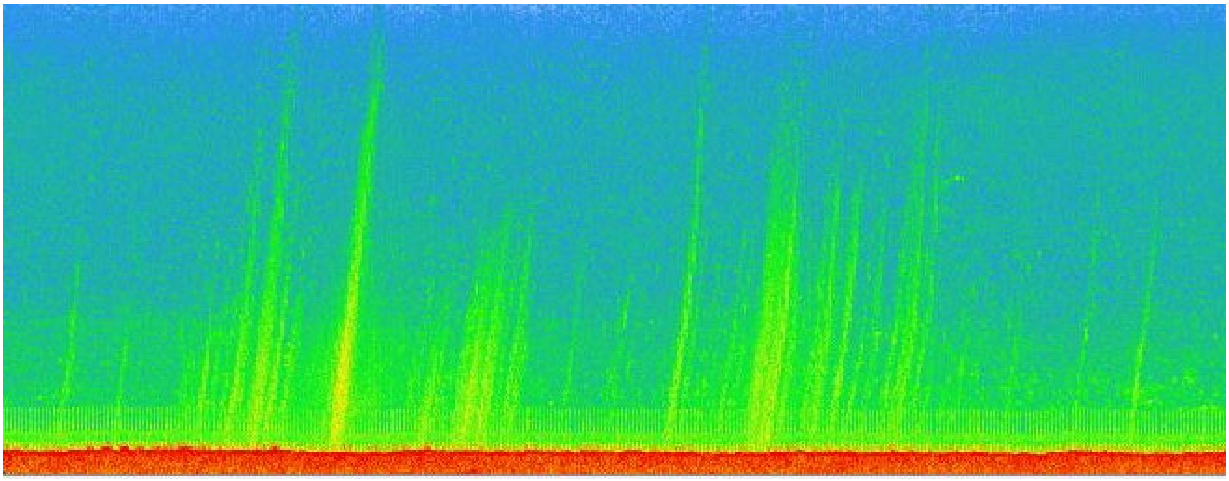
Longyearbyen – Tromsø

CAGE21-4 cruise report



Oil slicks, gas flares and glacial landforms in Hopendjupet and Sentralbanken

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Key words: gas flares, oil slicks, multibeam, gravity cores

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1 Contents

1. Scientific objectives

The cruise was part of the Centre of Excellence (SFF) Centre for Arctic Gas Hydrate. Environment and Climate (CAGE) at UiT - The Arctic University of Norway.

The cruise visited several areas in Hopendjupet, and Sentralbankrenna in the central Barents Sea (Figure 1), and had the following scientific objectives:

- Surveying and sampling of gas seepage associated with known and assumed sandstone reservoirs sub-cropping at the sea floor due to erosion of overlying cap rocks in Hopendjupet and Sentralbanken.
- Surveying and sampling of gas seepage related to leakage along faults and geological structures breaching the seafloor in Hopendjupet and Sentralbanken.
- Sampling of oil in sea surface slicks and within shallow sediment cores.
- Surveying of landforms associated with the retreat of the Barents Sea Ice Sheet in the outer Sentralbankrenna area.

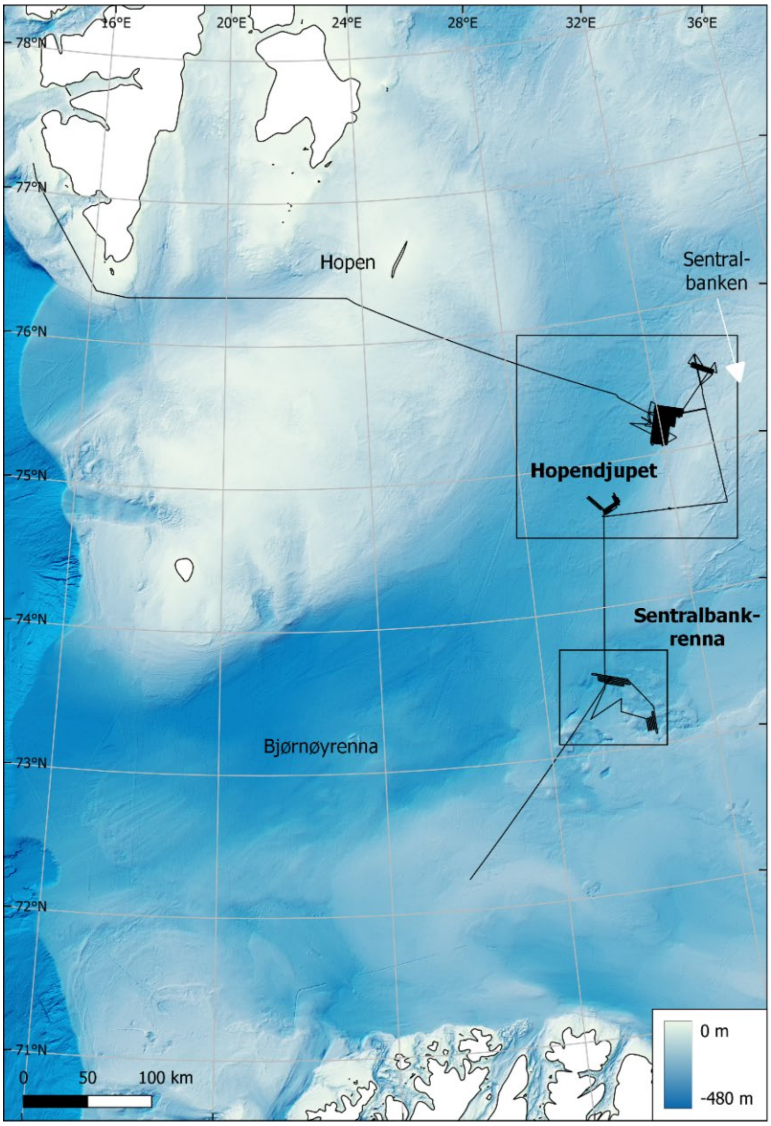


Figure 1: Working areas for cruise CAGE_21-4 in Hopendjupet and Sentralbankrenna. The ship track is shown in black.

1.1. Geological setting

Geologically, Hopendjupet (the Hopen Deep) represents a viable setting for significant gas flaring linked to thermogenic source rocks. The area is bounded by outcropping Jurassic-age reservoir rocks (Realgrunnen Sub-Group), indicating where Cretaceous age rocks have since been eroded by the Cenozoic ice sheets. On and around the structural highs, Triassic-age rocks (Upper Triassic Snadd Fm and Middle Triassic Kobbe Fm) subcrop at the seafloor. The major regional geological structures include the Sentralbanken (east) and the Gardarbanken (west) highs, which route and act as focus points for the migration of free gas from the subsurface. Fault zones associated with these structural elements provide additional pathways to the seafloor. Within this area CAGE cruise 20-2 identified extremely intense gas seepage, along with gas hydrate pingos. In addition, NPD and CIRFA have identified intermittent oil slicks in this region. North of Hopendjupet lies Storbanken, previously visited by CAGE during the CAGE_19-2 cruise, where structurally controlled flaring was also observed. Hopendjupet is also host to a large crater field, where km-scale depressions record the blowout of methane gas accumulations after the last deglaciation and when the gas hydrate stability zone (GHSZ) severely diminished (Andreassen et al., 2017). Today the GHSZ lies at around 360 metres of water depth in this region.

1.2. Glacial setting

The Barents Sea has been glaciated multiple times over the late Quaternary. During the most recent Late Weichselian glaciation (and likely during previous ones) a major ice stream operated within Bjørnøyrenna. This ice stream had several tributaries, one of which occupied Sentralbankrenna. At the centre of the ice sheet, this was likely one of the last places that deglaciated, and as such, the glacial landforms and sediments preserved here offer the possibility to investigate how the ice sheet behaved during its final demise.

2. Cruise participants

Name	**Position**	**Shift**
Monica Winsborrow (cruise leader)	Ass. Professor (CAGE)	Open/1
Henry Patton (cruise leader)	Researcher (CAGE)	2
André Jensen	Geologist (NPD)	1
Mauro Pau	Postdoc (CAGE)	1
Frank Jakobsen	PhD (CAGE)	2
Abidemi Akinselure	MSc (CAGE)	2
Truls Holm	Engineer (UiT)	1
Stormer Alexander Jensen	Engineer (UiT)	2

Some of the participants are shown in Figure 2. Work was organised in two time shifts. Shift 1: 04:00-12:00; 16:00-20:00. Shift 2: 12:00-16:00; 20:00-04:00 (TOS time). We departed from Longyearbyen 02.08 at 15:30, transiting to Hopendjupet, crossing two possible oil slicks west of Hopen. We arrived into port in Tromsø 13.08 at 08:30.

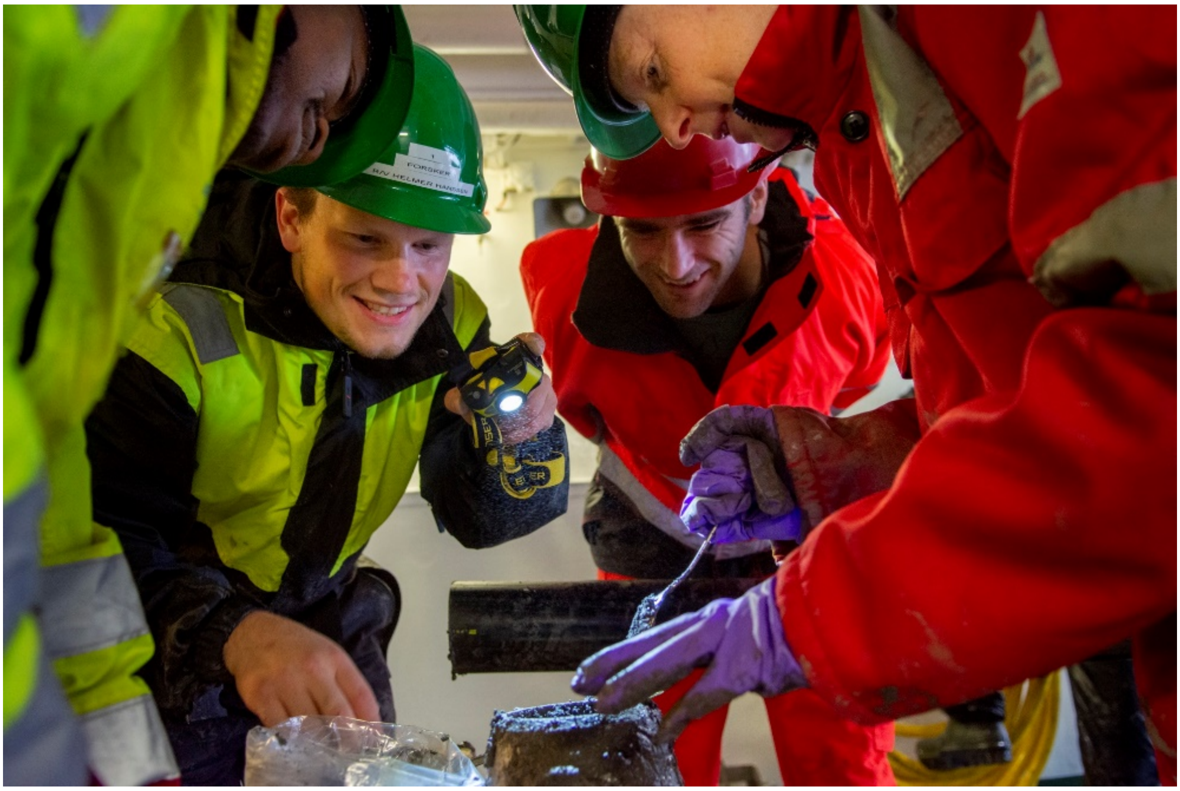


Figure 2: Anticipation as cruise participants study sediments from the seafloor in an area of intense methane seepage (Photo: M. Pau).

3. Corona-based risk assessment

There was a focus on reducing the risk of corona infection both before and during the cruise. The scientific crew was kept to a minimum with only 8 participants (all residents of Norway), and each had their own cabin as stipulated in UiT rules. All participants respected the self-quarantine time of 10 days within Norway prior to the cruise and completed a health check self-assessment immediately prior to coming on-board. In addition, all the scientific crew had negative Corona tests, a requirement to enter Svalbard (the engineers were already on board, having joined previous cruises). The UiT restriction of keeping expedition activity within a 48-hour sailing distance of Tromsø was respected at all times.

4. Equipment used

4.1. Sub-bottom profiler (Chirp)

The X-STAR Full Spectrum Sonar is a versatile wideband FM sub-bottom profiler that generates cross-sectional images of the seabed and collects digital normal incidence reflection data over many frequency ranges. X-STAR transmits an FM pulse that is linearly swept over a full spectrum frequency range (also called "chirp pulse"). The chirp system comprises a hull-mounted 4 x 4 transducer array operated at an energy level of 4 kW and at a shot rate of 1 s. The signal lasts 40 ms, starts at 1.5 kHz and ends at 9 kHz. The system can operate in water depths of up to 8000 m. The penetration depth depends on the sediment type and thickness; it can be up to 80 m in soft clay.

Six chirp profiles were acquired in the area of intense flaring of Hopendjupet, five of which correspond to NPD 2D seismic lines, and the sixth crosses the location of gravity cores 902 and 903 and the potential source of oil slick 2. A 2–8 kHz pulse was used for most of the surveying, with a ping rate of 0.3 Hz, with live data used for identifying suitable sites for gravity coring and to provide information of surficial sediment thickness across the area. Chirp was further collected continuously (along with multibeam echosounder data) during the surveying of Sentralbankrenna and most of the transit back to Tromsø.

During acquisition in areas of flaring or suspected flaring, the chirp was deactivated to reduce interference in the water column data for identifying flares and allow increased sailing speed from 8 to 10 knots.

4.2. Multibeam echosounder

Multibeam echosounders use a swath of beams giving off-track depth. Basic components of a multibeam system are two linear transducer arrays in a Mills cross configuration with separate units for transmitting and receiving. Echosounders measure the two-way travel time that a sound wave initiated by the transmitter needs to reach the seafloor and be reflected back to the receiver. The time-depth conversion can be done using the sound velocity through seawater calculated from the closest CTD measurements.

R/V Helmer Hanssen is equipped with the hull-mounted Kongsberg Simrad EM302 multibeam echosounder system. Its nominal sonar frequency of the sound waves is 30 kHz with an angular coverage sector of up to 150° and 432 beams per ping. The system was mainly used with a 60°/60° opening angle. The ping rate depends on the water depth and switched frequently between 0.5 and 2 Hz. The EM302 provides high-resolution bathymetric data up to a water depth of 7000 m. The achievable swath width on the seafloor depends on the water depth and the selected opening angle.

During the entire cruise, the EM302 provided continuous bathymetric data to give an overview of seafloor morphology in the study area. The QPS Qimera software was used to process/clean the data and create preliminary high-resolution bathymetric maps.

Another application of the EM302 is to monitor the water column. The acquired data were analysed using the QPS FM Midwater software. Before any analysis could be done, the provided sonar source files (*.all, *.wcd) had to be converted to the generic water column file format (*.gwc).

The objective of analysing water column data was the detection of acoustic flares indicating gas seepage from the seafloor to the water column, as well as their spatial mapping on top of the bathymetry and along the seismic lines acquired during the cruise. To improve the quality of this water column data while detecting gas flares, the chirp and EK60 (singlebeam echosounder) signals were switched off, allowing the EM320 ping rate to increase from 0.33 to c. 0.7 Hz, increasing the quality of the water-column data. A swath overlap of 50% was used in areas for mapping flares as beyond an opening angle of c. 45° the water column data becomes too 'noisy' to interpret. In

Storfjordrenna where bathymetric coverage was prioritised, an overlap of c. 0% was used.

The following steps were carried out to count gas flares and extract flare data in QPS FM Midwater:

a) Acoustic flares were identified and counted using a playback of the data in fan and stack view (Figure 3).
b) Identified flares were marked in the fan view using the geopicking tool.
c) The flares for each line were exported to an ASCII file.
d) The flare locations were imported to a QPS Fledermaus project.

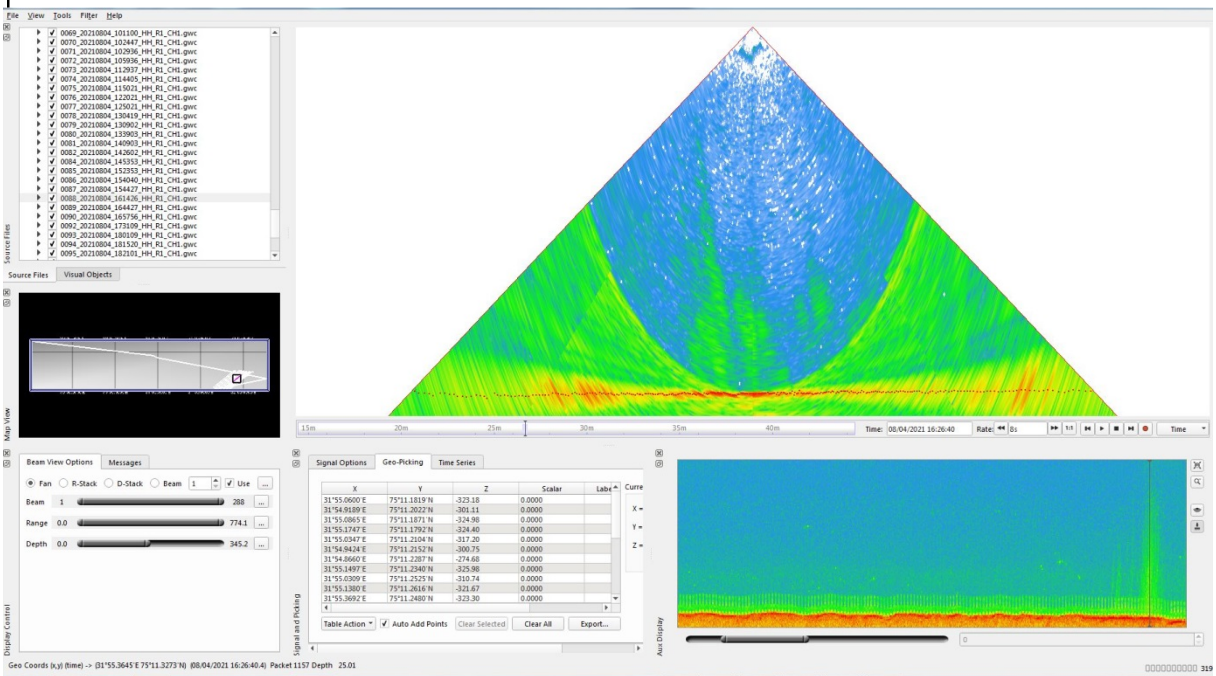


Figure 3: Picking of flare locations in FM Midwater.

To export flares in a 3D space the raw signal was clipped to a bare minimum to reveal just the flare. The beams used in the stack were also reduced to only those covering each flare/flare cluster. In the stacked view the pings related to the flare were then selected and exported to an ASCII text file for viewing in Fledermaus.

4.3. CTD and water sampling

CTD (Conductivity, Temperature, Depth) sensors measure the physical properties of seawater. In addition to measuring the conductivity, temperature and pressure (from which depth is calculated), the CTD sensors measure or calculate salinity of seawater, density, sound velocity, turbidity, fluorescence/chlorophyll and oxygen content. Furthermore, the CTD deck unit can trigger closing of Niskin bottles at discrete depths. Water samples may be taken from the Niskin bottles for further analysis.

R/V Helmer Hanssen uses a SBE 911plus CTD for producing vertical profiles of seawater properties. A winch is used to lower the CTD system into the water. The SBE 911plus

CTD can measure physical properties of the seawater from up to eight auxiliary sensors, in marine or fresh-water environments at depths up to 6000 m. However, the winch wire length limits CTD measurements on R/V Helmer Hanssen to approximately 3200 m. The CTD sensors record data at a rate of 24 samples per second. The 911plus system uses the modular SBE 3plus temperature sensor, SBE 4C conductivity sensor, SBE 5T submersible pump, and TC duct. The submersible pump pumps water along the sensor to measure the conductivity. The TC duct makes sure that temperature and conductivity are measured on the same parcel of water.

CTD data was collected at intervals during the cruise to measure variations in the sound velocity profile of the water column – a necessary calibration for multibeam echosounder surveying. Further targeted CTD data and water samples were collected at six sites during the cruise with the aim of tracing the passage of methane through the water column. Samples were collected at the following depths: 5, 15 and 25 m above the seafloor (2 samples at each depth), middle part of the water column (2 samples), and at 75, 25, 15 and 5 m below the sea surface. Figure 4 shows an example of a CTD cast and water sampling station.

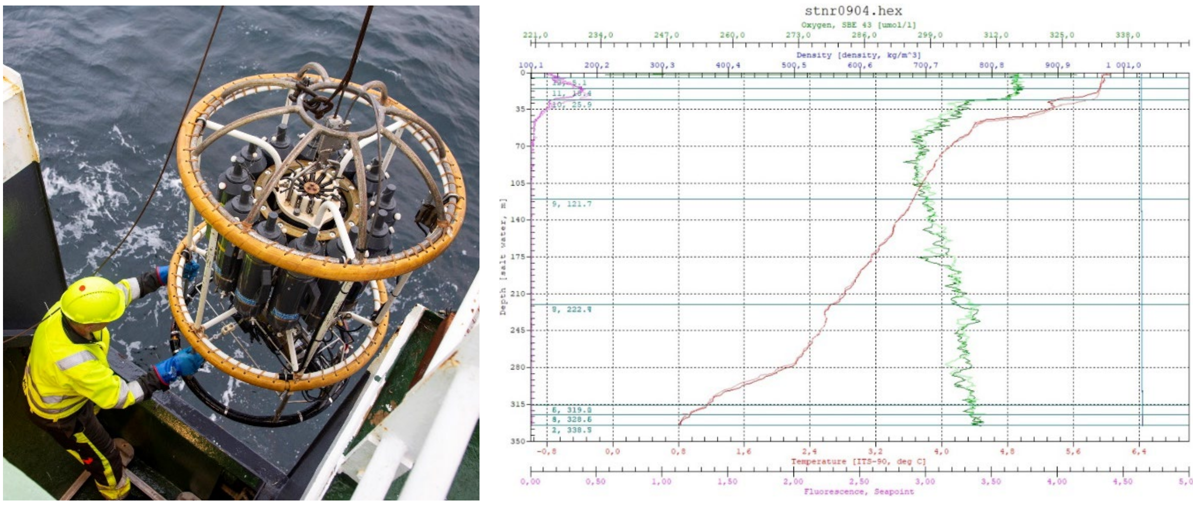


Figure 4: CTD acquisition and profile from station 904 showing the water column properties, and the depths at which water samples were acquired (Photo: M. Pau).

After rinsing to minimise carry-over, seawater was drawn from the Niskin bottles into 120 ml glass vials. 1 ml water was then removed by using a pipette, and replaced by 1 ml of 1 M NaOH solution to stop microbial activity. Any air bubbles present were eliminated carefully. The vials were sealed with rubber septa and aluminium caps prior to being stored dark and refrigerated at 4 °C.

4.4. Single beam echosounder

Single beam echosounders are common among all types of ships. Their primary purpose is to estimate the depth of the seafloor. In a single beam echosounder, the transducer projects a sound pulse through water in a controlled direction and the reflected wave is received. The depth is calculated from the travel time of the sound pulse. R/V Helmer

Hanssen has a keel-mounted Simrad EK 60 single beam echosounder with transducers at three different frequencies, 18 kHz, 38 kHz and 120 kHz. The 18 kHz transducer can be used for depths up to 10 km whereas 38 kHz and 120 kHz can only be used for depths up to 2 km and 500 m, respectively.

Single beam echosounder profiles were acquired at the same time as some of the chirp profiles across the Hopendjupet seep area and pingo field, using a frequency of 38 kHz. Apart from during this profile acquisition, the EK60 was switched off in order to help reduce interference and increase resolution in the EM302 data.

4.5 Box coring

The box corer (dimensions of 50*50*50 cm, volume 0,125 m^3 and weight 1200 kg) was used to obtain sediment samples from the uppermost sediment-water column interface (Figure 5). Once retrieved, two sediment samples were collected using a 5 ml syringe for headspace gas analysis, and a sediment sample was bagged and put into cold storage.

Figure 5: Box core following removal of the water overlying the seabed (Photo: M. Pau).

4.6 Gravity coring

Sediments were sampled with a gravity corer (max core length 6 m, outer diameter 119 mm). The main objective of the coring was to acquire sediments within areas of intense seepage and/or at potential oil slick source points within Hopendjupet and Sentralbanken, in order to characterise sediment properties and analyse their gas/oil content and composition.

11 gravity cores were acquired from 5 different sites. After retrieval of the gravity cores (Figure 6a), the plastic liners were cut into sections of up to 100 cm length. Headspace samples were taken from the top of each core, as well as the base of each core section. The cores were then covered with plastic caps, taped and labelled (Figure 6b). At each site two cores were acquired. One core was sampled on board for headspace gas and porewater, whilst the second was archived. Cores were stored in the cooling room at 4 °C for analyses once back onshore. If available, material in the core-catcher and core-cutter was saved into separate plastic bags and also put into cold storage.

Figure 6: **a**) Gravity core being raised onto deck; **b**) Preparation of retrieved core for cold storage. (Photos: H. Patton and M. Pau.)

4.7 Gas in sediments

Samples for headspace gas analysis were extracted from the top of each gravity core, and the base of each core section. In addition, headspace samples were taken in 5 gravity cores every 10 cm through holes drilled into the core liners. Sediment samples were also collected from the top of each box core (two samples per core). For all sampling we used a 5 ml syringe without the luer tip to collect 5 ml of sediments (Figure 7). The sediment sample was transferred to a 20 ml serum vial and 5 ml of 1 M NaOH solution was added to stop microbial degradation. The vial was immediately closed with a rubber septum and an aluminium crimp seal. The headspace gas samples were then stored at 4 °C for onshore analyses.

Figure 7: Collecting a headspace sample in gravity core base (Photo M. Pau).

4.8 Porewater sampling

Porewater was collected at 10 cm intervals along the sediment cores using 50-mm long Rhizon samplers (Rhizosphere Research Products, Netherlands) fitted to 10 ml, low-pressurised syringes (Figure 8). Part of the extracted porewater was subsampled for dissolved inorganic carbon analysis, and transferred to 1.5 ml vials with screw cap containing 20 µl of saturated $HgCl_2$ solution to stop microbial activity. These samples were stored refrigerated at 4 °C. An additional subsample was drawn into 5 ml plastic vials for sulphate analysis, and stored frozen at -20 °C.

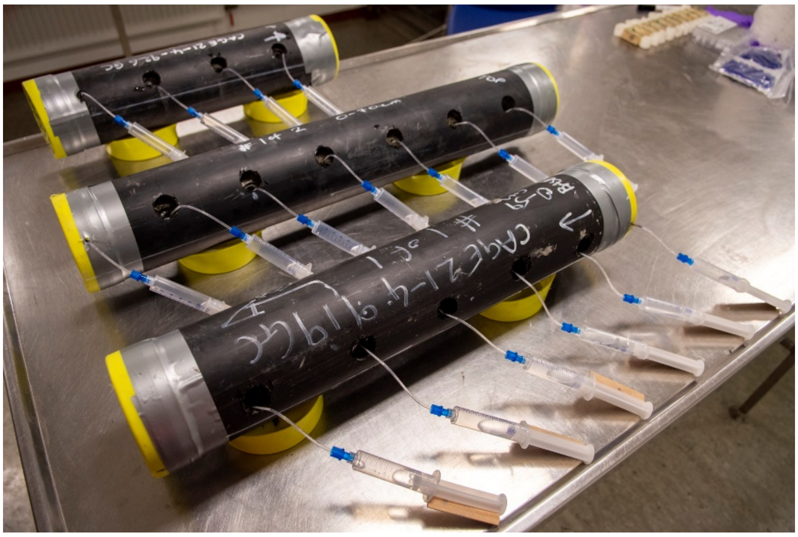


Figure 8: Porewater sampling in gravity cores (Photo: M. Pau).

4.9 Oil slick sampling

The working boat was used to sample sea surface oil slicks (Figure 9). The sampling was done using a ETFE membrane which is optimal for sampling oil sheens from the water surface. The membrane is subjected to an extensive solvent cleaning procedure to make sure it is not contaminated and must therefore be handled with care. It is handled with plastic gloves and attached at the end of a telescopic pole with which it is placed onto the water surface. The ETFE membrane encourages the oil to be drawn from the water surface and coat the surface of the ETFE. It can be repeatedly exposed to the sheen in order to build up the maximum amount of oil coat onto it. When the ETFE membrane has a good visual covering of oil, it is placed into a sample bottle with the help of a wooden spatula.


Figure 9: Oil slick sample acquisition from the working boat (Photo: H. Patton).

5 Study areas and ship tracks

The main study areas for cruise CAGE21-4 were Hopendjupet and Sentralbankrenna in the central Barents Sea. Within Hopendjupet, three key areas were visited: the Hopendjupet seepage area, the Hopendjupet Pingo Field (both visited during CAGE20-2), and the NE Sentralbanken High seepage area (Figure 10).

During the transit from Longyearbyen to Hopendjupet, we crossed two sites where possible sea surface oil slicks had been identified on satellite imagery. We saw no evidence for oil in either, and continued our transit to Hopendjupet without further stops. Here the first site visited was the Hopendjupet seepage area.

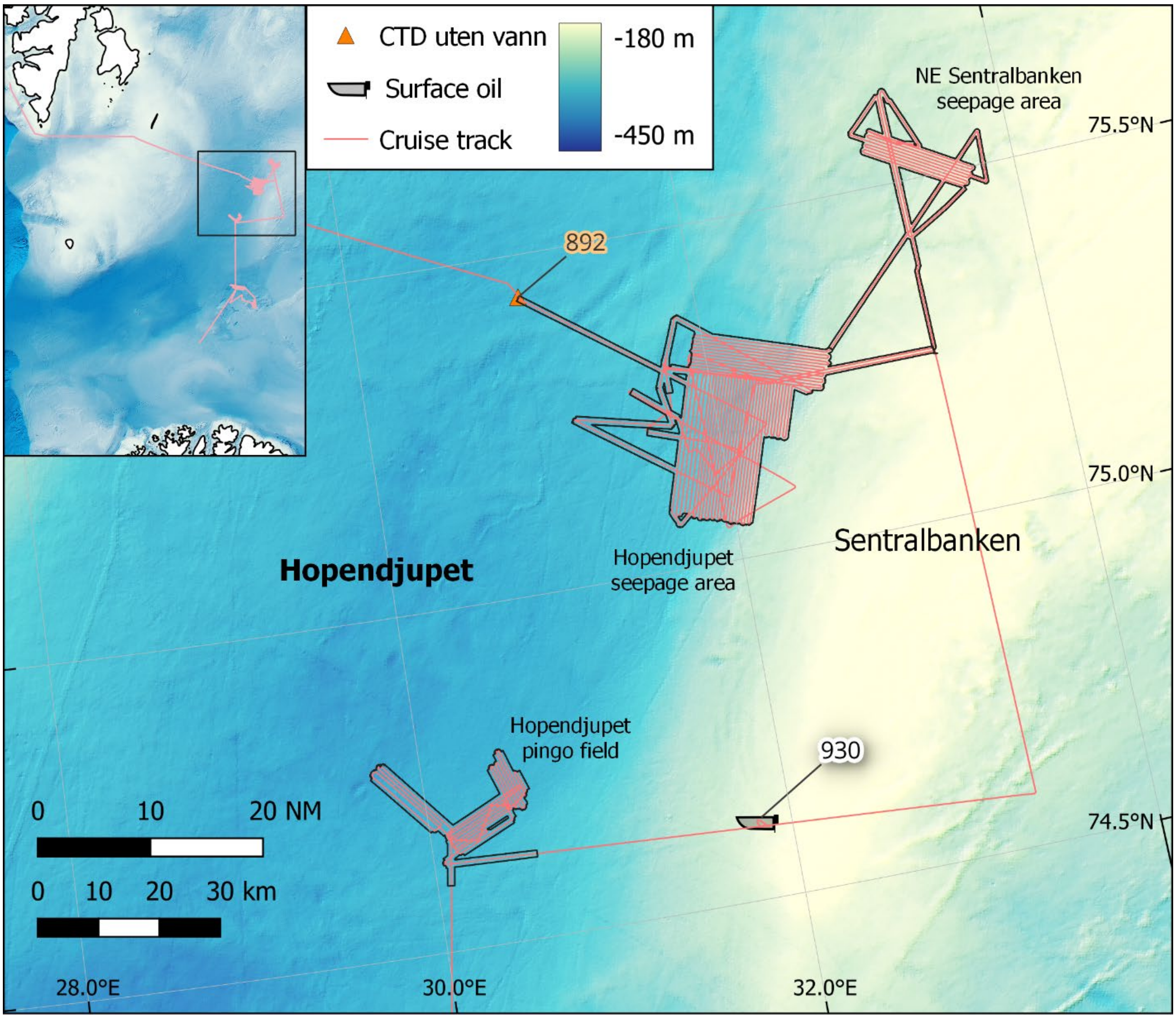


Figure 10. Ship track and areas of detailed surveying and sampling during in Hopendjupet and Sentralbanken during cruise CAGE21-4.

5.1 Hopendjupet seepage area

During cruise CAGE 20-2 the Hopendjupet seepage area was identified as a site with an exceptional density and intensity of seepage. Since, satellite imagery has also revealed possible oil slicks in the area. During this cruise we wished to extend the surveying conducted during the previous cruise, as well as to carry out an extensive sampling campaign targeting the sediments, water column and sea surface. An overview of multibeam/chirp/EK60, coring and sampling locations acquired the in Hopendjupet seepage area is given in Figure 11.

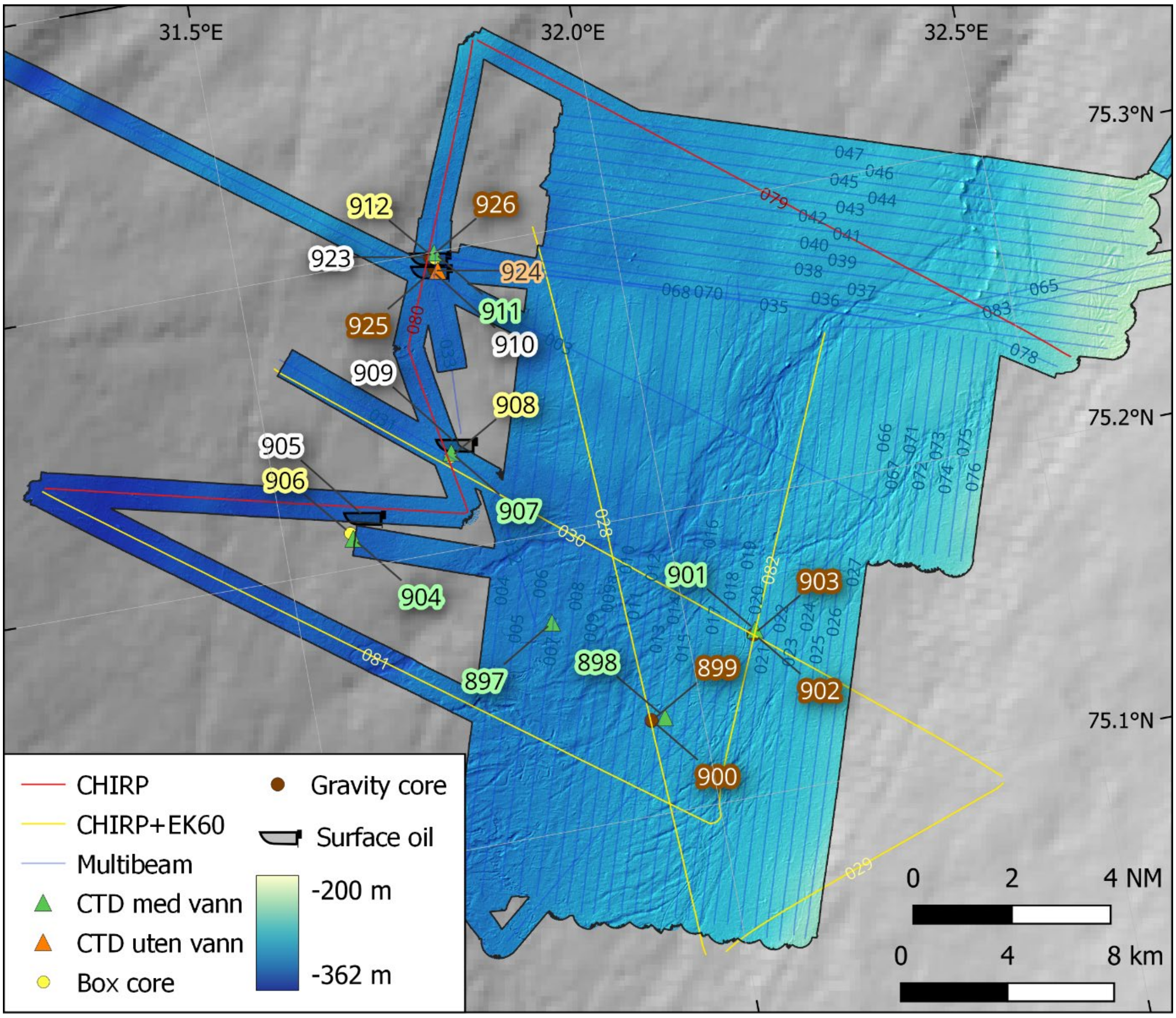


Figure 11. Summary of data acquisition in the Hopendjupet seepage area.

Acquisition of data within this area focused on constraining the extent of flaring in relation to subsurface structures, including the outcropping Storbanken High. EM302 water column data provided improved resolution and coverage for mapping flares compared to the singlebeam EK60 echosounder. Across the Hopendjupet seepage area more than 10,000 individual flares were identified, with many reaching the sea surface (Figures 12, 13).

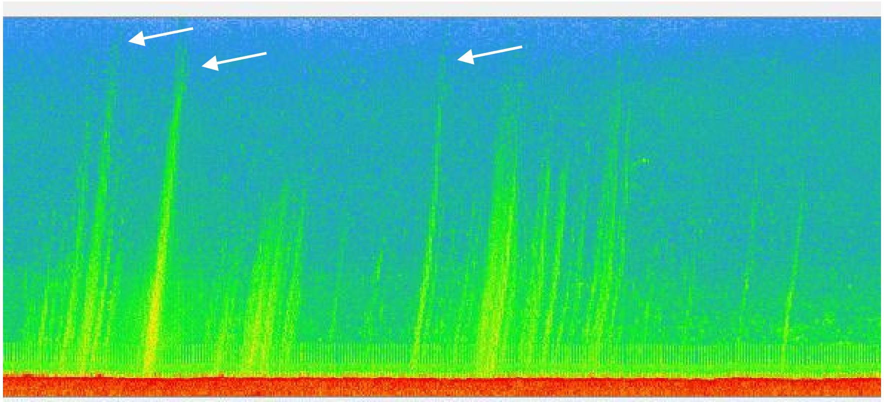


Figure 22: Intense flare activity (green) within the Hopendjupet seep area. Several of the flares appear to reach the sea surface (marked by white arrows).

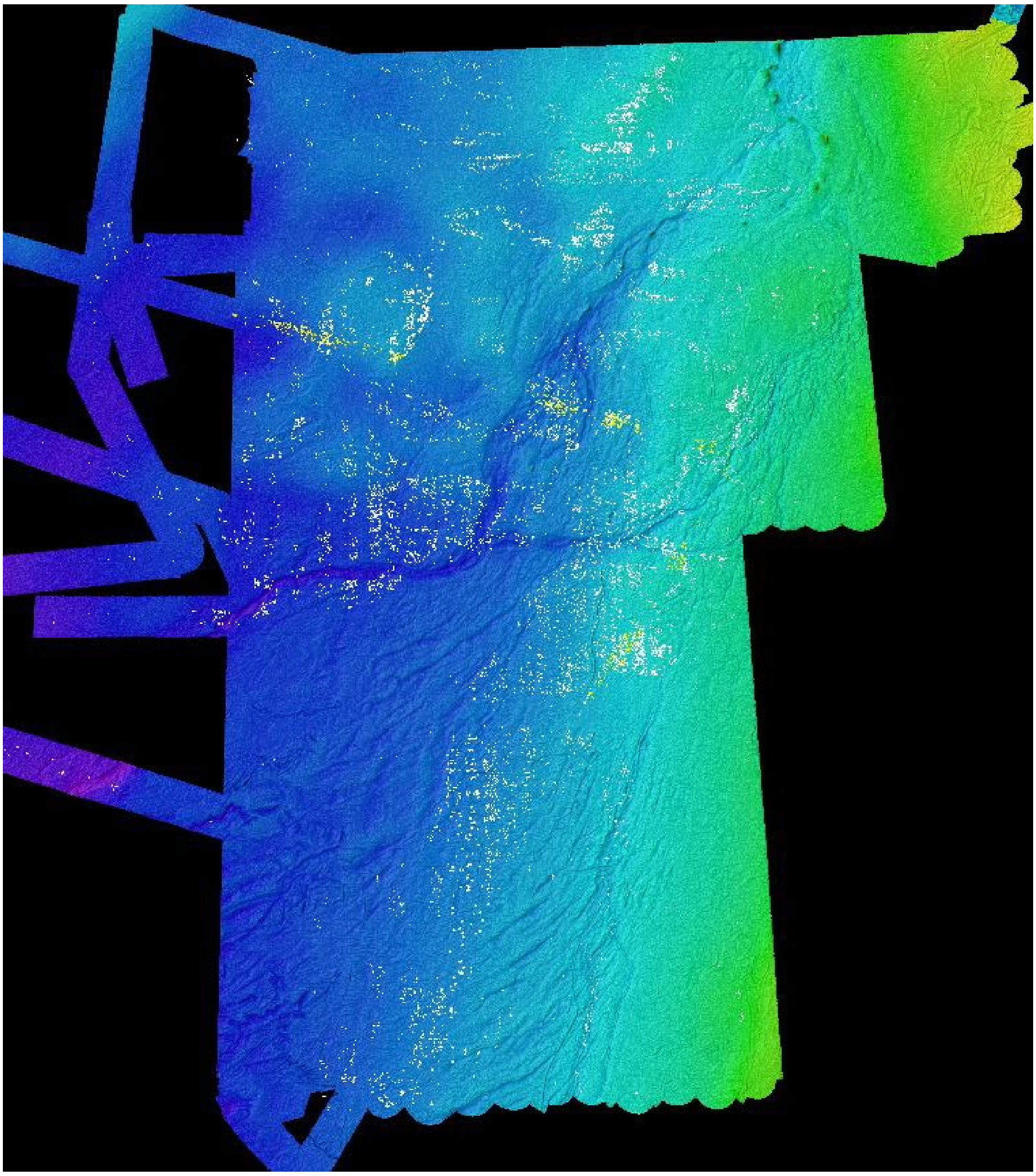


Figure 13: Multibeam swath bathymetry over the Hopendjupet seepage area showing extensive flaring locations (white dots).

Five locations were targeted for a combination of sediment, water and oil sampling. These were primarily sites of intense flaring. At two locations in the south-east of the seepage area, gravity cores (899, 900, 902, 903) and water samples (98, 901) were retrieved. At each location, one gravity core was sampled at 10 cm intervals for porewater and headspace gas, while a second was acquired for archiving (headspace gas samples were collected from the core top and the base of each section, in all cores).

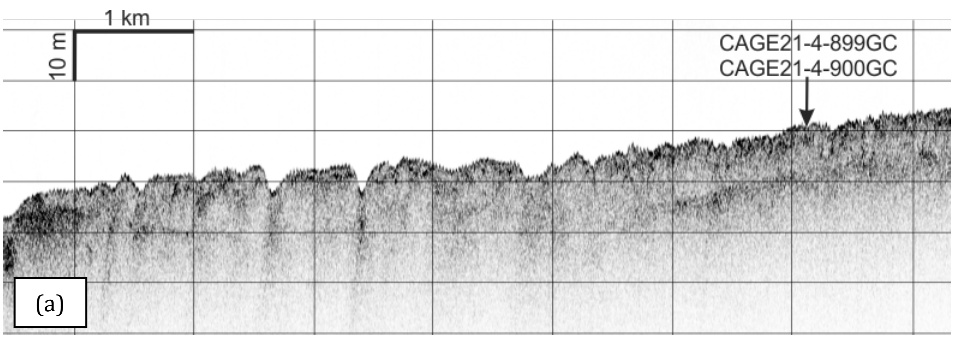
Three more sampling locations were located on the west of the seepage area. At the northern-most location oil slicks were observed on the sea surface (Figure 14), and gravity (925, 926) and box (912) coring, as well as oil (910, 923) and water (911) sampling was carried out. At the central and southern sites, box cores (906, 908), oil (905, 909) and water (904, 907) samples were retrieved. Headspace gas samples were collected from the core top and the base of each section, in all gravity cores, as well two samples from each box core. Further headspace and porewater samples were collected at 10 cm intervals in gravity core 926.

Water sampling was conducted at one further additional control site (897) where no seepage was observed.


Figure 14: Sampling oil slicks in the Hopendjupet seepage area (oil sample 923) (Photo: F. Jakobsen).

A survey comprising 6 chirp profiles (028–030 and 081–082) was acquired across the seepage area with the aim of imaging the shallow subsurface to identify surficial sediment thickness and distribution. These lines were acquired along NPD 2D seismic lines and at the three gravity coring locations (Figure 15).

Single beam echosounder data was collected during the acquisition of CHIRP lines 028–030, 81 and 82.



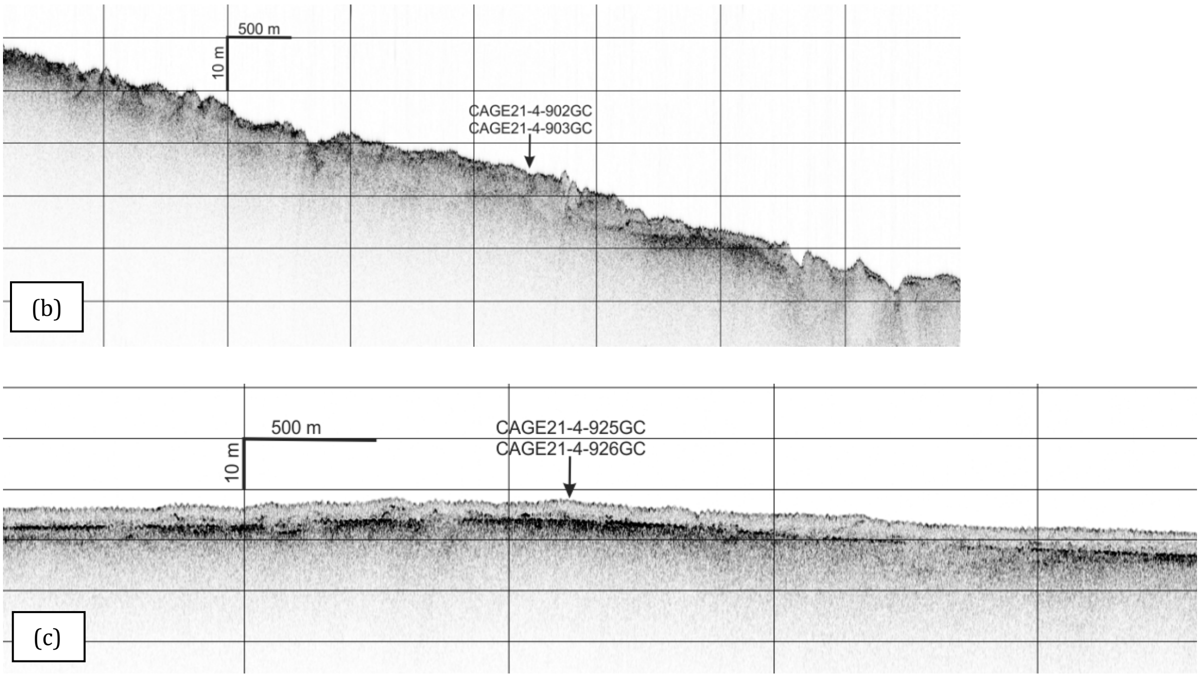


Figure 15: Chirp lines showing location of **a**) cores 899 and 900, **b**) cores 902 and 903, and **c**) cores 925 and 926.

5.3 Hopendjupet Pingo Field

The Hopendjupet Pingo Field was discovered during the CAGE 20-2 cruise based on the appearance of shallow acoustic anomalies on 2D seismic data. During this initial campaign, 10 potential pingos were identified and one was cored, retrieving gas hydrates. During cruise CAGE21-4 we revisited this area to carry out more surveying and sampling, an overview of which is provided in Figure 16.

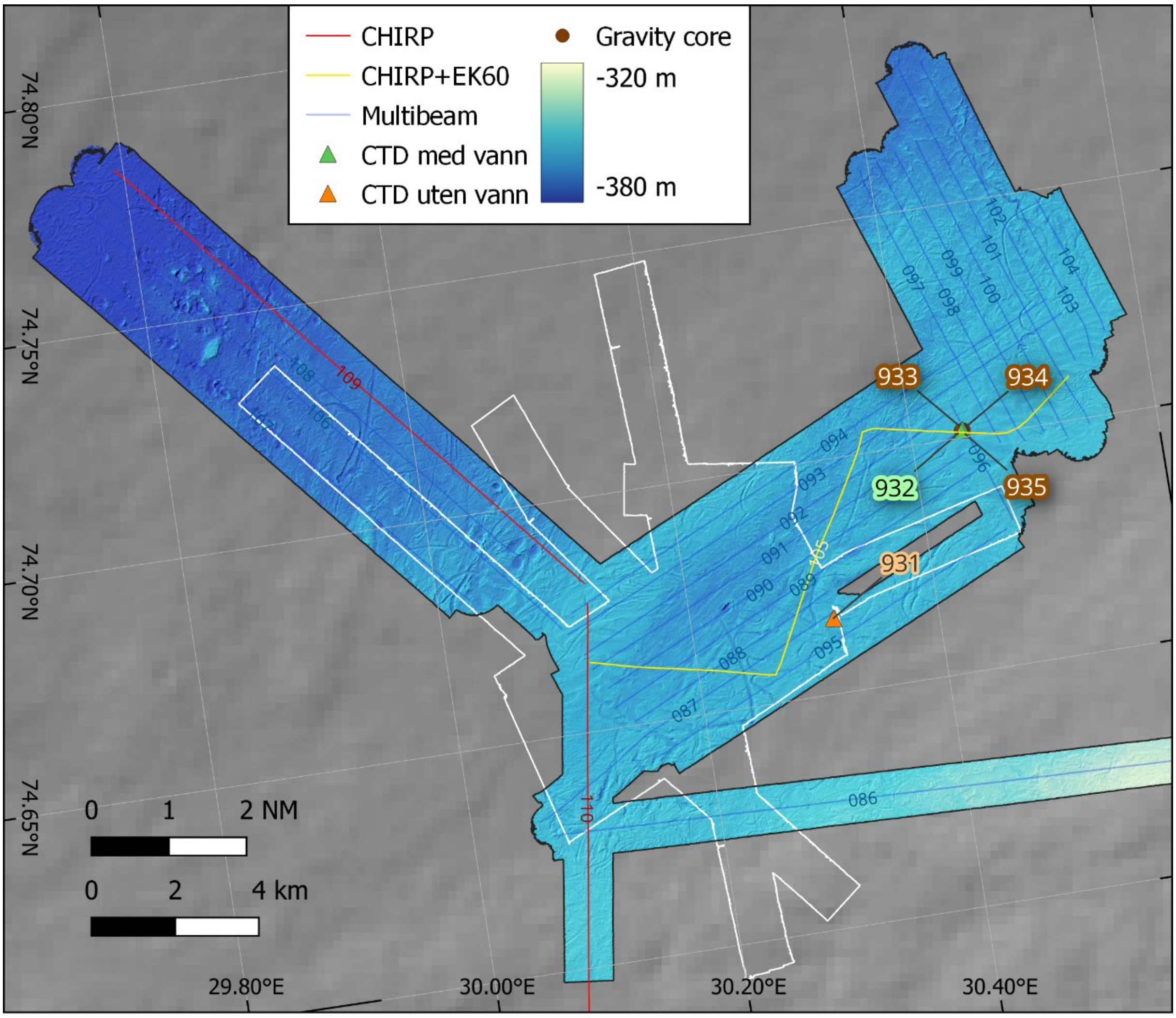


Figure 16: Surveying and sampling overview for the Hopendjupet Pingo Field. The outline of the original survey of CAGE20-2 is marked in white.

A new more extensive multibeam echosounder survey was completed across the Pingo Field. From this, the total number of potential pingos has risen to 20, associated with flaring of various degrees of intensity, often to the sea surface (Figure 17). This survey was extended to the northwest of the pingo area to investigate an area of hummocky terrain. No flaring was seen in this area.

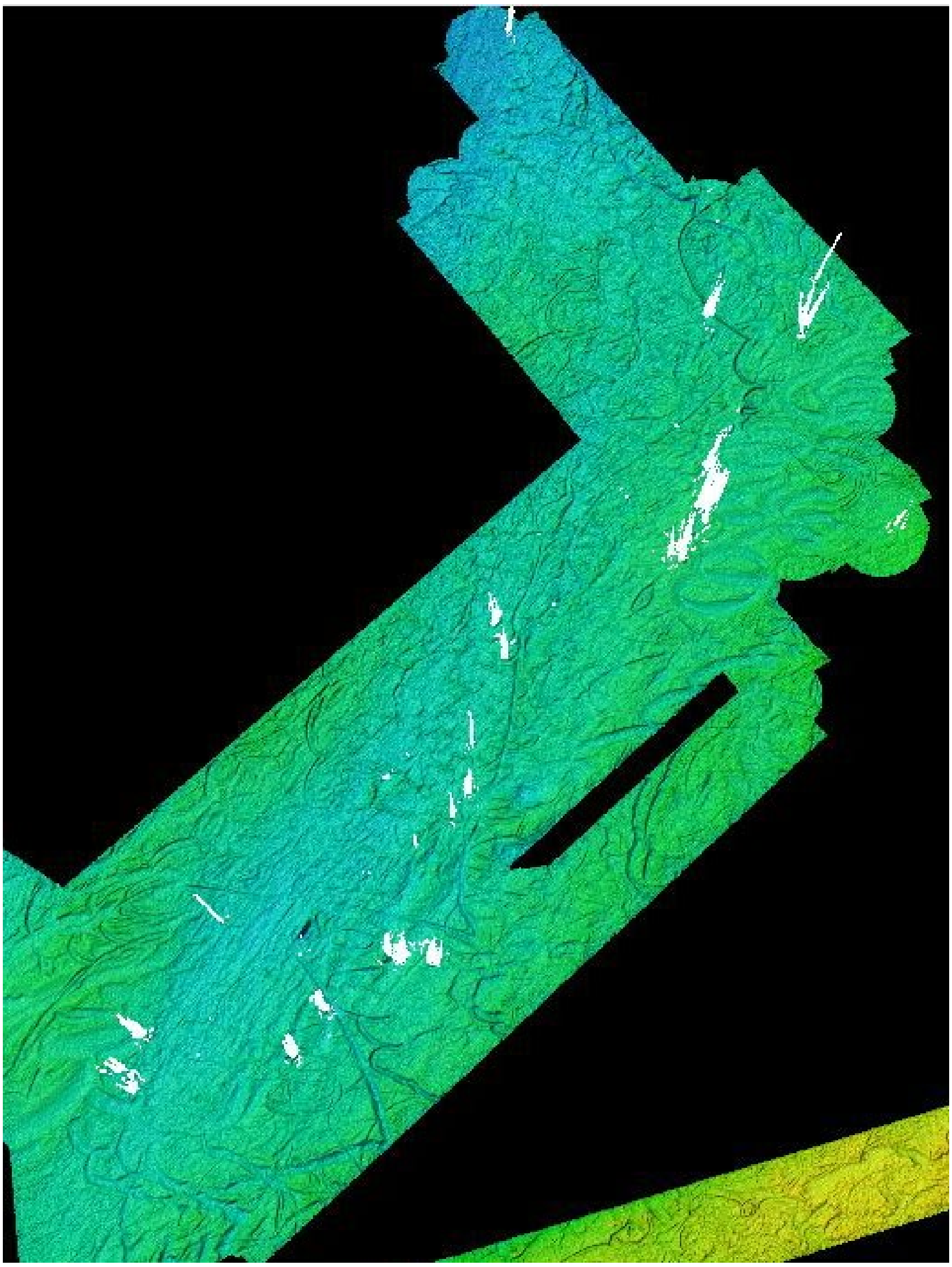


Figure 17: Multibeam swath bathymetry of the Hopendjupet Pingo Field with mapped flares indicated in white.

Two gravity cores (934, 935) were retrieved from a newly identified pingo in the northern part of the Pingo Field associated with high, intense flaring (Figure 18). Headspace samples were taken from the top, base of section 1 and core cutter of core 934 before archiving. Core 935 was sampled for headspace and porewater every 10 cm, before cool storing for further analysis onshore. Water samples (932) were also collected at this location.

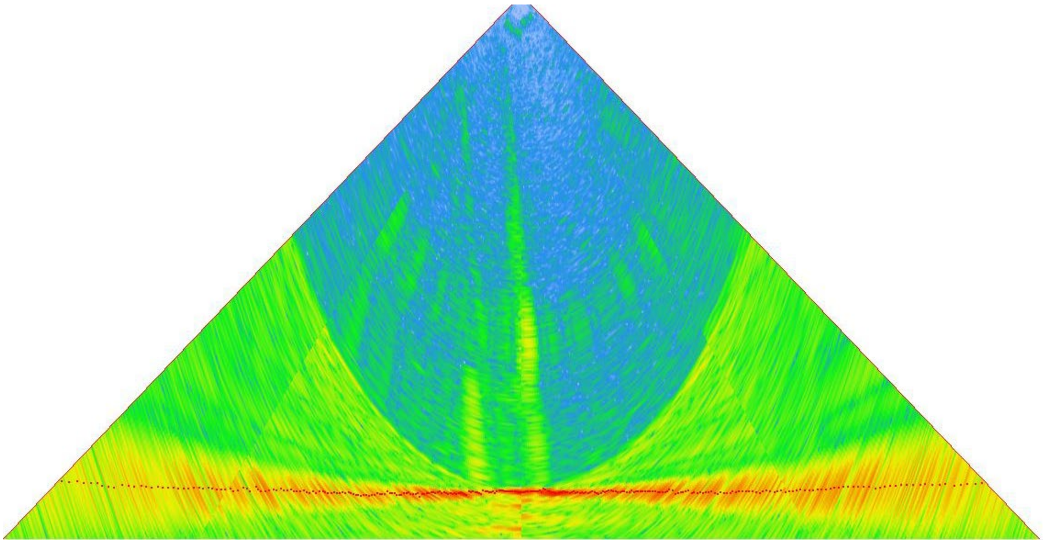


Figure 18: Intense flaring, reaching to the sea surface associated with the pingo where gravity cores 934 and 935 were retreived.

Two chirp profiles (105, 110) were collected. With line 105 crossing the pingo where gravity cores 934 and 935 were retrieved (Figure 19). Single beam echosounder data was collected during the acquisition of chirp line 105.

Oil was sampled from a possible slick on the transit from Hopendjupet seepage area to the pingo field (930).

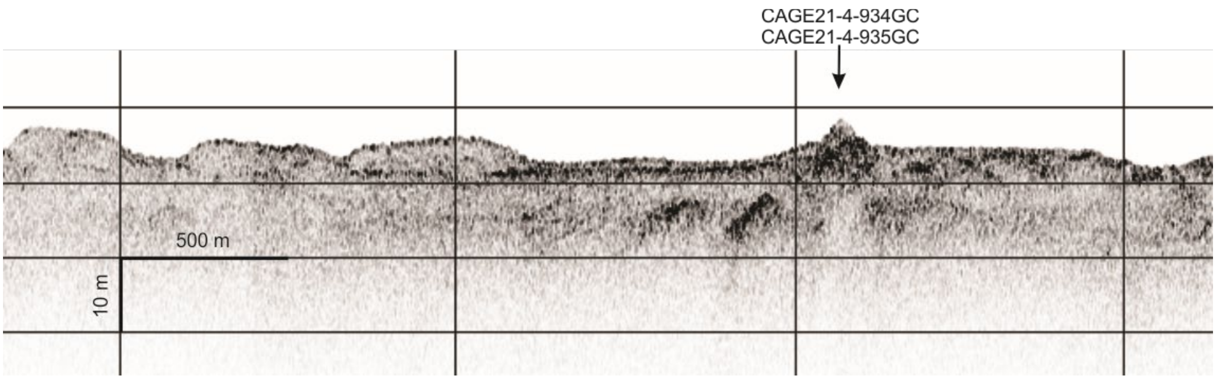


Figure 19: Chirp line 105 showing location of cores 934 and 935 in the Hopendjupet Pingo Field.

5.4 NE Sentralbanken High seepage area

A multibeam survey was acquired from Hopendjupet towards the NE part of Sentralbanken High where a persistent oil slick had been observed in satellite images, and 2D seismic indicated an anticline structure similar to the Hopendjupet seepage area. In NE Sentralbanken High, seepage surveying with multibeam echosounder, and sampling sediments and the water column was carried out (Figure 20). Poor visibility prevented the collection of oil samples.

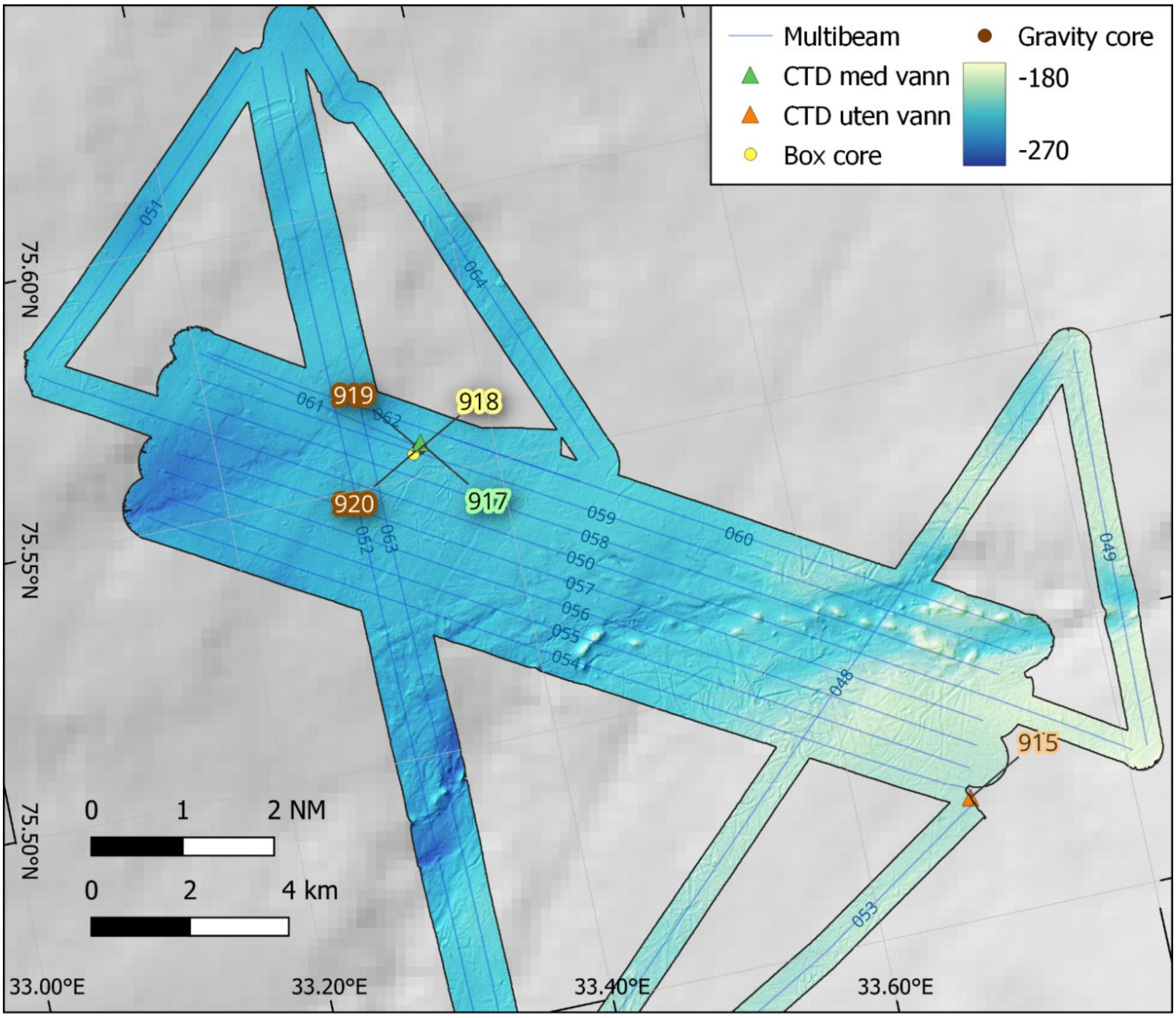


Figure 20: Surveying and sampling overview of the NE Sentralbanken High.

The initial multibeam echosounder survey lines (lines 048–052) followed NPD 2D seismic lines, allowing delineation of the broad area of seepage. Thereafter, a dense grid of lines (054–060) were acquired around the oil slick (identified from satellite imagery) and area of most intense flaring. This revealed localised, intense flaring (Figure 21).

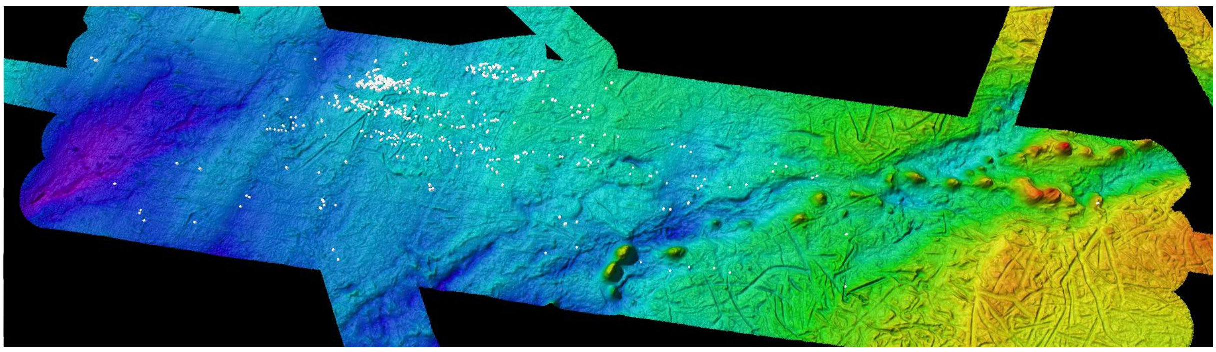


Figure 21: Multibeam swath bathymetry of the NE Sentralbanken High seepage area with mapped flares indicated in white.

Two gravity cores (919 and 920) and a box core (918) were acquired, along with water samples (917), at a site of intense flaring. Oil (Figure 22) was observed in the core cutter and catcher of 919 (the oil was sampled for onshore analysis by NPD), and oily rocks were found in the cutter of core 920.

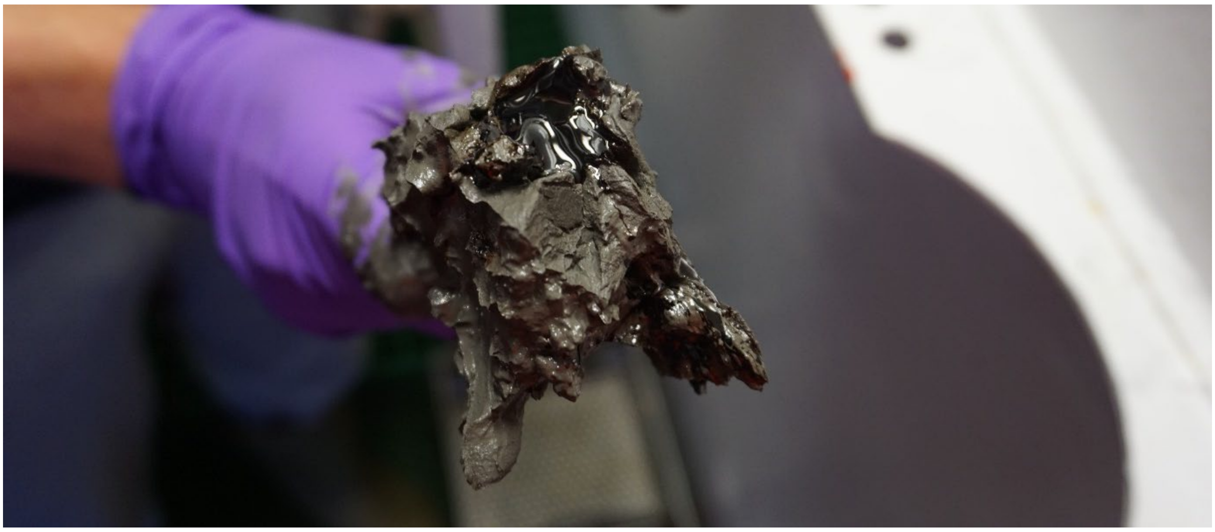


Figure 22: Oil was found in the core cutter and catcher of gravity core 919 (Photo: H. Patton).

One sample for headspace gas was collected from the core top and the base of each section in both gravity cores, and two samples were collected from the box core. Further headspace and porewater samples were collected at 10 cm intervals from gravity core 919.

Oil patches were observed on the sea surface from R/V Helmer Hanssen (Figure 23) at the location of gravity cores 919 and 920, but low visibility due to fog prevented sampling of these.

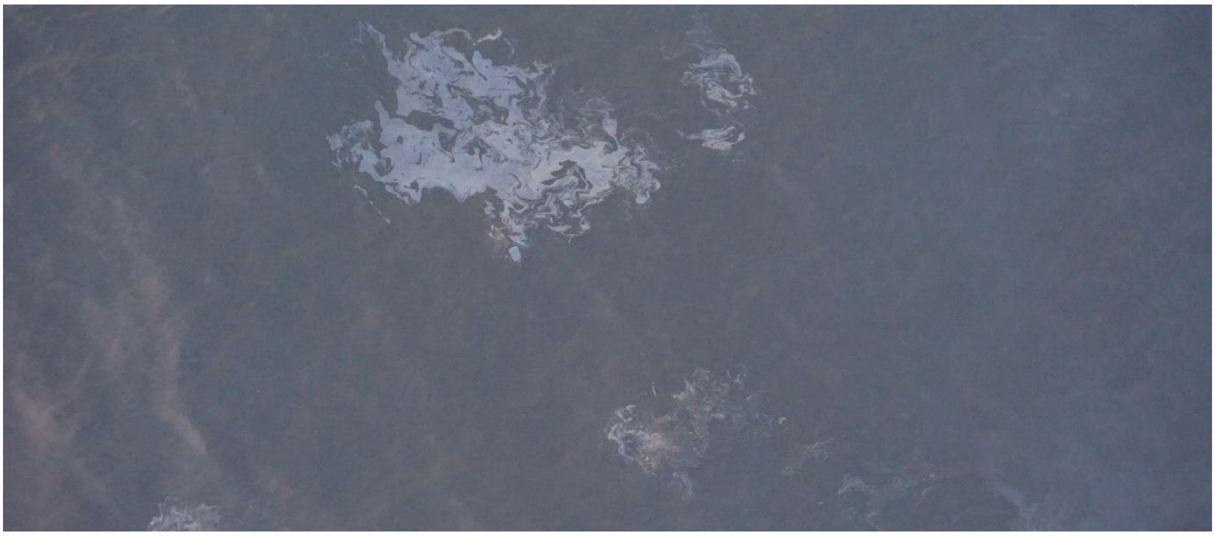


Figure 23: Oil slicks observed on the sea surface in NE Sentralbanken High, close to the location of gravity cores 919 and 920 (Photo: H. Patton).

5.5 Sentralbankrenna

Multibeam swath bathymetry and chirp datasets were acquired in the outer parts of Sentralbankrenna (Figure 24), with the aim of mapping landforms associated with the final deglaciation of this trough. This surveying targeted an area of hummocky terrain and a potential channel on the southern flank of the trough.

Further surveying in Sentralbankrenna was not possible due to a problem in the ship's engine, which required us to start our return to Tromsø several hours earlier than planned.

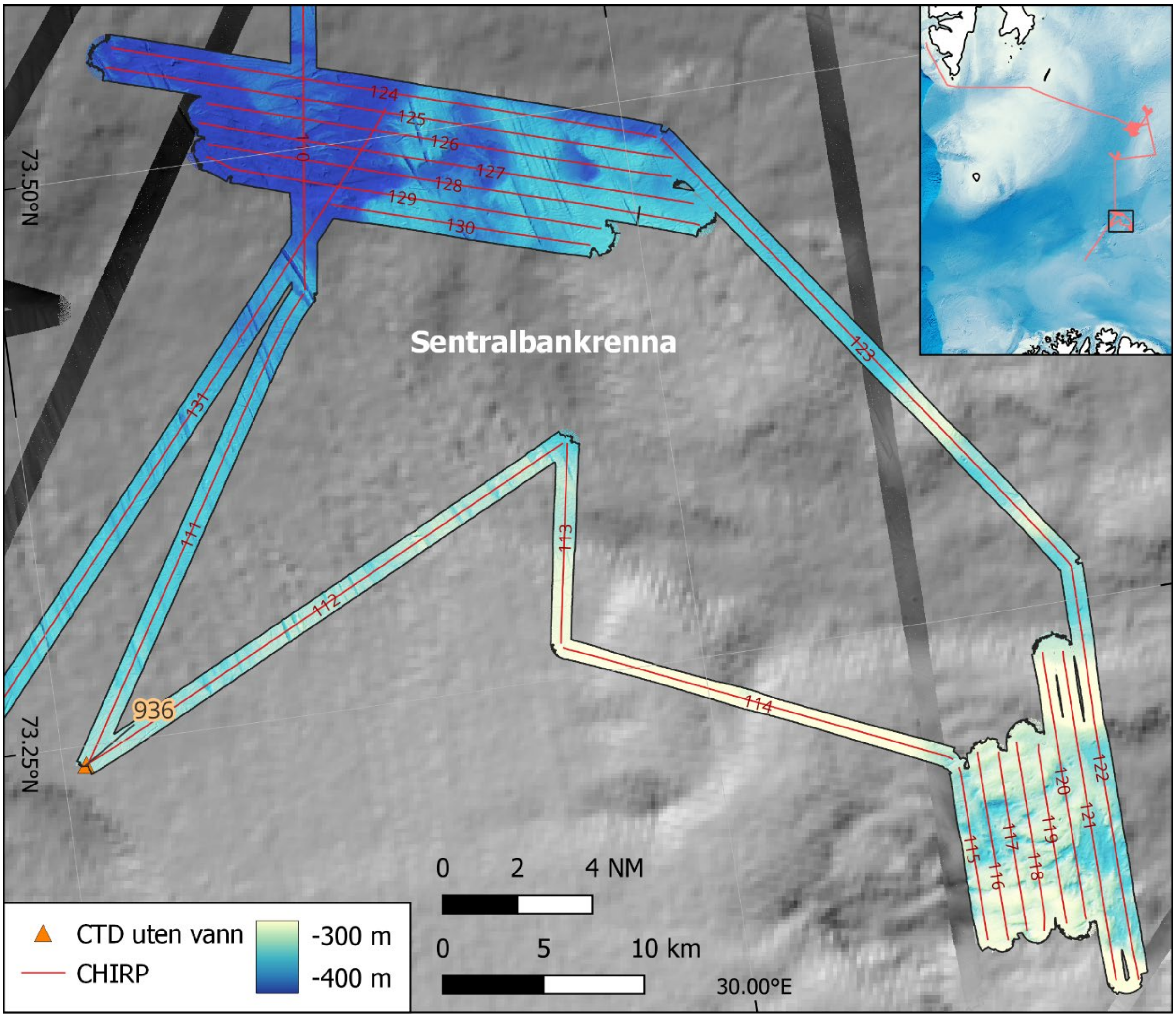


Figure 24: Surveying overview of Sentralbankrenna.

6 References

Andreassen, K., Hubbard, A., Winsborrow, M., Patton, H., Vadakkepuliyambatta, S., Plaza-Faverola, A., Gudlaugsson, E., Serov, P., Deryabin, A., Mattingsdal, R., Mienert, J., Bünz, S., 2017. Massive blow-out craters formed by hydrate-controlled methane expulsion from the Arctic seafloor. Science 356, 948–953. https://doi.org/10.1126/science.aal4500

7 Logs

7.1 Station log

Location	Activity	Station Id	Date (UTC)	Time (UTC)	Latitude (N) Longitude (E)	Bottles fired	Water Depth [m]	Recovery (cm)	Notes
Hopen	CTD	890	03.08.2021	02:59:57	76 20.367 16 21.782				
	CTD	892	04.08.2021	02:44:13	75 26.269 30 59.516				
Hopendjupet	CTD	897	05.08.2021	21:37	75 10.165 31 48.351	11			Bottle 12 did not fire
Hopendjupet	CTD	898	05.08.2021	22:54:51	75 07.889 31 56.038	12			
Hopendjupet	Gravity Core	899	06.08.2021	00:19:00	75 07.89 31 55.953		315,56	0,5	Top and base core headspace samples. Headspace and porewater samples every 10 cm
Hopendjupet	Gravity Core	900	06.08.2021	01:06:14	75 07.91 31 55.96		314,89	1,46	Archive core + core catcher

Hopendjupet	CTD	901	06.08.2021	01:56:52	75 09.245 32.05.182	12			
Hopendjupet	Gravity Core	902	06.08.2021	02:35:00	75 09.235 32 05.147		301,39	108	Top and base core headspace samples. Headspace and porewater samples every 10 cm (no samples at 70 cm).
Hopendjupet	Gravity Core	903	06.08.2021	03:27:49	75 09.223 32 05.085		301,75	120	Archive core
Hopendjupet	CTD	904	06.08.2021	05:23:49	75 12.537 31 35.330	12	341,84		
Hopendjupet	Oil Sample	905	06.08.2021	06:47:23	75 12.997 31 36.63				2 samples taken at southernmost site
Hopendjupet	Box Core	906	06.08.2021	07:22:08	75 12.719 31 35.294		340,6		2 headspace samples
Hopendjupet	CTD	907	06.08.2021	09:21:39	75 13.808 31 44.189	11			
Hopendjupet	Box Core	908	06.08.2021	09:47:39	75 13.867 31 44.144				2 headspace samples

Hopendjupet	Oil Sample	909	06.08.2021	10:35:12	75 14.118 31 44.835				no samples taken at middle site
Hopendjupet	Oil Sample	910	06.08.2021	11:19:56	75 17.648 31 45.354				
Hopendjupet	CTD	911	06.08.2021	13:00:04	75 17.828 31 45.694	11			Bottle 6 did not fire
Hopendjupet	Box Core	912	06.08.2021	13:39:17	75 17.872 31 45.775		330,88		2 headspace samples and one bagged sediment sample
Sentralbanken	CTD	917	07.08.2021	23:13:00	75 33.313 33 20.647	11			Bottle 6 did not fire
Sentralbanken	Box Core	918	07.08.2021	23:38:00	75 33.313 33 20.647				
Sentralbanken	Gravity Core	919	08.08.2021	00:59:00	75 33.327 33 20.699			0,59	Oil in the core cutter and catcher. Head space and porewater samples every 10 cm. Headspace at core top. Headspace and porewater at core base
Sentralbanken	Gravity Core	920	08.08.2021	01:39:00	75 33.327 33 20.699			0,88	Oily rocks in the catcher

Hopendjupet	Oil Sample	923	08.08.2021	12:15:38	75 17.914 31 45.453				2 cloth samples and 4 water samples in northern Hopendjupet slick
Hopendjupet	CTD	924	08.08.2021	13.38.58	75 17.579 31 45.690				
Hopendjupet	Gravity Core	925	08.08.2021	14:15:04	75 17.662 31 45.578		331,17	240	Top of core and base of each section headspace samples.
Hopendjupet	Gravity Core	926	08.08.2021	14:53:03	75 17.911 31 45.411		327,99	115	Top of core and base of each section headspace samples. Headspace and porewater samples every 10 cm
Hopendjupet	Oil Sample	930	09.08.2021	12:30:50	74 36.714 31 48.666				1 cloth sample taken in possible oil slick on transit to pingo area. Smooth sea surface patches but no clear oil
Hopendjupet	CTD	931	09.08.2021	16:56:00	74 40.024 30 18.967	0	362		Calibration multibeam
Hopendjupet	CTD	932	09.08.2021	22.55.03	74 42.083 30 26.686	8			CTD bottle 1 was sampled twice in glass bottle 1 and 2. CTD bottle 2 was sample by glass 3. CTD bottle 3 not sampled. CTD bottle 4-6 sampled with glass 4-6 respectively. CTD bottle 7 not sampled. CTD bottle 8 and 9 sampled with glass bottle 7 and

									8 respectively.
Hopendjupet	Gravity Core	933	09.08.2021	23.32.17	74 42.099 30 26.593		360	0	Empty barrel
Hopendjupet	Gravity Core	934	09.08.2021	23.57.43	74 42.097 30 26.513		362	128	sampled head space gas from top, base section 1 and core cutter.
Hopendjupet	Gravity Core	935	10.08.2021	00.42.54	74 42.097 30 26.455		362	66	sampled head space gas from top, base section 1 and core cutter, then every 10 cm (except at 60 cm). Sampled porewater every 10 cm (10-60cm).
Sentralbankrenna	CTD	936	10.08.2021	18:58:00	73 14.429 29 02.277				Bottles fired only to test bottle repair

7.2 Line log

Location	Line ID	Date	Time (UTC) START	Lat. [N] Long. [E] START	Time (UTC) STOP	Lat. [N] Long. [E] STOP	Pulse mode	Shot Rate (HZ)	Ship Speed (kn)
Hopen	CAGE21-4-HH-001-MB	03.08	03:11	76°20.332' 16°22.086'	15:22	76°19.624' 23°33.649'			8
Transit Hopen - Hopendjupet	CAGE21-4-HH-002-MB	03.08	15:22	76°19.624' 23°33.649'	02:41	75°26.374' 30°59.228'			11
Hopendjupet	CAGE21-4-HH-003-MB	04.08	03:06	75°26.180' 30°59.078'	07:35	75°09.996' 31°41.379'			8
Hopendjupet	CAGE21-4-HH-004-MB	04.08	07:51	75°05.495' 31°39.380'	09:05	75°16.902' 31°53.589'			10
Hopendjupet	CAGE21-4-HH-005-MB	04.08	09:11	75°16.709' 31°54.771'	10:24	75°04.919' 31°40.222'			10
Hopendjupet	CAGE21-4-HH-006-MB	04.08	10:29	75°05.177' 31°42.052'	11:44	75°16.811' 31°56.580'			10
Hopendjupet	CAGE21-4-HH-007-MB	04.08	11:50	75°16.481' 31°57.870'	13:04	75°04.884' 31°43.231'			10
Hopendjupet	CAGE21-4-HH-008-MB	04.08	13:09	75°04.849' 31°44.633'	14:26	75°16.475' 31°59.186'			10
Hopendjupet	CAGE21-4-HH-009-MB	04.08	14:30	75°16.359' 32°00.610'	15:40	75°04.701' 31°46.027'			10

Hopendjupet	CAGE21-4-HH-009a-MB	04.08	15:44	75°04.633' 31°46.938'	16:58	75°16.356' 32°01.695'			10
Hopendjupet	CAGE21-4-HH-010-MB	04.08	17:01	75°16.278' 32°02.609'	18:15	75°04.430' 31°47.867'			10
Hopendjupet	CAGE21-4-HH-011-MB	04.08	18:21	75°04.341' 31°48.000'	19:30	75°16.186' 32°09.735'			10
Hopendjupet	CAGE21-4-HH-012-MB	04.08	19:35	75°16.006' 32°04.658'	20:51	75°04.137' 31°50.026'			10
Hopendjupet	CAGE21-4-HH-013-MB	04.08	20:54	75°04.306' 31°51.008'	22:07	75°16.240' 32°06.739'			10
Hopendjupet	CAGE21-4-HH-014-MB	04.08	22:10	75°15.939' 32°06.702'	23:23	75°04.188' 31°51.969'			10
Hopendjupet	CAGE21-4-HH-015-MB	04.08	23:27	75°04.077' 31°53.022'	00:39	75°15.778' 32°07.627'			10
Hopendjupet	CAGE21-4-HH-016-MB	05.08	00:45	75°16.343' 32°09.124'	02:03	75°03.818' 31°54.667'			10
Hopendjupet	CAGE21-4-HH-017-MB	05.08	02:03	75°03.887' 31°54.933'	03:17	75°15.691' 32°09.736'			10
Hopendjupet	CAGE21-4-HH-018-MB	05.08	03:20	75°15.560' 32°10.708'	04:38	75°04.077' 31°57.275'			10
Hopendjupet	CAGE21-4-HH-019-MB	05.08	04:38	75°04.077' 31°57.275'	05:47	75°15.514' 32°11.747'			10
Hopendjupet	CAGE21-4-HH-020-MB	05.08	05:50	75°15.433' 32°12.645'	07:05	75°03.564' 31°57.777'			10

Hopendjupet	CAGE21-4-HH-021-MB	05.08	07:09	75°03.629' 31°57.923'	08:19	75°15.300' 32°13.682'			10
Hopendjupet	CAGE21-4-HH-022-MB	05.08	08:23	75°15.235' 32°14.652'	09:37	75°03.533' 31°59.913'			10
Hopendjupet	CAGE21-4-HH-023-MB	05.08	09:42	75°03.581' 32°01.166'	10:52	75°15.151' 32°15.708'			10
Hopendjupet	CAGE21-4-HH-024-MB	05.08	10:55	75°15.044' 32°16.734'	12:08	75°03.364' 32°01.896'			10
Hopendjupet	CAGE21-4-HH-025-MB	05.08	12:13	75°03.363' 32°02.998'	13:28	75°14.998' 32°17.739'			10
Hopendjupet	CAGE21-4-HH-026-MB	05.08	13:32	75°14.867' 32°18.755'	14:44	75°03.154' 32°03.832'			10
Hopendjupet	CAGE21-4-HH-027-MB	05.08	14:47	75°03.116' 32°04.762'	16:03	75°14.823' 32°19.734'			10
Hopendjupet	CAGE21-4-HH-028-CHIRP	05.08	16:51	75°18.436' 31°54.219'	18:24	75°03.006' 31°56.897'	2.0-6.0kHz : 40ms		10
Hopendjupet	CAGE21-4-HH-029-CHIRP	05.08	18:24	75°03.006' 31°56.897'	19:06	75°05.416' 32°22.213'	1.5-9kHz		10
Hopendjupet	CAGE21-4-HH-030-CHIRP	05.08	19:06	75°05.416' 32°22.213'	20:46	75°16.212' 31°31.797'	1.5-9kHz		10
Hopendjupet	CAGE21-4-HH-031-MB	05.08	20:49	75°16.339' 31°32.589'	21:17	75°13.230' 31°47.043'			10
Hopendjupet	CAGE21-4-HH-032-MB	05.08	21:18	75°13.072' 31°47.183'	21:36	75°10.265' 31°48.347'			10

Hopendjupet	CAGE21-4-HH-033-MB	06.08	11:04	75°15.633' 31°45.527'	11:21	75°17.662' 31°45.374'			9
Hopendjupet	CAGE21-4-HH-034-MB	06.08	12:15	75°17.775' 31°45.238'	13:02	75°17.850' 31°45.791'			4
Hopendjupet	CAGE21-4-HH-035-MB	06.08	14:21	75°17.483' 31°50.640'	15:35	75°13.506' 32°37.177'			10

8 Appendix

8.1 R/V Helmer Hanssen stasjonslapper (File: CAGE_21-4_Toktlogger.zip)

8.2 Flare count along multibeam echosounder lines (File: flare_countfile.txt)