CAGE - Centre for Arctic Gas Hydrate Environment and Climate Report Series, Volume 10 (2022)

To be cited as: Argentino, C. et al. (2022). CAGE22-1 Cruise Report: Environmental geochemistry and seafloor characterization of Repparfjord, Kvalsund, Northern Norway. *CAGE - Centre for Arctic Gas Hydrate Environment and Climate Report Series, Volume 10*. https://doi.org/10.7557/cage.6753
Additional info at: https://septentrio.uit.no/index.php/cage/database

ISSN: 2703-9625
Publisher: Septentrio Academic Publishing Tromsø Norway

R/V Helmer Hanssen
03-04-2022 to 06-04-2022
Tromsø – Tromsø

CAGE-22-1 Cruise Report

Environmental geochemistry and seafloor characterization of Repparfjord, Kvalsund, Northern Norway

Chief scientist: Claudio Argentino
Capt. R/V: Hans R. Hansen

DOI:

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Key words: Repparfjord, mine tailing, trace metal, seafloor imagery, geochemistry

Contents

Scientific Objectives

Repparfjord was used for submarine mine tailing disposal in the 1970s, receiving ~ 200-500 thousands of tons of copper-rich materials (Pedersen et al., 2018). The tailings were discharged through a pipe over a confined area in the inner part of the fjord without capping. Previous studies have shown that fjord morphology limited the lateral dispersion of tailing particles (Pedersen et al., 2018; Sternal et al., 2017), but also indicated high amounts of Cu, Cr, Ni exceeding the national sediment contamination thresholds (Mun et al., 2020). Chromium and Ni are predominantly bonded into inert silicate minerals and do not represent an environmental threat. Mineral characterization of historical tailings as well as thermodynamical modelling suggest that Cu is predominantly hosted in crystal lattices of sulfide minerals (Mun et al., 2020, 2021) and therefore Cu has potential for being released into the water column and interact with benthic communities (Mun et al., 2020; Pedersen et al., 2018). However, pore water data from Repparfjord are currently lacking, thus preventing the detection and quantification of in-situ leaching rates and fluxes out of the sediment.

The scientific objectives of CAGE22-1 expedition were to 1) explore the seafloor at the historical disposal area using a towcam-multicorer system. The visual seafloor observations allow us to characterize the composition and distribution of benthic communities and for targeted sediment samplings. 2) Collect sediment cores in and out of the disposal area and extract pore fluids for trace metals and gas analyses. Sediment cores are sliced onboard and will be used for geochemical (metals, organic carbon, total nitrogen) and micropaleontological analyses onshore. Pore fluids data will be used to detect and quantify any potential metal leaching from the tailings and associated fluxes and classify the pore water quality according to national guidelines (Statens forurensningstilsyn, 2007). A 7-step sequential extraction of tailing material and natural sediments will provide the information about metal content in the following fractions: 1. Water-soluble; 2. Exchangeable; 3. Fe-Mn-oxy-hydroxide-bonded; 4. Fe-oxide-bonded; 5. Sulfide-bonded; 6. Organic matter bonded and 7. Silicate-bonded. Foraminiferal investigations will indicate whether the presence of the historical tailing deposits influenced or have been influencing seafloor community density and distribution. 3) Obtain new CTD and multibeam data to constrain fjord oceanographic conditions and morphology.

Participants

(Alphabetical order)

	Shift		
Argentino Claudio		CS; Geochemistry	CAGE-UiT
Bernd Selina	1	Student	IG-UiT
Galimberti Giulia	2	Student	University Milan Bicocca
González González Josu	2	Student	IG-UiT
Hoff Marie	1	Student	University of Tübingen
Holm Truls		Engineer	IG-UiT
Huljek Laura	2	PhD student	University of Zagreb
Jensen Stormer Alexander		Engineer	IG-UiT
Lapikov Pavel	1	Student	IG-UiT
Lomotey Reginald	1	Student	IG-UiT
Mun Yulia		Geochemistry	IG-UiT
Nawrot Wiktor	2	Student	IG-UiT
Olsen Bjørn Runar		Engineer	IG-UiT
Panieri Giuliana		Micropaleontology	CAGE-UiT
Sendula Eszter	1	Geochemistry	IG-UiT
Strmic Palinkas Sabina		Geochemistry	IG-UiT

Shift1: 8:00-14:00; 20:00-02:00; Shift2: 14:00-20:00; 02:00-08:00
Breakfast: 07:30-08:30; Lunch 13:30-14:30; Supper 19:30-20:30

Study Area

Repparfjord

Repparfjord is located in the Troms and Finnmark County (northern Norway), approximately 200 km northeastern from Tromsø (Figure 1). The fjord is oriented NW-SE, it is 13 km long and up to 4 km wide, covering an area of 37 km^2 (Figure 2). The fjord is connected to the open ocean through two openings: Kvalsundet to the west and Sammelsundet to the nord.

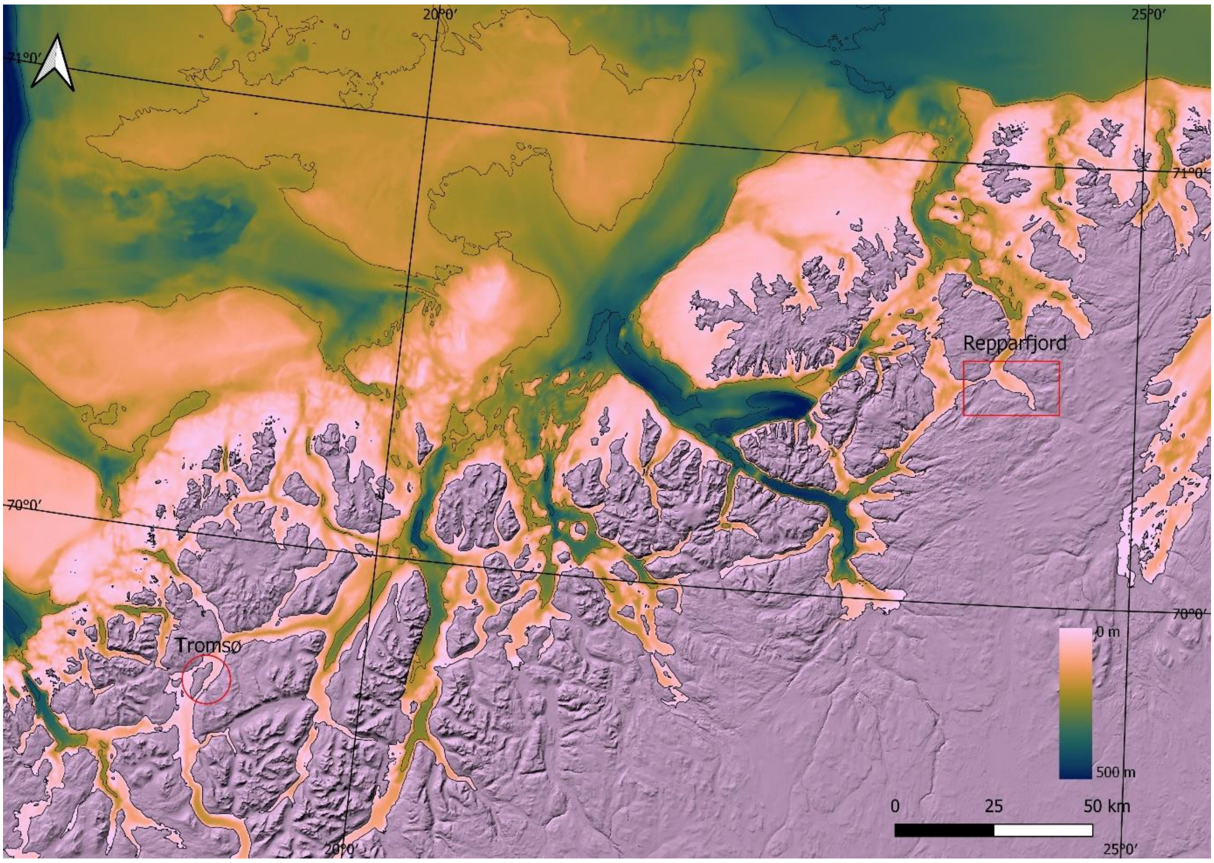


Figure 1. Overview map indicating the location of Repparfjord 70°30'31.1"N 24°09'02.5"E, northern Norway. Bathymetry data from Gebco. The color scale used for Figs. 1 and 2 is accessible for people with color-vision deficiencies (Crameri et al., 2020).

Repparfjord can be subdivided into two main basins, hereafter defined outer fjord and inner fjord. The outer fjord has maximum depth of 130 m, and becomes shallower moving to the the SE sector (50 m). The inner fjord is smaller and has maximum water depth of ~ 65 m. The two areas are separated by a by an ENE-WSW orientated sill structure acting as a natural barrier to the dispersion of tailing particles, which are mostly confined to the semi-enclosed inner fjord basin (Sternal et al., 2017). Water circulation in the inner fjord is characterized by a strong bottom current running inwards at the onset of high tide, and a weaker, outwards bound bottom current at low tide, overlain by fresh water from the Repparfjordelva river. Maximum current velocity measured in summer time is 51 cm/s (Akvaplan-niva, 2011). Average bottom water temperatures in the fjord measured in April 2019 ranged from 3.2 °C to 4.0 °C with small differences between the inner and out sector, with salinity of 34 psu (hi.no).

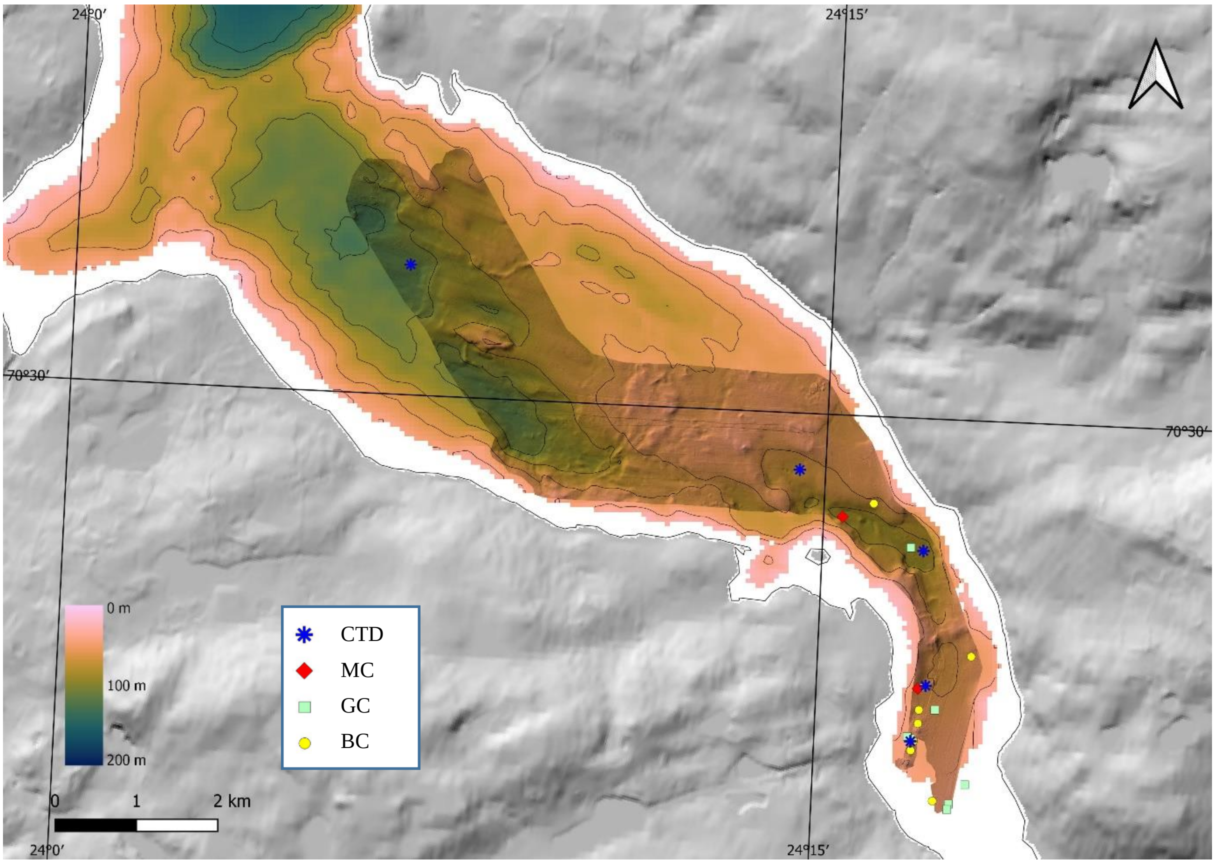


Figure 2. Distribution of sampling locations on multibeam data (shaded relief) acquired during the present cruise. Background bathymetry from MARENO project 50m grid(mareano.no). MC=multicore; GC=gravity core; BC= box core.

Equipment and sampling methods

Gravity Corer

We employed a gravity corer equipped with a 6m-long steel barrel and a 1.3 t head weight. Before each coring operation, we inserted a plastic liner with an inner diameter of 10 cm into the steel barrel and attached the core catcher and cutter. Back on deck, the plastic liner was pulled out of the barrel and cut into 1-meter sections. Sections were sampled for pore waters and finally taken to the cool room (4 ˚C). We collected 3 gravity cores.

Box corer

The box corer is a steel sampling box used to collect a large volume of sediment (50cm X 50cm X 75cm) from the seafloor with negligible disturbance. The box corer lands on the seafloor and sinks into the sediment, the slicer cuts through the sediment and seals the bottom of the steel box. Once the sediment is recovered onboard, we collect the surface water with a hose and then manually push multicore plastic liners (10 cm diameter) into the sediment for sub-samplings. We collected 8 box cores.

Multicorer and TowCam system

The multicore sampling system is a KC Denmark DK8000 multicore acquiring 6 sample cores simultaneously. The multicorer has been converted in a TowCam/Multicorer. The frame has been used to place the tow cam, the lights, lasers and the batteries. The multicore recovers six

parallel 70 cm long tubes with a diameter of 10 cm (Figure 3) from the same spot at the seafloor. The core tubes, predrilled for pore water analyses every cm and headspace gas, are loaded with open upper and lower ends. When the multi corer lands on the seafloor, the tubes are pushed into the soft sediment by lead weights and closed on both ends. Up to 60 cm of sediment and the immediate overlying water can be sampled. This allows the analysis of undisturbed faunal samples within their undisturbed environment. Once on board, the core tubes filled with water end sediment. The liners were carefully taken out of the sampling device, the ends are sealed, and the cores moved, in an upright position, in the wet laboratory. Once in the lab, in racket to keep them vertical, the sampling of pore water, micropaleontology and sediment geochemistry start. To sample the cores, one extruder has been used.
In the present cruise, we were able to use real-time imaging capability to precisely guide the sampling locations of the Multicorer samples. We collected two multicores.
The TowCam system was set up with one DSPL Multi SeaCam HD video camera with 1080p/30 and two DSPL Selite LED lights with 9000 lumen each, in addition we used two ISA500 Altimeters from Impact Subsea, two DSPL batteries supplying 24V / 60Ah each. Communication between top side and subsea is through 1 single mode fiber from the MacArtney pressure housing located on the subsea platform and the deck unit through 550m winch cable on the MacArtney winch (aka yellow winch). The video was recorded on a Blackmagic Design HyperDeck Studio HD Mini recorder with two SD cards with a capacity of 256GB each.

Figure 3 TowCam-Multicorer system ready for deployment.

Multibeam echosounder

R.V Helmer Hanssen is equipped with a Kongsberg Simrad EM302 multibeam echosounder. The EM302 has 432/432 beams which can be adjusted based on need to cover a set range in either m (across the seafloor) or degrees (angle of the outermost beam towards the seafloor). In this cruise, the beams were set to record equidistantly (no weighting to the middle or end of the swath), at a coverage angle of 60°/60°.

CTD

The CTD (Conductivity, Temperature, Depth) measures the physical properties of seawater, including the velocity of sound through the water column. The R.V. Helmer Hanssen uses a

SBE 911plus CTD for acquiring vertical profiles of water column properties. In this expedition we used the CTD to adjust the sound-velocity profile of the water column.

Sub-bottom profiler (Chirp)

The chirp aboard the R.V. Helmer Hanssen has been substituted before the cruise and now consists of a INNOMAR deep-36. The sub-bottom profiler generates super shallow subsurface reflection profiles enabling us to estimate the thickness of the sediment cover, to investigate the sedimentary structures beneath the seafloor and the presence of shallow gas accumulations.

The hull mounted 4x4 transducer array operated on a frequency of 4kHz with a ping-rate of 1 per second. (1Hz) with up to 9kW power output. In this cruise we used the chirp to identify mine tailing deposits from background marine sediment.

Pore water and gas extraction

Pore water samples were extracted using pre-wetted Rhizon filters (0.15 µm pore size) and collected into sterile 10 ml syringes (Figure 4). A total of ~350 pore water samples were collected and split into 3 aliquots: 1) sub-samples for dissolved inorganic carbon analysis (1.5 ml) were transferred to micro tubes containing 10 µl of $HgCl_2$ to stop microbial activity and stored at 4˚C. 2) Sub-samples for trace metals (5 ml) were transferred to Eppendorf tubes, acidified with10 µl of ultrapure nitric acid and stored at 4˚C; 3) the remaining volumes were sampled for anions (> 1 ml), transferred to 5 ml Eppendorf tubes and kept frozen at -20C.

Figure 4 Pore water extraction from a push core collected from a box core. Rhizons are inserted every cm and water is collected into 10 ml syringes. Photo credits: Selina Bernd.

Bulk sediment samples were collected using 5 ml syringes without the luer tip. Sediment was transferred into a 20 mL serum vial containing 5 mL of 1M NaOH. The vial was immediately closed with a rubber septum, sealed with an aluminum crimp cap and shaken. The samples were stored at 4˚C for onshore headspace analyses. A total of 4 sediment samples for headspace gas analysis were collected.

Micropaleontology

The living benthic foraminifera will be identified in order to have a good knowledge of the dominant species in the Repparfjord. The faunal density, diversity and ecology will be investigated and linked with the metal concentration in the sediment. The faunal microhabitats of the dominant species will be determined aiming at identifying the influence of pore water chemistry and area characteristics on species.

1 Sampling of living foraminifera

At each multicore and box core station (Table XYZ), one sediment core from the multicorer or from the box corer was sliced every centimeter from 0 to 5 cm depth. The samples collected were stored in containers in a 2 g.L-1 solution of Rose Bengal in 96% ethanol, in order to be preserved and to stain the living organisms (Figure 5). The samples have to stay at least 14 days in the solution before the analysis. All samples will be washed and sieved, the >63 and >125 µm size fraction will be analysed. Isotopic measurement will be done on both living (stained) and dead benthic foraminifera, as well as on planktonic foraminifera.

Figure 5 Sampling of living foraminifera in plastic jars and fixation in Rose Bengal. Photo credits: Selina Bernd.

2 Sampling of fossil foraminifera:

At each multicore and box core station (Table XYZ), one sediment core from the multicorer or from the box corer was sliced every centimeter from 0 to the bottom of the core (Figure 6). The samples collected were stored in plastic bag and place in the fridge to facilitate the freeze drying once in the lab.

Figure 6 Slicing of a sediment core using spatulas. Samples are then transferred into zip-lock bags and stored in the freezer. Photo credits: Selina Bernd

Ship-board analyses

Eh-pH analysis

Physicochemical measurements were performed using a multimeter HACH HQ440D Laboratory Dual Input. RedOx (Eh, redox potential), pH, and conductivity (electrical conductivity) meter electrodes are connected to the multimeter. Eh and pH were measured in pore water samples. The multimeter had an automatic temperature compensation (ATC) at 25°C. The pH was calibrated before the measurements. The multimeter was left for 10 minutes to stabilize in the environment of each sample. To prevent contamination, the electrodes were cleaned with distilled water and dried with paper before every use.

Spectrophotometric analyses

Selected pore water samples were measure for Cu and Zn contents using a Macherey-Nagel NANOCOLOR UV/VIS spectrophotometer. The standard cuvette tests for the determination of Cu and Zn within the range 0.01-10.0 mg/L and 0.02-3.0 mg/L, respectively, were used.

Seafloor observations

(Giulia Galimberti, Josu Gonzalez Gonzalez, Giuliana Panieri)

Two video imaging survey were conducted in the inner and outher Repparfjord using the CAGE TowCam system. A total of 6h18’ have been recorded. The surveys were meant to observe the seafloor in the Repparfjord, in the inner fjord where the tailing was disposed, and in the outer fjord that should represent a pristine environment. The observations focused on the characteristics of the seafloor: type of sediments, presence of ice rafted debris, type of organisms.

The inner fjord is muddy, dark brown/greyish colour, colonized by dense polychaetes with rare anemones. The polychaetes are 4-5 cm high. Subsequent sampling revealed that the polychaetes are ca 10 cm in length and have a diameter of ca 2 mm. Trails and sea stars have been also observed. Occasionally, at the seafloor there are elongated patches whitish in colour, that ranges from few centimetres to several meters.

The sill area (Figure 7) is very different from the inner and outer fjord, and is characterized by subangular ice rafted debris densely colonized by red-pink algae and other sessile organisms, mostly anemones. Anemones appear to be also at the seafloor, isolated and in patches. Other organisms observed during the video surveys are sponges, brittle stars, Solaster, bivalves, gastropods, fish, sea urchins. We observed trails and clusters of either fish holes or bioturbations.

The outer fjord is characterized by a muddy seafloor with numerous fish holes and some biological trails. We observed rare anemones and isolated ice rafted debris colonized by sessile organisms (anemones). Rare Solaster and other brittle stars have also been observed. From the video it looks that in this are there are more and more diverse fish than in the other surveyed areas. Ray, flat fish, and other red fish have been observed during the dive. In this area there were fewer polychaetes.

Below are reported few images characteristics of the different areas in the Repparfjord.

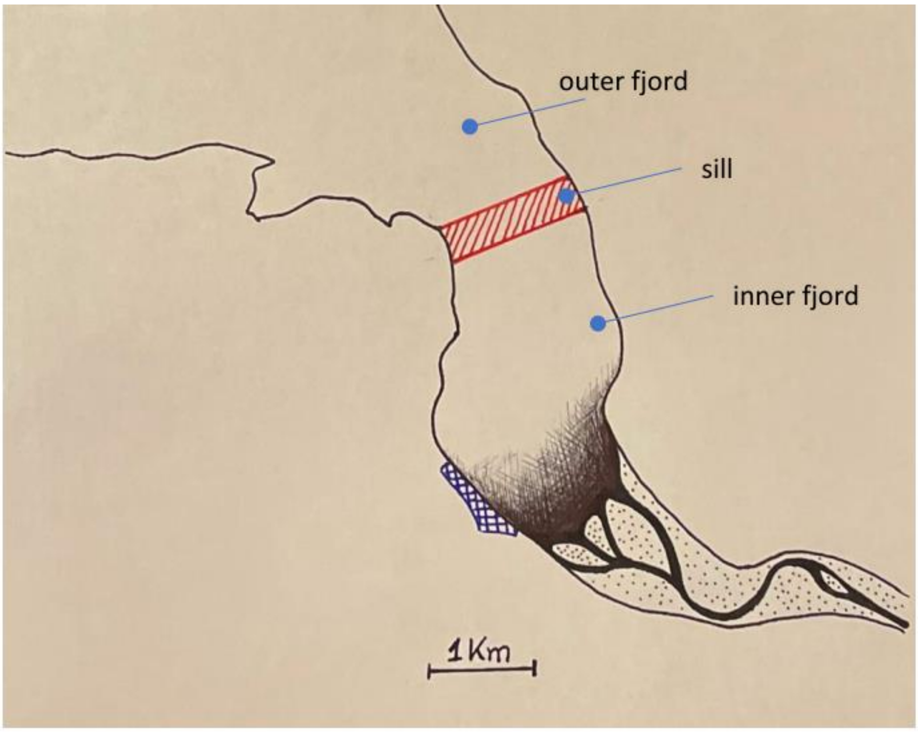


Figure 7. Skecth of Repparfjord. J.Gonzalez

Plate 1: Main seafloor characteristics in the tailing area, inner fjord.

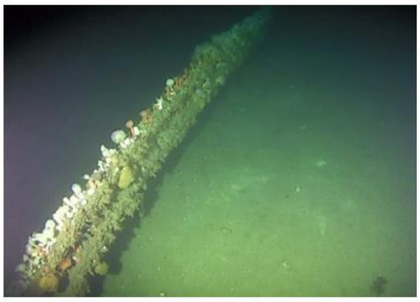
The tailing area in the inner fjord is characterized by dense polychaetes and rare anemones.

Tailing area in the inner fjord with polychaetes and trails.

Extensive white/light grey sediment patches and trails. Polychaetes are abundant.

Tailing area with trails and fish holes.

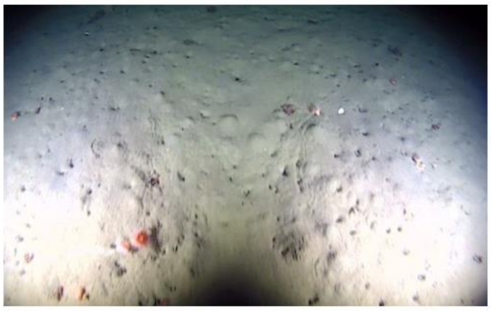
Fish holes and one Solaster seastar and one anemone.



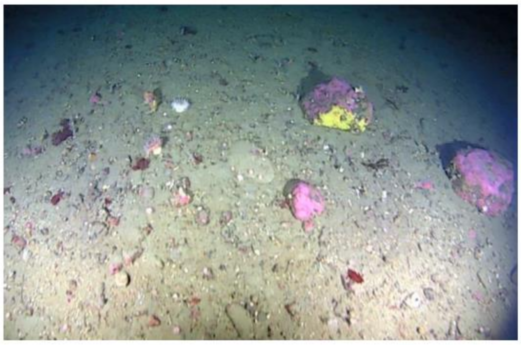
Pipeline colonized by anemones and other sessile organisms.

Plate 2: Main seafloor characteristics in the sill area

Seafloor with some pebbles, anemones, sea stars and red algae and sponges.



Bioturbated seafloor with fish holes, anemones and trails.



Subangular pebbles, IRD, colonized by pink unarticulated coralline algae and yellow sponge. Different species of anemones are also present.

Gravelly seafloor. The IRD, with different dimension, are colonized by epifauna and anemones.

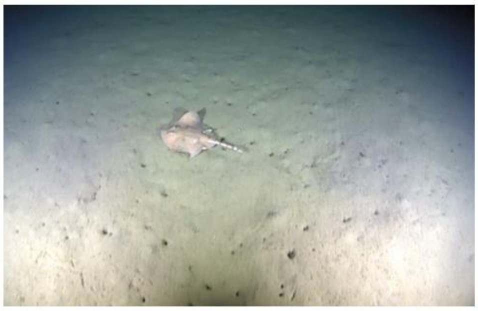
Radicipes gracilis (octocorallia)

IRD and pebbles with sessile fauna.

Plate 3: Main seafloor characteristics of the outer fiord


Flat fish in an area with tube worm.


Group of fishes


Fish from Raja family


Anemones, algae, and fish holes.

Cruise Narrative

All dates and times are local time (UTC+2 hrs).

2nd April
All participants on board by 23:00. The scientific personnel took a tour of the ship and had a briefing in the auditorium. Left the Helmer Hanssen ankerplasse at 23:26 and began transit to Repparfjord.

Day 1 3rd April
After breakfast performed safety briefing. Introduction to study area and environmental geochemistry lecture in the auditorium. Started testing the new chirp. Entered Repparfjord at around 13:00. Conducted a CTD in the outer fjord. Started chirp line + multibeam along the fjord followed by TowCam dive in the historical tailing area and the future disposal area (outer fjord). After dinner, multicoring in a tube worm-dominated seafloor area north of the main tailing area followed by box coring. Throughout the night we explored the fjord with chirp+multibeam. Air T = -3 to -1 C; wind speed (avg) = 5 m/s; humidity (avg) = 65 %.

Day 2 4th April

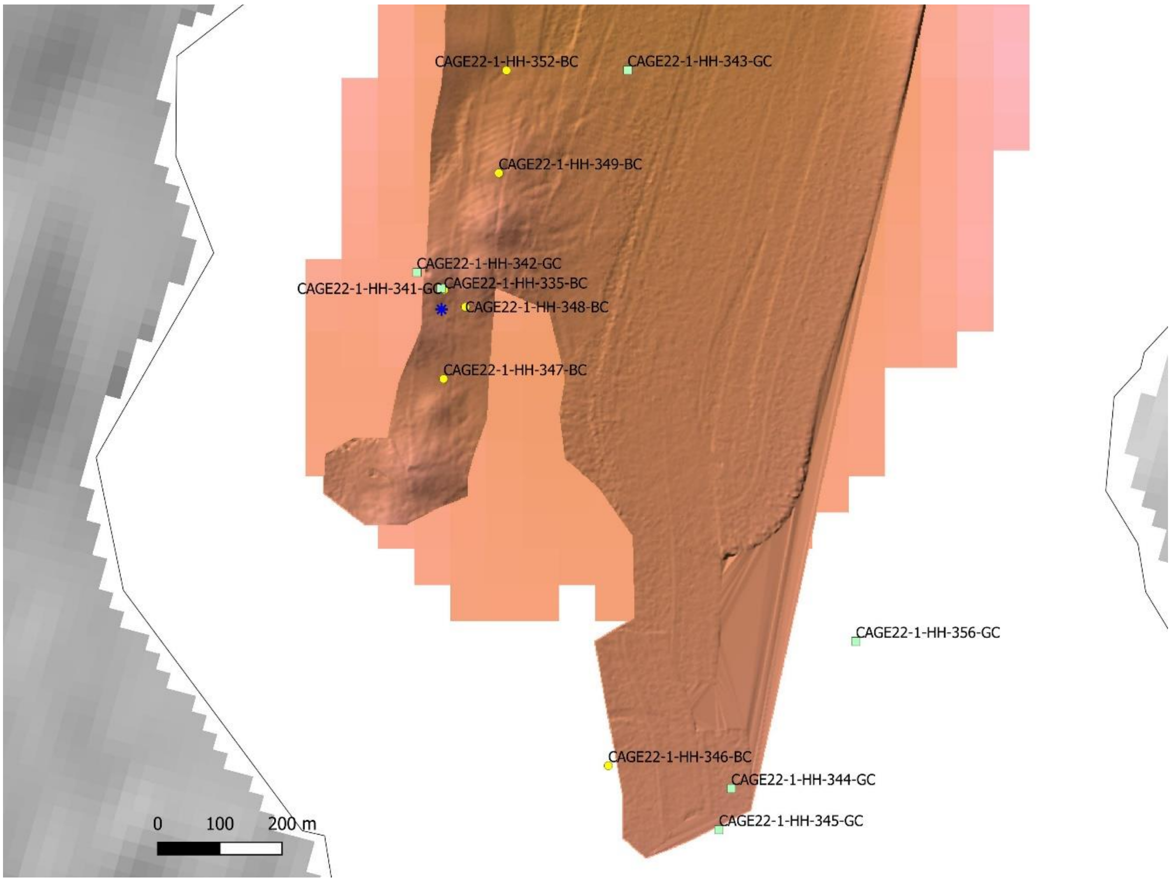
Before breakfast we conducted 4 CTDs in the inner fjord. After breakfast we did 3 gravity corings (1 successful) in tailing area and 2 corings close to the river delta (1 successful). We started a transect of box corings passing through the tailing area from the south to the north; 3 before dinner, 3 after dinner. Conducted multibeam+chirp survey overnight. Air T = -12 to -3 C; wind speed (avg) = 5 m/s; humidity (avg) = 80 %.

Day 3 5th April
Before breakfast, at around 6 am, we conducted a box coring in the tailing area, and then prepared for multicore video survey. We saw a porpoise in the eastern inner fjord, passing in front of the mine processing plant at ~50 m from shoreline, moving north. TowCam dive started in the tailing area and ended in the future disposal area. Attempted 2 multicorings in the future disposal area but failed, so we collected a gravity core. Moved out close to the delta and collected a gravity core. Tried a box coring in the future disposal area but only few cm of sediment inside (collected for foraminifera). The weather got worse, started raining and wind gusts at 16 m/s. Finished multibeam coverage of outer fjord and started the transit to Tromsø at 21.30. Air T = -2 C; wind speed (avg) > 10 m/s; humidity (avg) = 65 %.

Day 4 6th April
All participants arrived safely in Tromsø at around 11.35 am.

List of samples

Cores		recovery (cm)	pore water	headspace	sliced	living foraminifera	large sediment samples	archive
CAGE-22-1-HH-334-MC	A	37	x					x
	B	40.5		x	x			
	C	36.5			x	x		
CAGE-22-1-HH-335-BC	A	14	x		x			
	B	13.5			x	x		
CAGE-22-1-HH-341-GC							x	
CAGE-22-1-HH-343-GC		60	x	x				
CAGE-22-1-HH-345-GC		40	x	x				x
CAGE-22-1-HH-346-BC	A	17			x	x	x	
	B	14			x		x	
	C	13	x					
CAGE-22-1-HH-347-BC	A	30.5			x	x	x	
	B	24					x	x
	C	22	x	x			x	x
CAGE-22-1-HH-348-BC	A	18	x					x
	B	25			x	x		
CAGE-22-1-HH-349-BC	A	12	x					x
	B	13			x			
CAGE-22-1-HH-350-BC	A	25	x					x
	B	27.5			x	x		
CAGE-22-1-HH-351-BC	A	22	x					x
	B	29			x	x		
CAGE-22-1-HH-352-BC	A	27.5			x	x		
	B	22	x					x
CAGE-22-1-HH-355-GC		94	x				x	x
CAGE-22-1-HH-356-GC		97	x				x	x
CAGE-22-1-HH-357-BC		11			x	x	x	



Close-up view on sampling distribution on the mine tailing deposits (cone-shaped features) and close to the river delta (southernmost samples).

Logs

Table A1 – Stations

Location	Station Id	Date (mm.dd)	Time (UTC)	Lat. [N] Long. [E]	Water Depth [m]	Recovery	Notes
Outer Repparfjord	CAGE22-1-HH-331-CTD	3/4/2022	11:12	70°30.861' 24°06.612'	116.95		no water sampling
Inner Repparfjord	CAGE22-1-HH-334-TC_MC	3/4/2022	17:42	70°28.216' 24°17.011'	59.69	37	tailing area (tube worm habitat). A=37 cm pore water, gas sediment geochemistry, foram; B= 40.5 cm, C= 36.5
Inner Repparfjord	CAGE22-1-HH-335-BC	3/4/2022	20:12	70°27.883' 24°16.914'	43.60	14	2 tubes. Very stiff sediment. A =14 cm; B= 13.5 cm

Inner Repparfjord	CAGE22-1-HH-337-CTD	4/4/2022	04:47	70°29.126' 24°17.001'	89.92		no water sampling
Inner Repparfjord	CAGE22-1-HH-338-CTD	4/4/2022	05:05	70°28.237' 24°17.159'	63.80		no water sampling
Inner Repparfjord	CAGE22-1-HH-339-CTD	4/4/2022	05:18	70°27.866' 24°16.910'	48.99		no water sampling
Inner Repparfjord	CAGE22-1-HH-340-CTD	4/4/2022	05:55	70°29.626' 24°14.489'	73.39		no water sampling
Inner Repparfjord	CAGE22-1-HH-341-GC	4/4/2022	07:33	70°27.884' 24°16.907'	44.58		tailing area_failed (collected some reworked sediment)
Inner Repparfjord	CAGE22-1-HH-342-GC	4/4/2022	08:21	70°27.897' 24°16.842'	43.40		tailing area_failed
Inner Repparfjord	CAGE22-1-HH-343-GC	4/4/2022	09:18	70°28.080' 24°17.363'	59.80	60	tailing area_60 cm
Inner Repparfjord	CAGE22-1-HH-344-GC	4/4/2022	10:23	70°27.463' 24°17.713'	44.05		close to delta_failed
Inner Repparfjord	CAGE22-1-HH-345-GC	4/4/2022	11:05	70°27.427' 24°17.686'	43.70	40	close to delta_
Inner Repparfjord	CAGE22-1-HH-346-BC	4/4/2022	12:54	70°27.478' 24°17.393'	47.66	17	close to delta_A=17 cm; B=14 cm; C=13 cm
Inner Repparfjord	CAGE22-1-HH-347-BC	4/4/2022	14:17	70°27.806' 24°16.923'	51.58	27	tailing area_A=27 cm; B=24 cm; C=22cm
Inner Repparfjord	CAGE22-1-HH-348-BC	4/4/2022	16:12	70°27.869' 24°16.971'	49.10	25	tailing area_A=18 cm; B=25 cm

Inner Repparfjord	CAGE22-1-HH-349-BC	4/4/2022	20:03	70°27.986' 24°17.042'	49.19	13	tailing area_A=12 cm; B=13 cm
Inner Repparfjord	CAGE22-1-HH-350-BC	4/4/2022	21:21	70°28.223' 24°17.059'	61.15	27.5	tailing area (tube worm habitat)_A=25 cm; B=27.5 cm
Inner Repparfjord	CAGE22-1-HH-351-BC	4/4/2022	22:14	70°28.442' 24°18.037'	58.54	29	out of tailing area (north east)_A=22 cm; B=29 cm
Inner Repparfjord	CAGE22-1-HH-352-BC	5/4/2022	03:55	70°28.075' 24°17.050'	59.25	28	tailing area_A= 28 cm; B= 22 cm
Outer Repparfjord	CAGE22-1-HH-354-TC_MC	5/4/2022	11:01	70°29.328' 24°15.375'	88.77		new tailing area_failed
Outer Repparfjord	CAGE22-1-HH-355-GC	5/4/2022	13:07	70°29.144' 24°16.750'	90.19	94	future disposal area
Inner Repparfjord	CAGE22-1-HH-356-GC	5/4/2022	14:14	70°27.595' 24°18.018'	44.46	97	close to delta
Outer Repparfjord	CAGE22-1-HH-357-BC	5/4/2022	15:59	70°29.424' 24°15.980'	69.69	3	future disposal area_little sediment inside

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Group picture of the cruise participants