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CRUISE REPORT

Benthic Habitats in Denmark Strait (BENCHMARK)

R/V G.O.Sars, Cruise No. 2021107

August 1 – August 10th, Reykjavik (Iceland) – Reykjavik (Iceland)

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1. Summary

Denmark Strait is the body of water separating Greenland and Iceland. With a minimum width of 290 km and bisected by the Greenland-Iceland Rise (GIR), it is a region of complex oceanographic settings, where warm saline Atlantic Waters interact with cold waters of Arctic origin. As a result of these oceanographic processes, the environmental gradient across Denmark Strait is one of the steepest in the northern hemisphere (Andrews et al. 2002), with major differences in water mass characteristics, extent of sea-ice cover, and near-bottom temperature. In addition, the composition of the sea bed in terms of sediments and geomorphic units is highly variable. These major differences in environmental settings are likely to result in a high diversity of benthic habitats.

Existing information on the distribution of benthic invertebrates in Denmark Strait is derived from the analysis of the bycatch during bottom trawl surveys within Icelandic and Greenlandic waters (Ólafsdottir and Guðmundsson, 2019; Blitcher and Hammeken Arboe, 2017), observations during the BIOICE project within the Icelandic EEZ (Anonymous2005, Omarsdottir et al. 2013), and underwater video transects carried out in Icelandic waters by the Marine and Freshwater Research Institute. These observations suggest that the GIR and adjacent slopes in Denmark Strait may have a high density and diversity of benthic megafaunal taxa, including the presence of Vulnerable Marine Ecosystems (VMEs). Nevertheless, in general, the composition and distribution of benthic habitats in Denmark Strait is poorly known.

The BENCHMARK (Benthic Habitats in Denmark Strait) cruise was carried on board the R/V G.O. Sars between August 1st, and 10th, 2021 (Reykjavik – Reykjavík), with the main objectives of collect underwater video and photographs to characterise the composition and distribution of epibenthic fauna in the Denmark Strait, with a particular focus on taxa considered indicators of Vulnerable Marine Ecosystems, and to survey water mass properties and flow structure across the Denmark Strait. EUROFLEETS+ financed the cost of the vessel operation, ROV crew, and travel costs for the scientific crew. In addition, it supported the cost of improving the capabilities of the vessel to transmit live video feed on the internet. Thanks to the professionalism of the vessel crew and the ROV operators, and aided by excellent weather conditions, we were able to fulfill all the objectives of the cruise. We complied a rich set of observations that will be analyzed in the coming months, with preliminary results presented in this report.

2. Research Programme/Objectives

The primary of the BENCHMARK cruise was to collect underwater video and photographs to characterise the composition and distribution of epibenthic fauna in the Denmark Strait, with a particular focus on taxa considered indicators of Vulnerable Marine Ecosystems. Dives using an ROV (Remotely Operated Vehicle) were carried out successfully in 25 stations located along three transects running in a NW-SE direction across the Denmark Strait.

Specific aims of the cruise were:

1) Obtain baseline information on the distribution and composition of benthic ecosystems (including biota and sediment types), contributing to the mapping of benthic habitats on Greenlandic and Icelandic waters in general, and to the identification of potential Vulnerable Marine Ecosystems in particular.

2) Validate the predictions of the distribution of VME indicator taxa obtained by the NovasArc project for Denmark Strait.

3) Obtain new records of VME indicator taxa to allow the fitting of high-resolution predictive models of VME indicator taxa in Denmark Strait.

4) Survey water mass properties (temperature, salinity, nutrients) and flow structure across the Denmark Strait, contributing to the characterization of currents in Denmark Strait and providing baseline information to understand the distribution patterns of benthic taxa.

5) Collect high-resolution bathymetry and backscatter data using a multibeam echosounder in selected locations.

3. Narrative of the Cruise

By Julian M. Burgos

The cruise departed from Reykjavík, Iceland, on August 1st, 2021, at 8am UTC. The initial hours of the cruise were allocated to safety training, including the use of survival suits, access to emergency exits, etc. We also received information on life on board and on procedures related to Covid19.

The first task was the organization of shifts. The main activity during the survey were the ROV dives, and these could occur at any time during the day or night. Therefore we set up two groups of three scientists to control the cameras and take annotations during the ROV dives, working in 12 hours shifts: Chris Yesson, Emmeline Broad, and Nanette Hammeken covered the day shift, while Bylgia Sif Jónsdóttir, Laure de Montety, and Petrún Sigurðardóttir, worked the night shift. After each dive, these scientists processed the samples obtained by the ROV. The remaining scientists did not worked on shifts, but on an ad-hoc manner depending on the location of sampling sites, of the activities occurring on-boards, and on the amount of work not completed when reaching a new sampling station. Julian M. Burgos supervised the activities on board, planned modifications to the survey plan, and coordinated with the vessel crew the transit to sampling sites and the deployment of sampling gear. Steinunn H. Olafsdóttir collaborated with annotations during ROV dives and processing of samples. Andreas Macrander obtained water column profiles with the CTD, monitored the underway sensors, and processed water samples. Davíð Þór Óðinsson also obtained CTD profiles, while Nanette Hammeken collaborated with the processing of water samples. Davið Þór Óðinsson operated the multibeam echosounder. Finally, Roeland Develtier collaborated with the operation and maintenance of the ROV as part of his training activities.

In most cases, the activities in each sampling stations were as follow:

1. Deployment of the CTD and Rosette sampler to obtain a water column profile of temperature and salinity. A water sample was obtained near the seabed to measure carbon.

2. Collection of multibeam data. In locations where there was no multibeam data available, we collected high-resolution bathymetry and backscatter data using the EM 302 echosounder. Data was obtained on an area of approximately 20 km2 surrounding the sampling site. The purpose of this was twofold: a) to assist the navigation of the ROV and identify the location of interesting features on the seabed, and b) to provide information to contextualize the observations carried out during the dive.

3. Deployment of the ROV Ægir 6000. The ROV was used to obtain videos and photographs along a transect with a median length of ~ 1km. The high-definition video camera mounted on top of the ROV was used continuously during the dive. In addition, short video clips and photographs were taken with the Ultra HD camera (4K), to aid in the identification of the organisms observed. Specimens, mostly of sponges and corals, were obtained with the ROV manipulators and with the suction sampler (Figure 1).

Figure 1: Collection of sample using the ROV manipulator.

4. After the ROV returned to the surface and was raised to the vessel, the specimens collected where taken to the wet lab to be processed (Figure 2). Each specimen was measured and photographed. Tissue samples were obtained for DNA sequencing. Samples of spicules from sponges were stored for aiding the taxonomic identification. Large sponges and corals were hanged to dry.

Figure 2: Processing of specimens obtained by the ROV sampling tools.

The initial survey plan included 23 ROV dives along three NW-SE transects. The first transect was located south of the Iceland-Greenland ridge including the continental slopes toward the Irminger Basin (south transect). The second transect was located on the Iceland- Greenland ridge (center transect), and was selected to complement the Látrabjarg transect survey regularly by the hydrographic surveys of MFRI (Sólveig R. Ólafsdóttir et al, 2020). The third transect was located north of the ridge and included the Greenland shelf edge, the deep Blosseville Basin, and the Iceland shelf edge (Våge et al., 2013). This transect complements the Kögur section sampled regularly by MFRI (Sólveig R. Ólafsdóttir et al., 2020).

Before the cruise it was decided to relocate some of the stations of the southern transect on the Mardöll seamount (Figure 3). On August 2nd at 6:28 am we initiated the first ROV dive, numbered 436 according to the vessel’s logging system. This dive was located on top of the Mardöll seamout at 972 m depth. Three additional dives (437,438 and 439) were carried out the same day on this feature. On August 3rd we carried out a dive on the slope towards the Irminger Basin at 1764 m (dive 440), and a dive on a cone-shaped seamount (1193m, dive 441). The same day we attempted three dives on the slope near the limit between the Icelandic and Greenlandic EEZ’s (dives 442, 443 and 444). This area is dominated by the overflow current and the ROV transects could not be carried out because the near-bottom currents were too strong and the ROV could not be detached from the tethering system in a safe manner. We still managed to obtain some photographs and video of the seabed in one of the dives (dive 444). In that area, additional CTDs were deployed to obtain a better description of the overflow current, bringing the total number of CTD stations in this area up to five (CTD stations 203 to 207). On August 4th, already in Greenlandic waters, we carried out three dives (dives 445, 446 and 447) on the shelf and in the Kangerlussuaq trough at depths between 376 and 404 m. At this point we ended the southern transect.

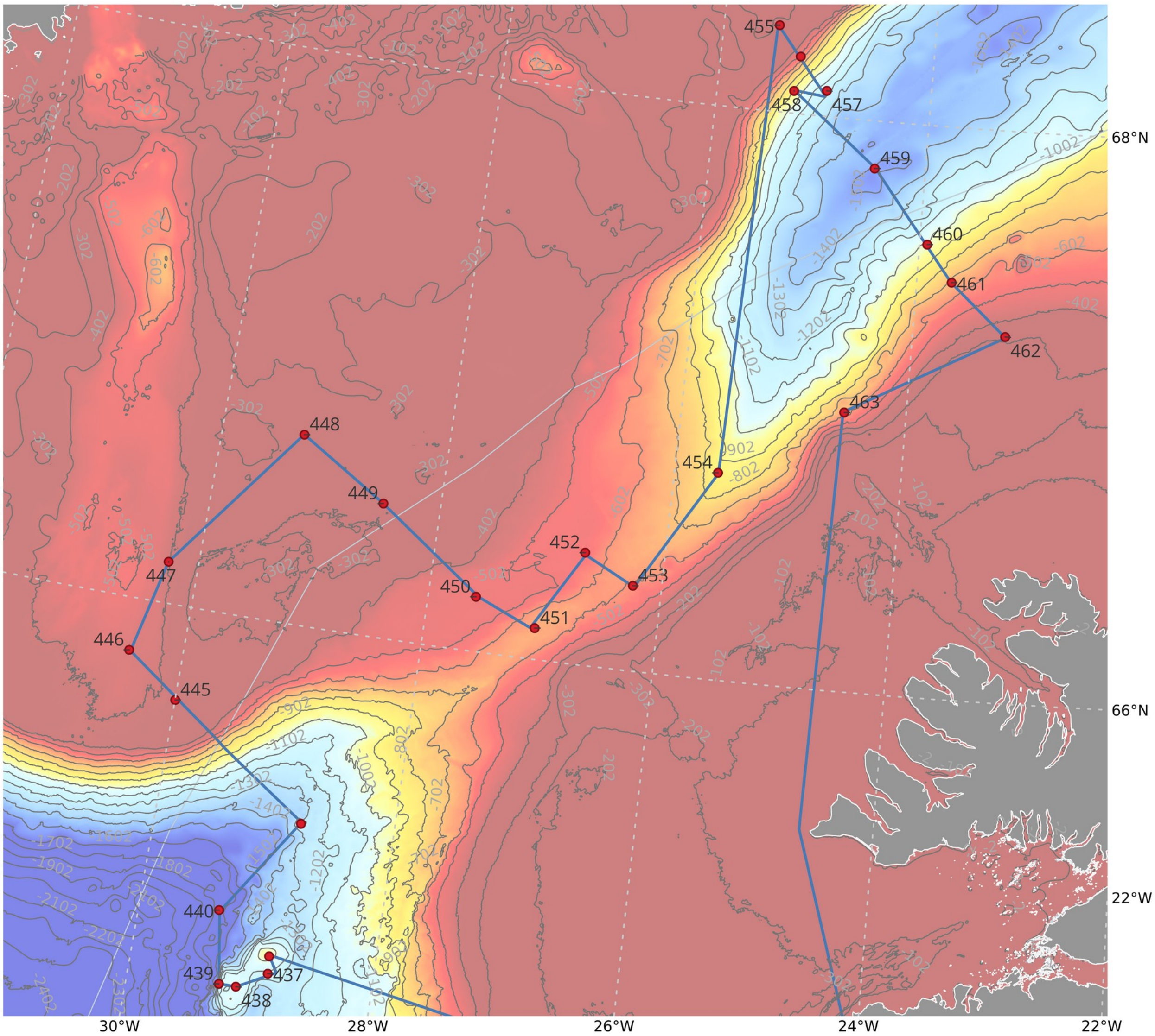

Figure 3: Vessel track and location of succesful ROV dives during the cruise.

On August 5th two additional dives were carried out within the Greenland EEZ (dives 448 and 449) , plus an additional dive (dive 450) after crossing into the Icelandic EEZ. On August 6th three dives (dives 451, 452 and 453) were carried out on the Denmark Strait channel. Dive 453 was streamed live through the Facebook page of the Zoological Society of London, with the scientific crew providing commentary on the species and habitats observed. In addition, a dive (dive 454) was carried out on an area known to fishermen as the « potato garden », because of the high density of sponges. After that, we navigated to the north back into the Greenland EEZ, to initiate the northern transect. On August 7th we carried out three dives (dives 455, 456 and 457) on the slope of the Greenlandic shelf, at depths between 308 and 1158 m. One of the dives planned in this area at 900m deep was not possible because of the risk due to presence of icebergs and foggy conditions . Therefore, on August 8th we carried an additional dive (dive 458) at 903 m. This day we also carried a dive deep in the Bloseville basin (dive 459, 1471 m deep), and two dives on the Icelandic slope (dives 460 and 461). On August 9th the last two dives took place (dives 462 and 463). The last dive was live streamed through the Eurofleets+ site, although without commentary. On August 10th we returned to Reykjavík, where the scientific and the ROV disembarked. Afterwards the vessel returned to Bergen, Norway.

4. Multibeam mapping

By Davið Þór Óðinsson

In some of the sampling sites (n=8) within the Iceland EEZ, high-resolution bathymetry and backscatter maps derived from multibeam echosounder data were available from the seabed mapping programme by the Marine and Freshwater research institute. In the other sites, multibeam data was collected using an EM302 echosounder, with the objective of aiding in the navigation of the ROV, and to provide context to the observation carried during the dive. The EM302 was operated in Dual Swath Mode, emitting 288 beams over 150° of angular coverage, receiving extra soundings per beam, for a total of 432 soundings. The device emitted a second consecutive transmission with a slight tilt in forward direction at short intervals and received a total of 864 measuring points per ping cycle.

A conductivity, temperature and depth profile (CTD) was acquired before or after every multibeam patch to ensure the data was sound velocity corrected with the latest conditions in the water column. Tide corrections were not considered to have a large impact on the multibeam patches since each patch was limited to about 60 minutes. The multibeam patch was surveyed with ~10% overlap of the adjacent survey line to ensure full coverage.

Seafloor Information System (SIS) developed by Kongsberg was used for data acquisition and Caris Hips & Sips developed by Teledyne was used to process the data during the survey. Bathymetry data was gridded with a resolution of 10 x 10 meters using the swath angle method where the weight a sounding contributes to the surface varies with the grazing angle of the sounding with the seabed. This gives soundings closer to the nadir angle a higher weight during the gridding algorithm. Soundings were examined and rejected using the beam validation method, possible noise was rejected by subjective evaluation of the hydrographer. The density of soundings +-30° from the nadir angle in the final bathymetry maps varied between 2 to 10 soundings per cell, with higher sounding density on multibeam patches shallower than 300 meters.

Backscatter data was gridded with a 5x5 meter cell size using the Geocoder engine. The time series for each beam was used in the calculations with a 5-minute window. An inherent artifact was observed in the backscatter data using the medium ping method in SIS, where systematically a returning transmission had higher beam intensities resulting in “stripes” in the along track direction of higher backscatter values.

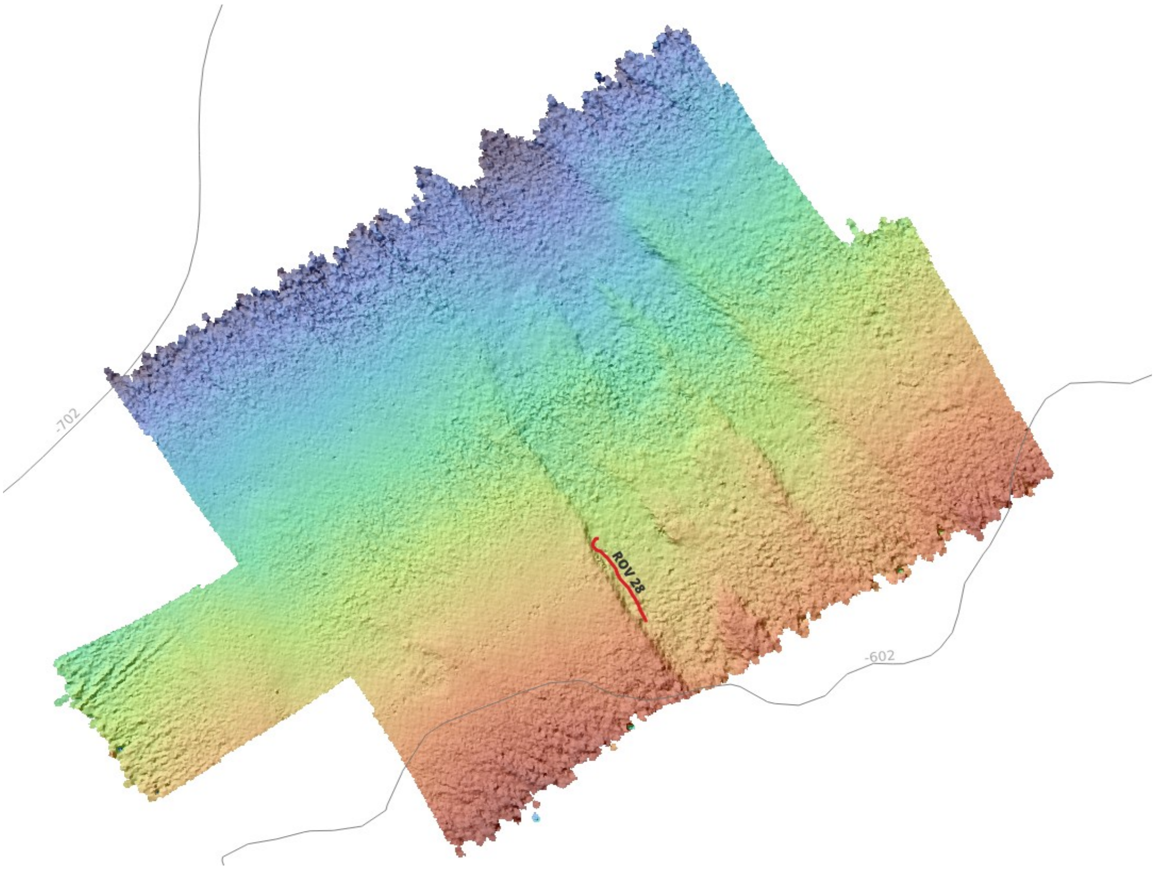

Figure 4: Example of high-resolution bathymetry collected during the cruise. The red line indicates the track followed by the ROV during the subsequent dive (dive 463).

5. Physical Oceanography

By Andreas Macrander

Introduction

One aim of the Benchmark cruise was to determine the different water masses and currents in Denmark Strait, which include the Irminger Current of Atlantic origin, the East Greenland Current (EGC) of polar origin, and the dense Denmark Strait Overflow and its sources. The observations of temperature, salinity, Dissolved Oxygen, Dissolved Inorganic Carbon (DIC), Total Alkalinity (TA), and current velocity, aid at characterizing environmental conditions of benthic habitats, and they add to previous hydrographic observations of the area, in particular the quarterly hydrographic surveys of the MFRI.

The Benchmark cruise comprises three sections that cover the area south and north of the Denmark Strait sill, and the central part of the strait. The location of the stations were chosen as to also enable comparison with long-term observations of regular hydrographic surveys and current meter mooring arrays.

- The southern section, ca. 130 km south of the Denmark Strait sill, covers the Irminger Sea (Våge et al., 2011), the dense plume of the Denmark Strait Overflow (Käse et al., 2003), and waters on the Greenland shelf and the Kangerlussuaq trough.
- The central section at the sill of Denmark Strait is an extension of the Látrabjarg section occupied 4x per year by the hydrographic surveys of MFRI (Sólveig R. Ólafsdóttir et al, 2020, and previous reports; Mastropole et al., 2017). In addition to the Látrabjarg hydrographic data, there are also 25 years of current meter timeseries at the sill (Jochumsen et al., 2017) to compare with.
- The northern section is an extension of the Kögur section occupied by MFRI 4x per year (Sólveig R. Ólafsdóttir et al., 2020, and previous reports). The section spans the Greenland shelf edge, the deep Blosseville Basin, and the Iceland shelf edge (Våge et al., 2013). On this section, data of a year-long Kögur current meter array aid further the interpretation of the environmental conditions (Harden et al., 2016).

Both the central and the northern sections can be combined with the MFRI 2021 summer survey (Bjarni Sæmundsson B09-2019, https://sjora.hafro.is/) which served the Látrabjarg and Kögur lines within two days from the G.O. Sars cruise.

Material and Methods

During the cruise, a range of instruments was employed in hydrographic and current observations:

- Thermosalinograph (TSG)

During the entire cruise, the underway sampling system of G.O. Sars collected data on near – surface properties. From an intake in the ship‘s hull at ca. 4 m depth, seawater is continuously pumped through the system, including a Sea-Bird SBE 21 CTD (Seabird, 2015) with sensors for temperature and conductivity, which are used for calculating salinity. Additional sensors are for temperature directly at the seawater intake (T2), and fluorescence.

The TSG data has not been calibrated, but comparison with calibrated CTD data suggests an empirical correction of -0.05°C for T2, and +0.08 mS cm^{-1} for conductivity, respectively, resulting in salinity ca. 0.08 higher than in the raw data. The accuracy of the corrected data can be assumed to be +/- 0.1 °C and +/- 0.05 for temperature and salinity, respectively, though differences between CTD and TSG are larger at some stations due to local variability.

Fluorescence can be used as a qualitative indicator of plankton abundance.

- Acoustic Doppler Current Profiler (ADCP)

R/V G.O. Sars is equipped with a vessel-mounted ADCP, type Ocean Surveyor 75 kHz (Teledyne RD Instruments, 2020). The ADCP measures current velocity down to a depth of ca. 600 m, utilizing Doppler frequency shift in the acoustic backscatter signal. The ADCP was operated most of the time, though it was turned off during some of the multibeam surveys in order to minimize acoustic interference.

After subtracting the vessel speed determined from GPS, absolute current velocity is obtained. Here, 5 minute average data is used, which was detided by removing barotropic tides from the raw data. Tide predictions are from the OSU TPXO Iceland 1/60° tidal model (Egbert and Erofeeva, 2002), using TMD Tide Model Driver (Erofeeva et al., 2020). Nevertheless, current data have to be interpreted with caution due to large short term variability.

- Conductivity-Temperature-Depth (CTD)

At 27 stations (Fig. 2), a CTD (conductivity – temperature – depth) was deployed obtaining a full profile of water mass properties from surface to ca. 10 m above the bottom. The CTD used was a Sea-Bird SBE911plus system (Seabird, 2020), with sensors for pressure, temperature (two sensors), conductivity (two sensors), as well as sensors for dissolved oxygen, fluorescence (for Chlorophyll), and PAR (photosynthetically available radiation). From P, T, C, salinity was calculated, as well as potential temperature, potential density, and sound speed. At each station, updated sound speed profiles were utilized in the multibeam surveys. In this report, density is shown as σ_Θ (potential density minus 1000 kg m^{-3}).

The CTD data was quality controlled and crosschecked with samples analysed for salinity in the lab at IMR. A correction of +0.002 mS cm^{-1} was applied to conductivity, resulting in corrected salinity ca. 0.002 higher than in the raw data. Based on comparison with the second sensor pair, accuracy of the calibrated data is assumed to be +/- 0.002 °C, and +/- 0.002 for salinity, respectively.

Oxygen and fluorescence data have not been checked by reference samples but can be used as qualitative values.

The Ægir 6000 ROV was also equipped with a CTD, type Valeport miniCTD Profiler (Valeport, 2021). This CTD is less accurate than the SBE911plus CTD of the vessel, due to the somewhat obstructed location of the instrument behind the ROV's skids, and infrequent calibration. Compared to the SBE911plus CTD, the ROV CTD data reveal a large scatter, but on average, temperature of the ROV CTD is 0.24 °C too low, while conductivity exhibits a minor pressure-dependent offset, resulting in salinity being 0.24 to 0.26 too high. After application of an empirical correction, the ROV CTD data can be assumed to be within +/- 0.02 °C, and +/- 0.01 for salinity, though scatter is still large (see Fig. 5 for an example). Data can be used as a guideline for environmental conditions on those three stations where a separate CTD has not been taken.

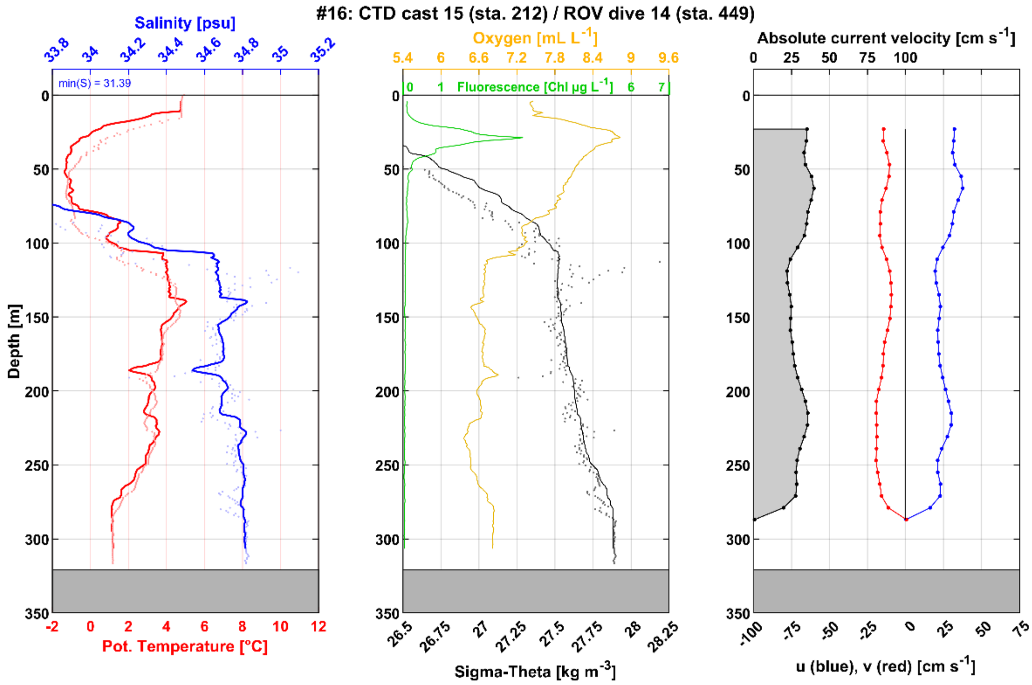

Figure 5: Example of profile data at CTD station 212 / ROV dive 14 (Greenland shelf, central section, see Fig. 2). Left panel: Temperature (red) and Salinity (blue) of the SBE 911plus CTD (solid lines), and empirically corrected ROV CTD data (dots). Middle panel: Potential density from SBE 911 plus CTD (solid black line) and ROV CTD (dots). Also shown is fluorescence (green) and oxygen (yellow). Right panel: ADCP data from the same station. Note scatter in ROV CTD data, though some differences between the profiles may also be due to short term changes in layer thickness, as the data were not taken at exactly the same time/position.

- Water Sampling

The CTD was equipped with a water sampler; at most stations, sampling bottles were closed ca. 10 m above the bottom. The ROV was also equipped with a sampling bottle, which was used on a few stations.

Salinity samples were taken at all stations for post-cruise calibration of the CTD data at IMR (see previous section).

Additionally, 24 water samples were taken for analysis of DIC and TA. These samples were analysed on land at MFRI. Both measurements follow the standard operating procedures described in the Guide to best practices for ocean CO2 measurements (Dickson et al., 2007). DIC is determined by coulometry, and TA is determined by open cell potentiometric titration.

Accuracy of DIC data can be assumed +/- 2 µmol kg^{-1}, and TA +/- 2µmol kg^{-1}. From DIC and TA, pH was computed on the total scale at in situ temperature using CO2Sys-v2.1 (Pierrot et al., 2006).

Preliminary Results

At the sea surface, the underway observations revealed warm (11-13°C) and saline (34.97-35.03) conditions on the Iceland side of the strait (Fig. 6). In contrast, on the Greenland side and on the entire northern section, sea surface temperature was 3-8°C, while salinity was extremely low (31-32 for the most part). As revealed by CTD profiles, this surface layer extended only over the upper 15-35 m, reflecting the effects of summer warming, ice melt, and little mixing as meteorological conditions during the cruise were rather calm.

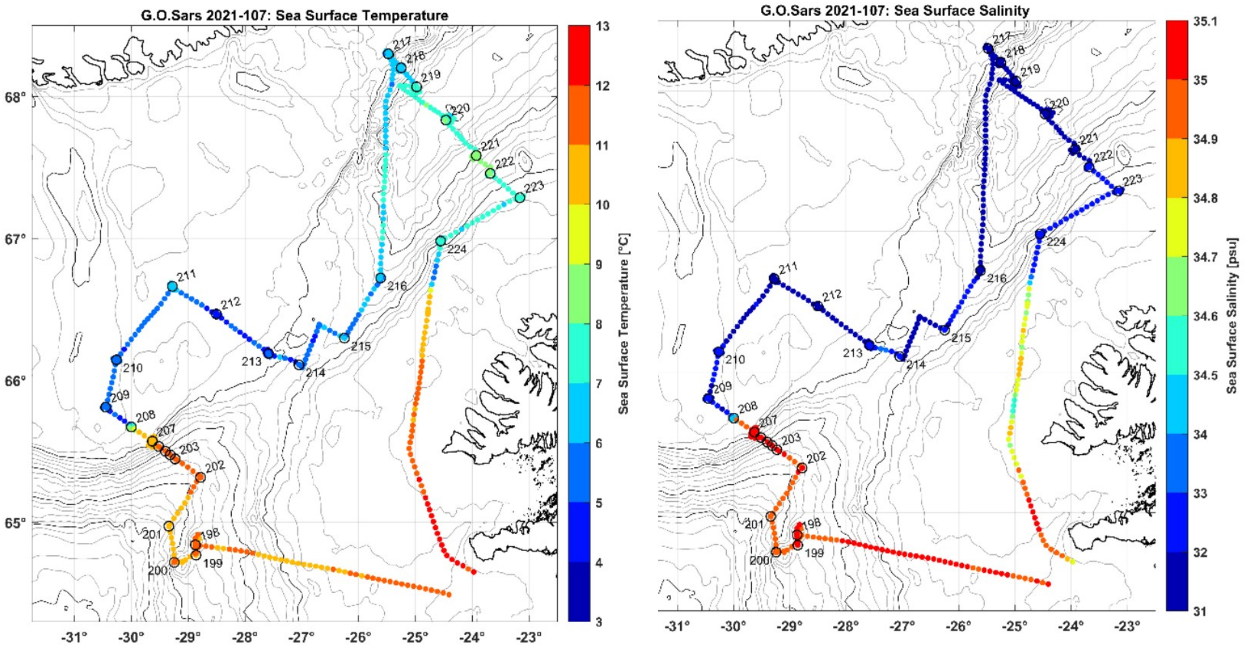

Figure 6: Left panel: Sea Surface Temperature. Right panel: Sea Surface Salinity. Note the nonlinear color scale for salinity. Numbers refer to CTD stations; for clarity, numbers 204-206 have been omitted.

ADCP data at 300 m depth (Fig. 7) reveal the northward flowing Irminger Current on the Iceland side of the southern section. The southwest flow of the dense overflow plume is evident at stations 203-207, though the strongest near-bottom flow which prevented ROV operations at stations 204 and 205 occurred at depths of 800-1200 m, beyond the range of the ADCP. On the Greenland side and in the Kangerlussuaq trough, westward flow of the East Greenland Current (EGC) and spill jet was observed (von Appen et al., 2014).

On the central section, while there is southwestward flow in the deepest part associated with the dense overflow, some eddy activity is suggested by variable current directions, agreeing with findings from current meter moorings (Macrander et al., 2007).

North of the sill, southwestward flow is found along the Greenland shelf slope (shelf-break EGC), and on the Iceland shelf edge (sta. 224) associated with the North Icelandic Jet (Harden et al., 2016). In contrast, weaker currents were observed in the deep part of the northern section.

Further analysis of the ADCP data in conjunction with the CTD profiles is required. Also, short term variability must be taken into account when interpreting the current meter data.

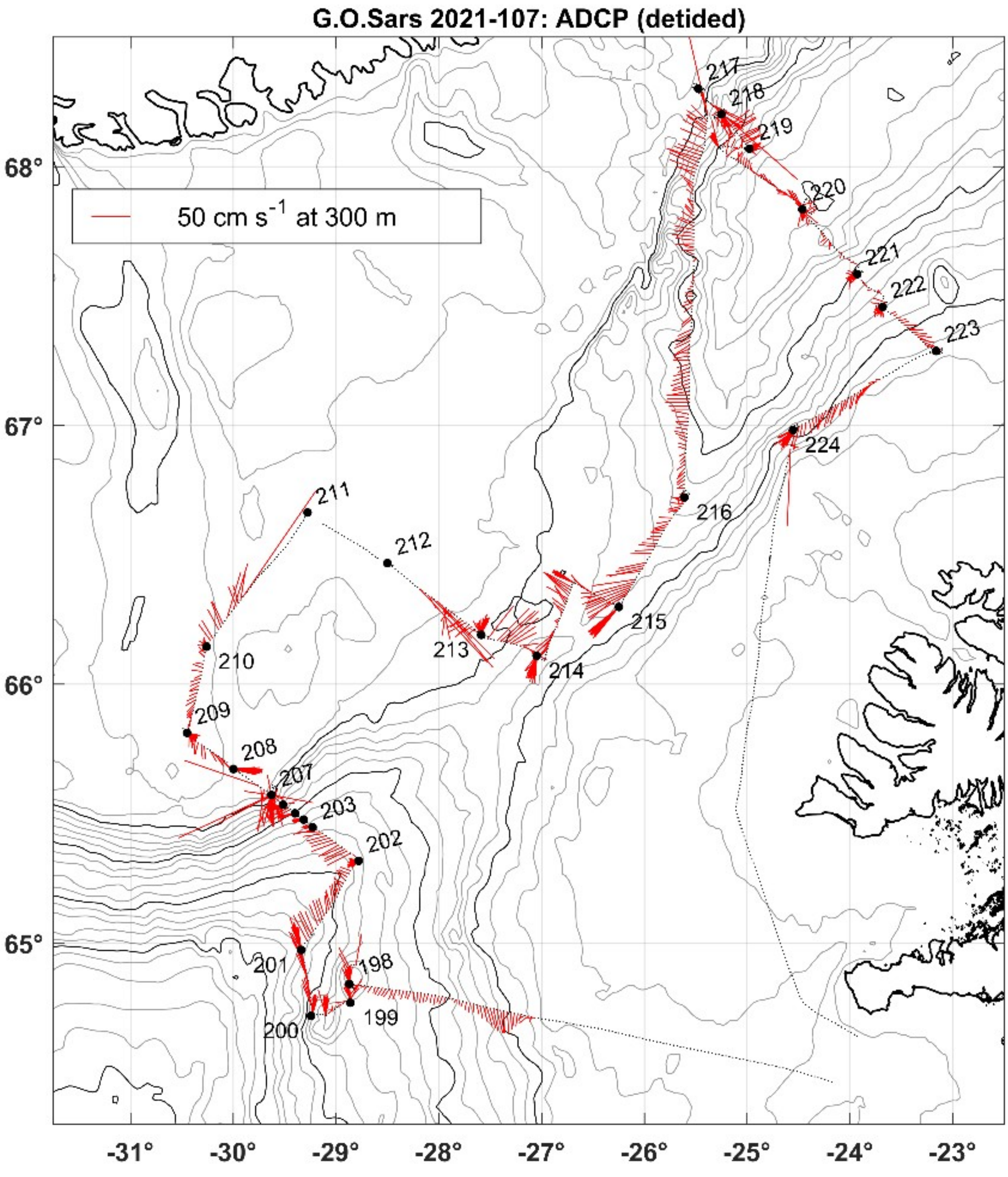

Figure 7: Detided ADCP current velocity at 300 m depth. CTD stations shown with black dots and numbers.

The water mass distribution is revealed by the CTD sections. On the southern section (Fig. 8), warm and saline Atlantic Water of the Irminger Current occupies the upper 500 m on the Iceland side all the way onto the Greenland shelf. Below the Atlantic Water, intermediate and deep waters with T = 4.4-5 °C and lower in oxygen are found, originating from Labrador Sea and Iceland-Scotland Overflow Waters (Våge et al, 2011). On the Greenland shelf edge at 750-1200 m depth, a thin layer of the rapidly flowing Denmark Strait Overflow plume is evident, with T = 0-0.5 °C (Käse et al., 2003). Arctic conditions with low temperature and salinity are limited to the westernmost part of the section. In the Kangerlussuaq trough (sta. 209 and 210), a layer of dense water (σ_Θ > 27.8 kg m^{-3}) indicating a flow of Overflow water across the Greenland shelf eventually merging the dense plume further downstream ("spill jet", von Appen et al., 2014).

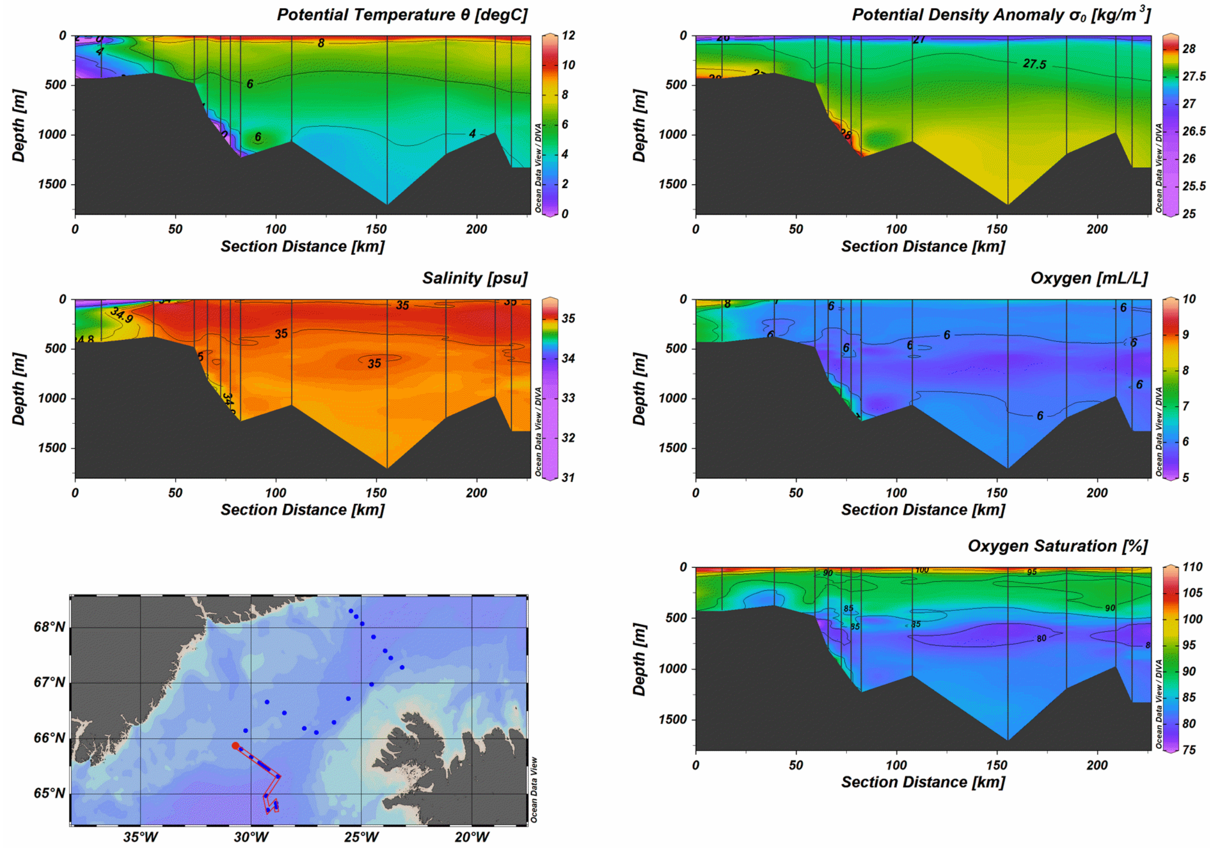

Figure 8: Southern section. To the left is the Greenland shelf; to the right, the section covers a seamount on the Iceland side. Note nonlinear color scales for Salinity and Potential Density.

On the central section (Fig. 9), overflow water with density σ_Θ > 27.8 kg m^{-3} is present at all stations. On the Greenland shelf, bottom temperature ranges between 0 and 2°C, whereas the coldest and densest part of the overflow is found at the deepest stations. Above the overflow water, the East Greenland Current ist made up of bodies of different water masses, some of them with temperature up to 5 °C and salinity 34.8, suggesting some recirculation or mixing with waters of Atlantic origin. The upper 50 m of all stations is characterized by extremely fresh melt water, with a minimum salinity of 31-32. Warm and saline Atlantic Water is limited to the Iceland side of the section (Mastropole et al., 2017).

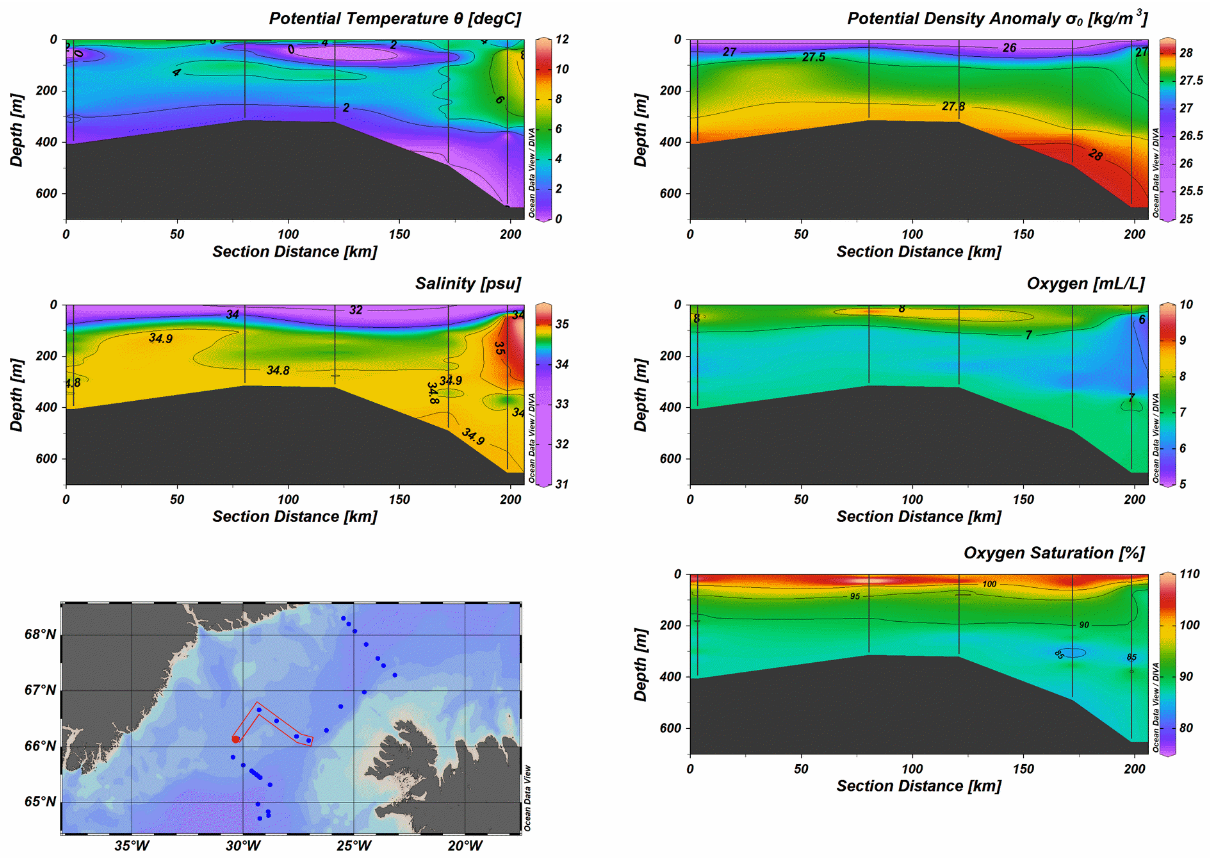

Figure 9: Central section; Greenland is to the left. The two easternmost stations compare to the LB10 and LB8 standard stations of the MFRI hydrographic surveys. Note nonlinear color scales for Salinity and Potential Density.

On the northern section (Fig. 10), the warm and saline Atlantic Water is limited to a subsurface core on the Iceland side; elsewhere and in the deep basin prevail cold (0°C) waters of Arctic origin. The deepwater isopycnals (σ_Θ > 27.8 kg m^{-3}) are banking upward on both sides of the section, associated with southward flow of the shelfbreak EGC on the Greenland side, and the North Icelandic Jet on the Iceland side, both contributing to the Denmark Strait Overflow (Våge et al., 2013; Harden et al., 2016).

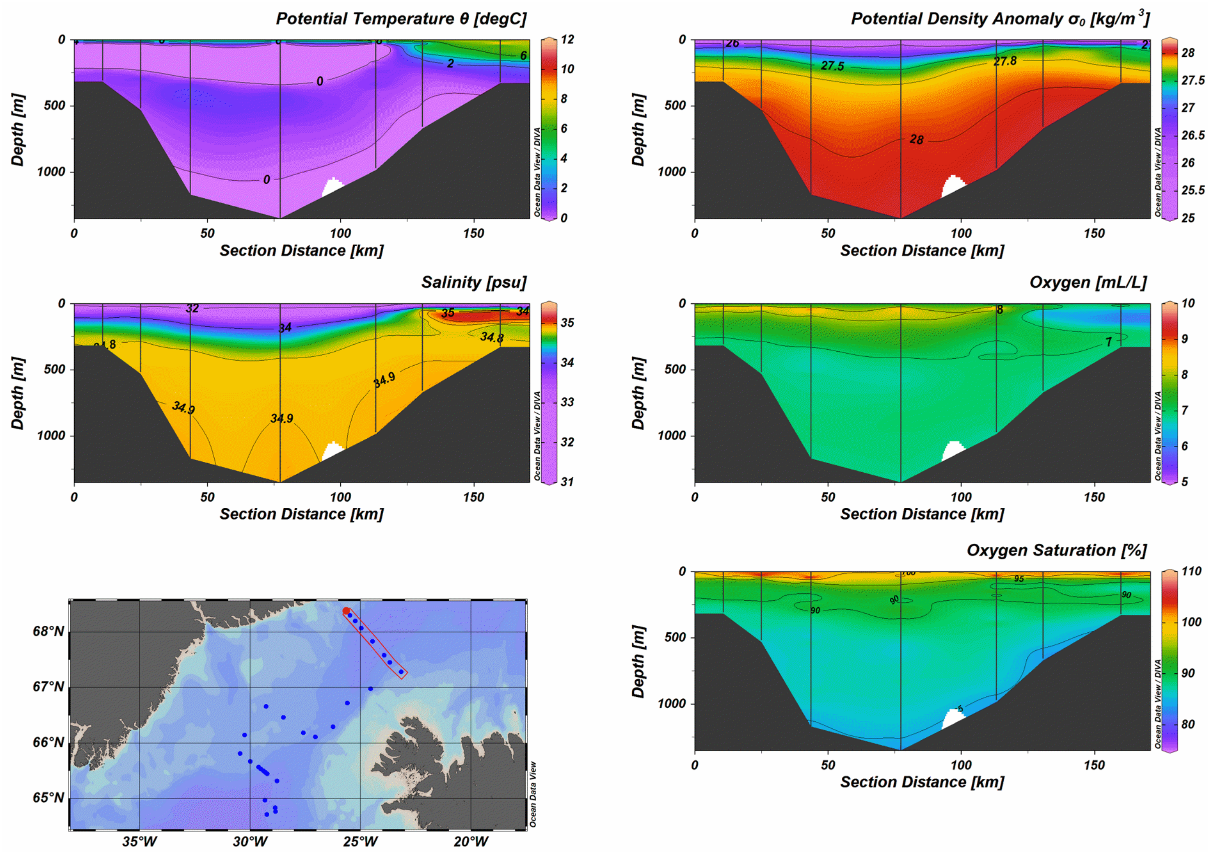

Figure 10: Northern section; Greenland is to the left. Note nonlinear color scales for Salinity and Potential Density.

Dissolved Inorganic Carbon (DIC) at the bottom ranged from 2169-2176 µmol kg^{-1}, Total Alkalinity (TA) from 2292-2305 µmol kg^{-1}; both DIC and TA have the highest values in the Atlantic Water and lowest values in the East Greenland Current (not shown). Measured pH at the bottom ranged from 7.946 to 8.042 (Fig. 11). pH is generally lowest in the warm and salty Atlantic Water found on the southern section, while pH of the overflow plume in the deeper part of the Greenland shelf edge is higher, as well as the outflow in Kangerlussuaq trough. pH is highest in the Arctic waters of the East Greenland Current, and particularly in the source waters of the Overflow, on the shelf edges on either side of the northern section. Though the carbon data appear consistent with other observations of MFRI, further analysis is needed to better understand the carbon chemistry of the bottom waters in Denmark Strait and possible implications for benthic organisms.

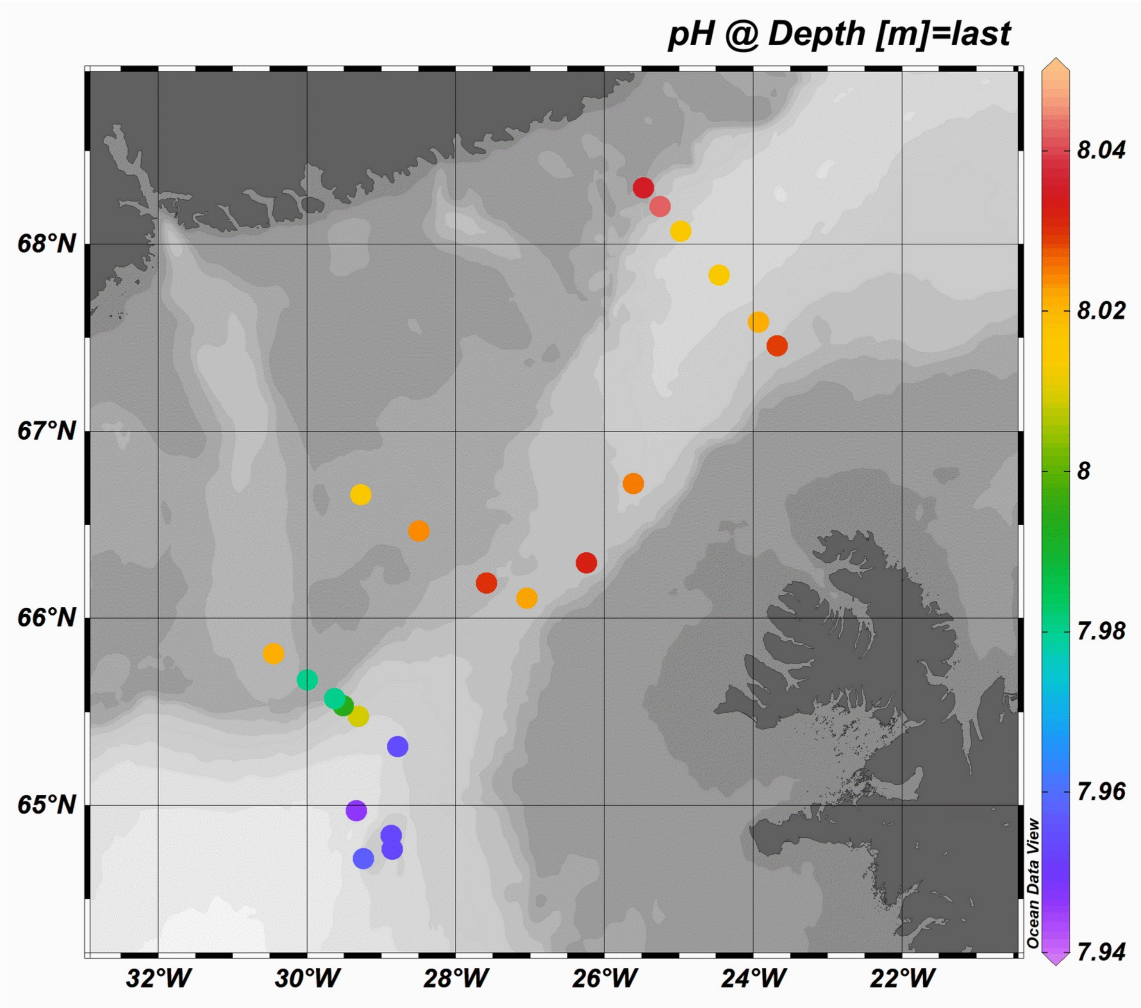

Figure 11: Computed near-bottom pH on the total scale at in-situ temperature.

6. Observations of benthic fauna and habitats

By Steinunn H. Ólafsdóttir and Julián M. Burgos

One of the main objectives of the survey was to carry out dives with the ROV Ægir 6000 to obtain videos and photographs of the benthic fauna and communities, and to utilize the ROV sampling tools (manipulator and suction sampler) to obtain specimens for taxonomic identification. The original survey plan included 23 ROV dives. Thanks to the excellent weather conditions we were able to do 25 successful dives. In two additional dives we were not able to reach the bottom, and on one due to high currents we were not able to detach the ROV from the tethering system but we were able to photograph and film the seabed, albeit in a limited way. A summary of the observations in each dive is presented in Table 1.

Table 1. Summary of the ROV dives with description of substrate, region/geoform, depth range and Vulnerable Marine Ecosystem (VME) indicator species and VME types. VME indicator species according to NAFO/ICES and NEAFC lists (ICES 2016). VME types according to the OSPAR classification (OSPAR 2010).

Dive	Substrate	Region/Geoform	Depth m	VMEs and VME indicator species
436	Firm muddy sand with spicule mat	Top of Mardöll.	972-974	Tetillidae, Ancorinidae, Geodiidae Polymastiidae spp., *Hyalonema* sp., *Pheronema carpenteri*, Acanella VME: Sponge aggregation
437	Muddy sand with spicule mat	East slope of Mardöll	1234-1206	*Stauropathes arctica*, *Craniella longipilis*, VME: Sponge aggregation
438	Muddy sand with spicule mat	Top of Mardöll	1027-1030	Tetillidae, *Pheronema carpenteri*
439	Hard bottom, sand, gravel, boulder	West slope of Mardöll	1222-1110	*Solenosmilia variabilis*, *Acanella* sp., Anthomastus.
440	Mud layer on top of hard. Mud. Huge amount of marine snow. Strong current.	Irminger Basin	1744	*Paragogria*, *Ptilella grandis*, Geodiidae, Tetillidae, Polymastiidae.
441	Hard ground	Cone shaped mound on the Irminger Basin	800-1100	*Soloenosmilia variabilis*, Caryophylliidae, Anthomastus, Plexauridae
442	Failed to reach the bottom.	Greenland slope		
443	Failed to reach the bottom.	Greenland slope		
444	Gravel	Greenland slope	490	
445	Gravel, sand	Kangerdlugssuaq trough	375	
446	Mud gravelly with cobbles, . Iceberg marks – trawl marks?	Kangerdlugssuaq trough	429	*Umbellula encrinus*, *Gersemia* sp.
447	Mud. Iceberg marks. Gravel, bobbles. Trawl marks ?	Kangerdlugssuaq trough	402	*Umbellula encrinus*, Polymastiidae, Neptheididae
448	Gravelly mud	Dohrn Bank	310	Tetillidae
449	Cobbles, sand, gravel vs mud and dropstones	Dohrn Bank	319-309	Rossellidae, Ancorinidae
450	Hard bottom, boulder, gravel,	Greenland-Iceland Ridge	485	Mycalidae, *Gersemia*, Polymastiidae, Rossellidae, Geodiidae, Nephtheidae VME: Sponge aggregation, coral garden
451	Hard bottom, gravel	Greenland-Iceland Ridge	648	Rossellidae VME: Sponge aggregation
452	Hard bottom, gravel	Greenland-Iceland Ridge	513	Rossellidae, Nepthteididae, VME: Sponge aggregation
453	Hard bottom, gravel	Greenland-Iceland Ridge	594	Nephteididae, VME: Sponge aggregation and coral garden
454	Mud, cobbles, boulder. Iceberg plough mark	Greenland-Iceland Ridge	848	
455	Hard bottom, boulder, cobbles, muddy	Greenland shelf	310	Polymastiidae, Rossellidae, Tetillidae Sponge aggregation
456	Hard bottom, boulder, gravel	Greenland slope	511	
457	Gravelly mud	Greenland slope	1184	Umbellula encrinus
458	Mud, boulder	Greenland slope	902	Rossellidae
459	Mud, cobbles	Blosseville Basin	1450	Rossellidae

460	Mud	Iceland slope	979	Nephtheidae
461	Mud, boulder	Iceland slope	695	Polymastiidae
462	Cobbles, sand, boulders	Iceland slope	334	Nephtheidae
463	Sand or gravels and cobbles	Iceland slope	565	Nepthteidae, Virgulariidae, Polymastiidae VME: Sponge aggregation Sea pen field High biodiversity/biomass

South Transect

Mardöll seamount: Dives 436 to 439

The first four dives, stations 436, 437, 438 and 439, were conducted on top and in the slopes of the flat seamount Mardöll (Figure 12). This site was chosen because records from benthic by-catch in the Autumn Groundfish survey showed very high sponge catch and because these is the largest mountain in the research area.

Dive 436 was conducted on top of the Mardöll, at 1029 m deep. The images confirmed a dense sponge aggregation along the entire transect (Figure 13). This type of a sponge aggregation habitat is referred to as “Ostur” sponge and includes large round sponges belonging to several species that often are found together. This type of habitat was described in the Denmark Strait by Klitgaard and Tendal (2004).

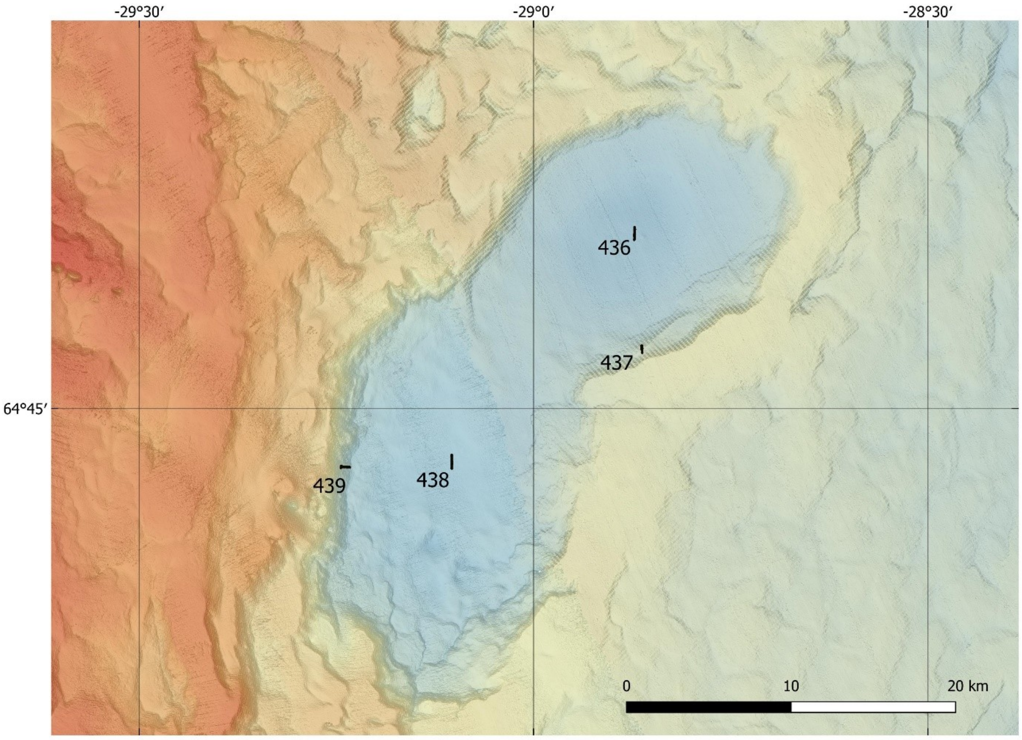

Figure 12: Mardöll seamount. Two dives were conducted on top of the mountain, one at the eastern slope and one at the western slope.

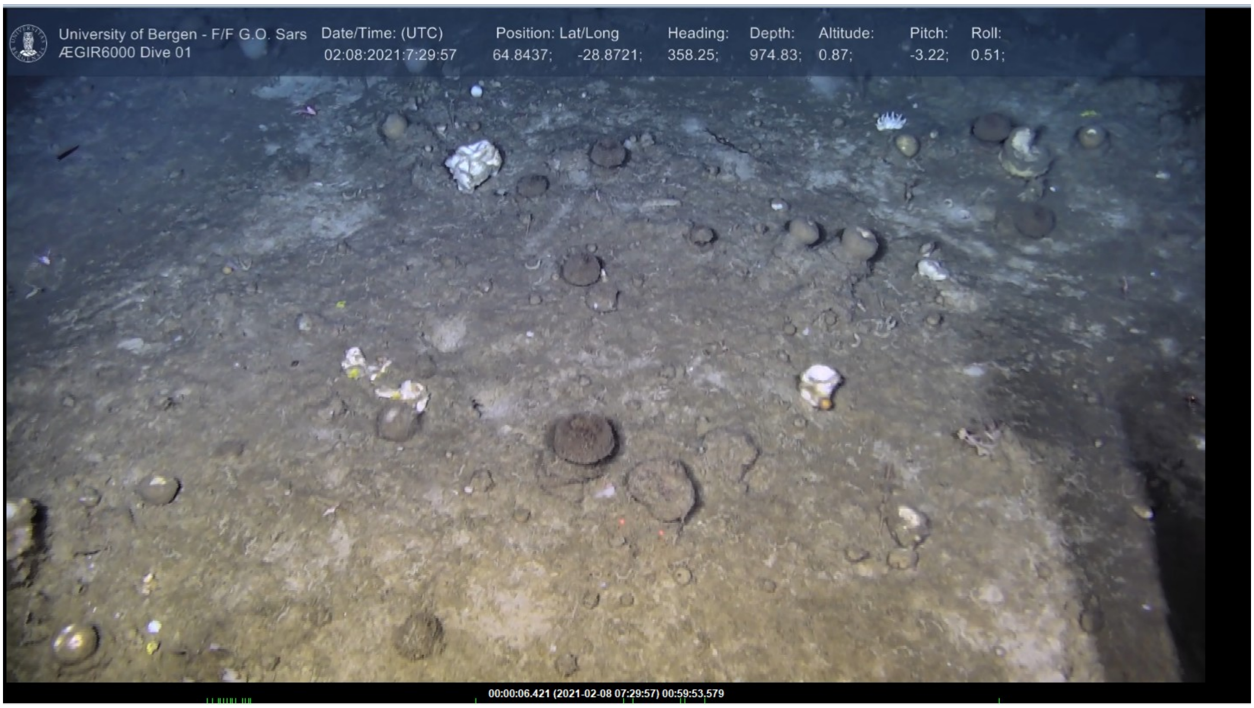

Figure 13: Sponges observed on top of the Mardöll seamount during dive 436 .

The first inspection of samples confirmed the presence of *Craniella longipilis*, *Geodia* (unid.), *Stryphnus* cf. *fortis* and the glass sponge *Pheronema carpenteri*. The bamboo coral *Acanella*, and *the* coral *Radicipes* were also seen. Dive 437 took place in the eastern slope of the Mardöll seamount (figure 14). The sediment and the community were similar to the previous dive, with sponges in the main role. Black corals were also observed.

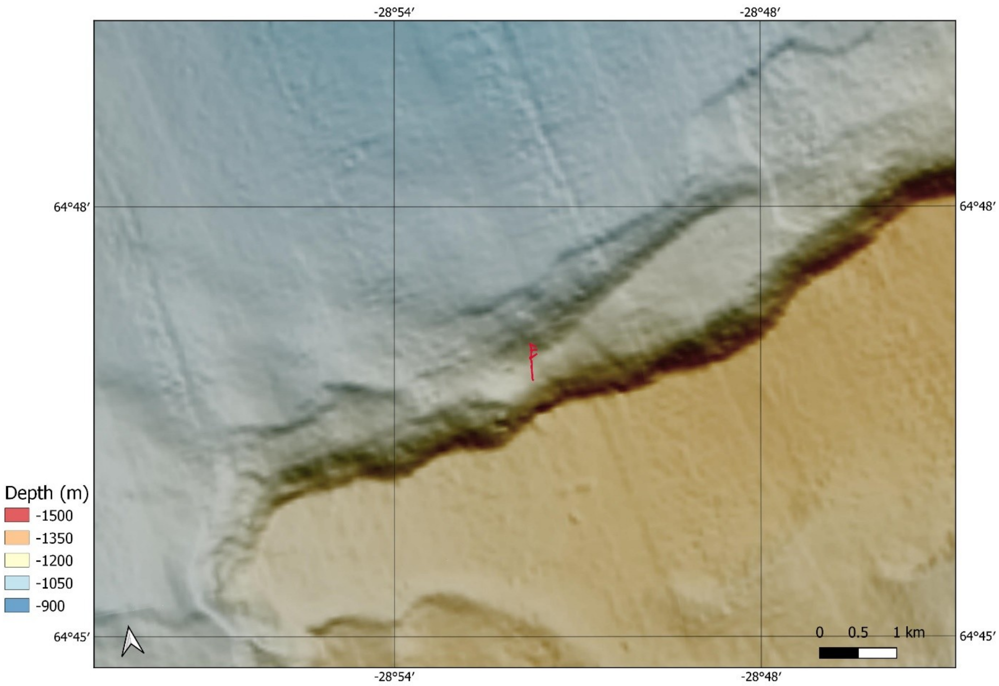

Figure 14: Dive 437 on the slope of the Mardöll flat seamount. The red line indicates the path of the ROV.

Dive 438 was conducted on the top of the mountain, towards the southwest at approximately 1033 m deep. The community was mostly sponges on a muddy sand covered by a mat of sponge spicules.

Dive 439 was conducted in the western slope of the southern mountain (figure 15) at ~1445 m deep. The slope was very steep and the substrate was hard, indicating strong currents. Coral species were observed like *Solenosmilia variabilis* and the mushroom coral Anthomastinae (figure 16).

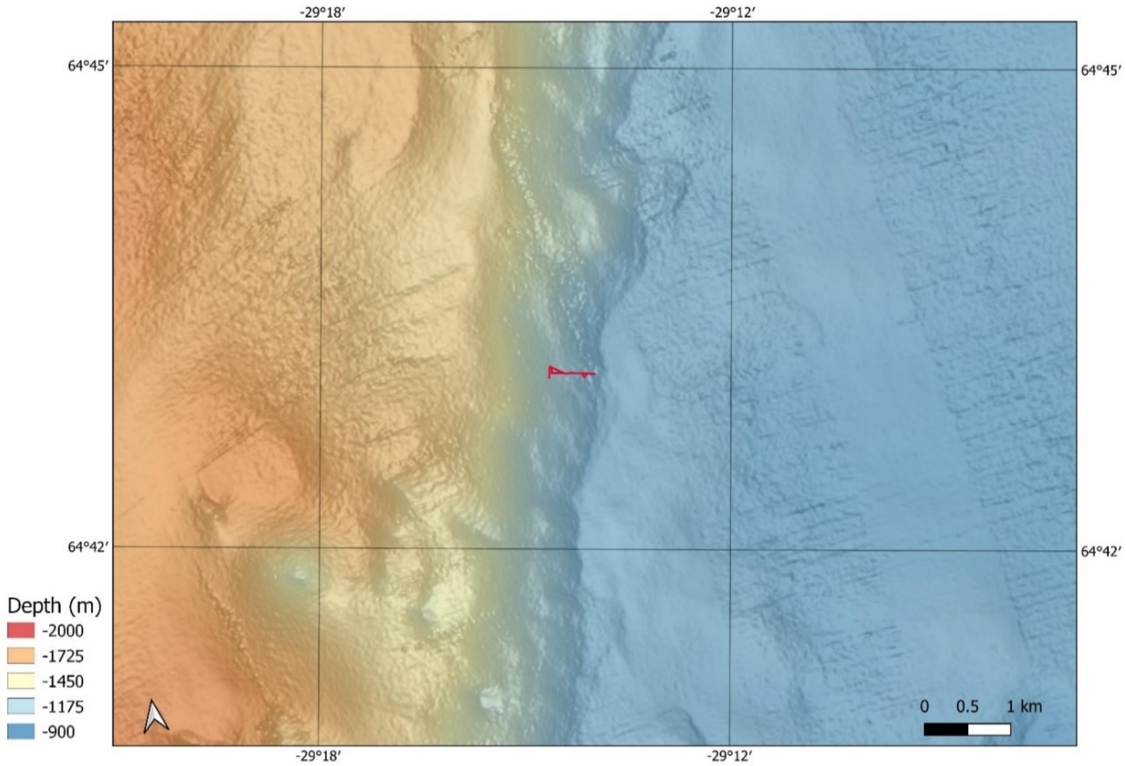

Figure 15: Dive 439 in the steep western slope of the Mardöll flat seamount.

Figure 16: Solenosmilia variablilis sampled from a boulder. Various species of sponges, crinoids, ophiuoides and Anthomastinae.

F

Irminger Basin: Dives 440 and 441

Dive 440 was the deepest dive in this survey, at approximately 1764 m on the Irminger Basin (figure 17). In this dive we observed a mixed bottom of soft and hard sediment with gravel and cobbles. Branches of bubble gum coral (*Paragorgia arborea*) were observed attached to pebbles. On softer sediment were found very large round sponges (figure 18).

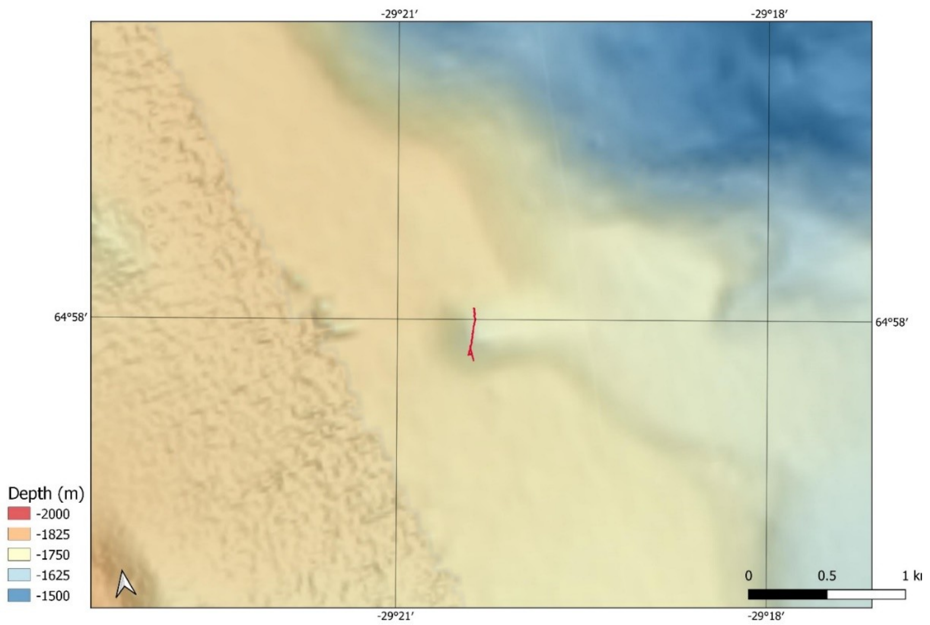

Figure 17: Track of Dive 440 on the Irminger Basin.

Figure 18: Paragrogia arborea attached to hard bottom (left). Round massive sponges on mixed bottom.

During dive 441 we climbed the southern slope of a conical shaped mound (figure 19), at an approximate depth of 1193 m. The seabed consisted of steep walls and hard gravelly bottom. Taxa observed included stony corals, crinoids, ophiuroids, sponges, mushroom corals (Anthomastinae), bamboo corals, Plexauridae corals, actiniaria and colonial tunicates (Figure 20).

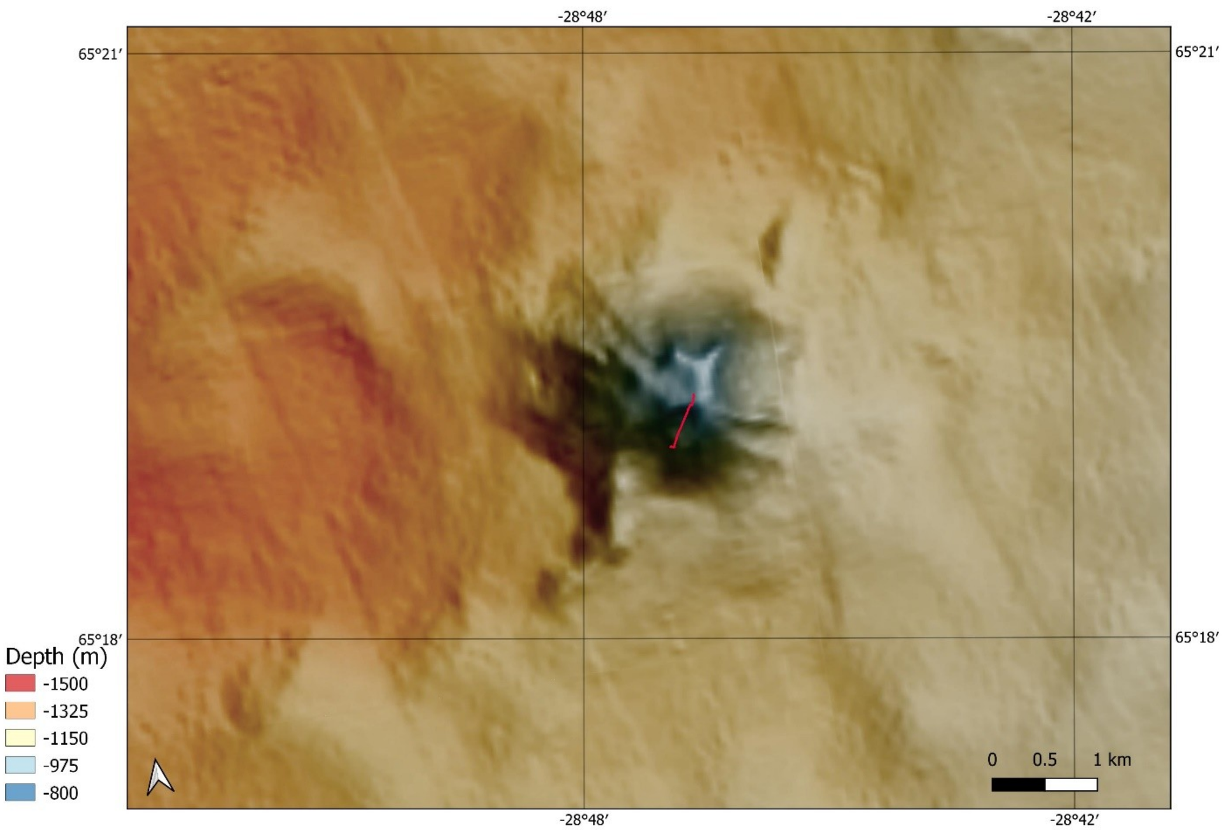

Figure 19: Dive 441 on the south flank of a conical shaped mountain.

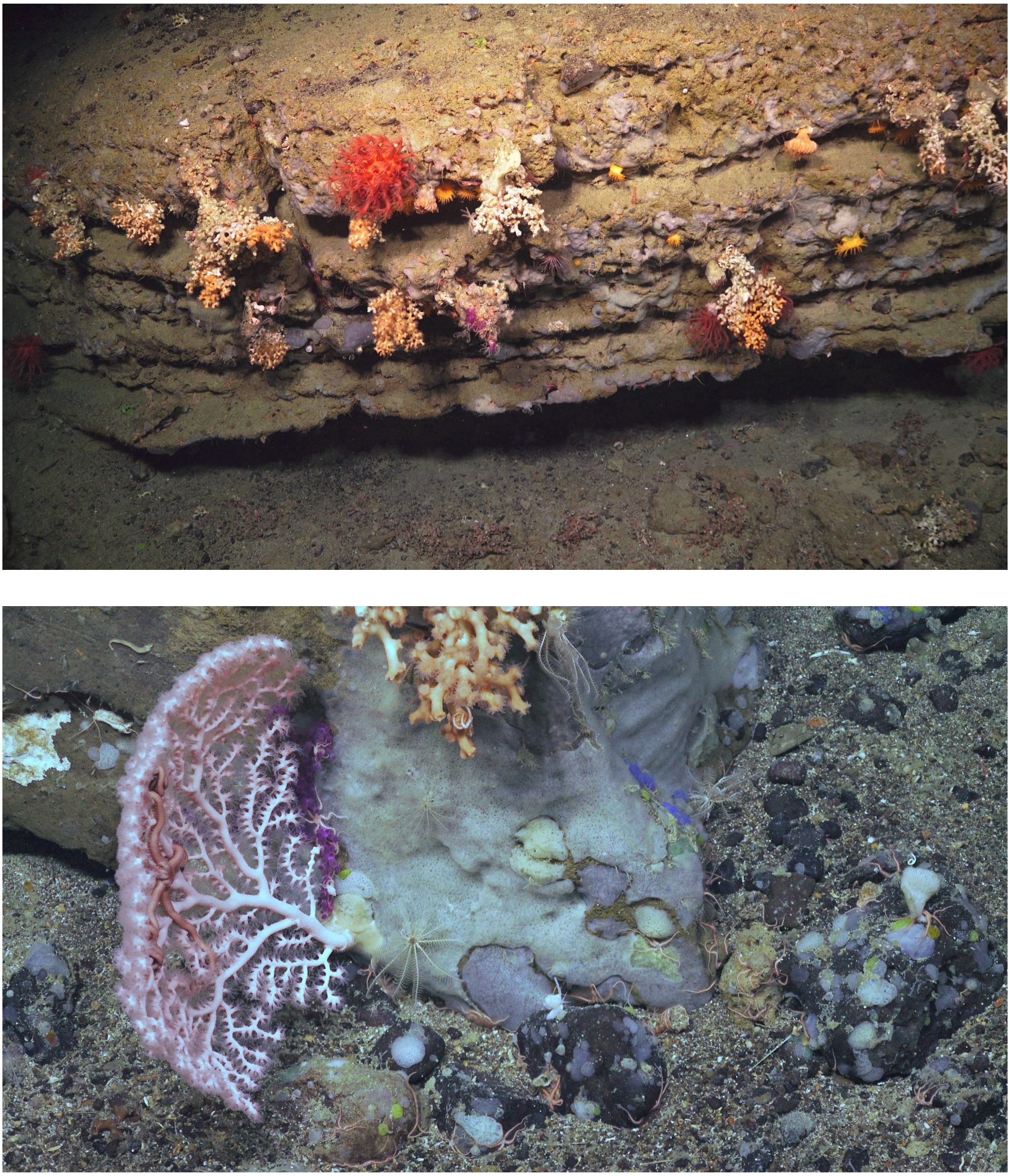

Figure 20: Multiple coral species were attached a the steep wall on top of the conical mound.

Greenland slope: Dives 442 to 444

We attempted three dives to characterize the Greenlandic slope towards the Irminger Basin. In this location, ADCP measurements suggested the presence of the overflow current, with high current velocities near the bottom. During the fist two dives the current was too strong and the ROV was not able to reach the bottom. In the last attempt the ROV reached the seabed, but the current was still very strong and the ROV was not released from the Tether Management System (TMS). Nevertheless it was possible to maneuver the ROV to get an overview of the seafloor and the benthic fauna in the vicinity at a depth of 490 m. In this location gravelly sediments were predominant, with large fan-shaped and irregular sponges, and occasional Actiniarians (figure 21).

Figure 21: Fan shaped sponges on gravelly bottom.

Kangerdlugssuaq Trough: Dives 445 to 447

Dives 445, 446 and 447 were carried out in the Kangerdlugssuaq trough on the Greenlandic shelf. In this areas iceberg plough marks were conspicuous features in the sea bed. Among these three dives, dive 445 was the shallowest, at an approximate depth of 376 m (figure 22). The fauna was dominated by *Actinauge* sp. sea anemones on hard bottom with cobbles, gravel and sand, with occasional white and purple cauliflower corals and sea stars (figure 23).

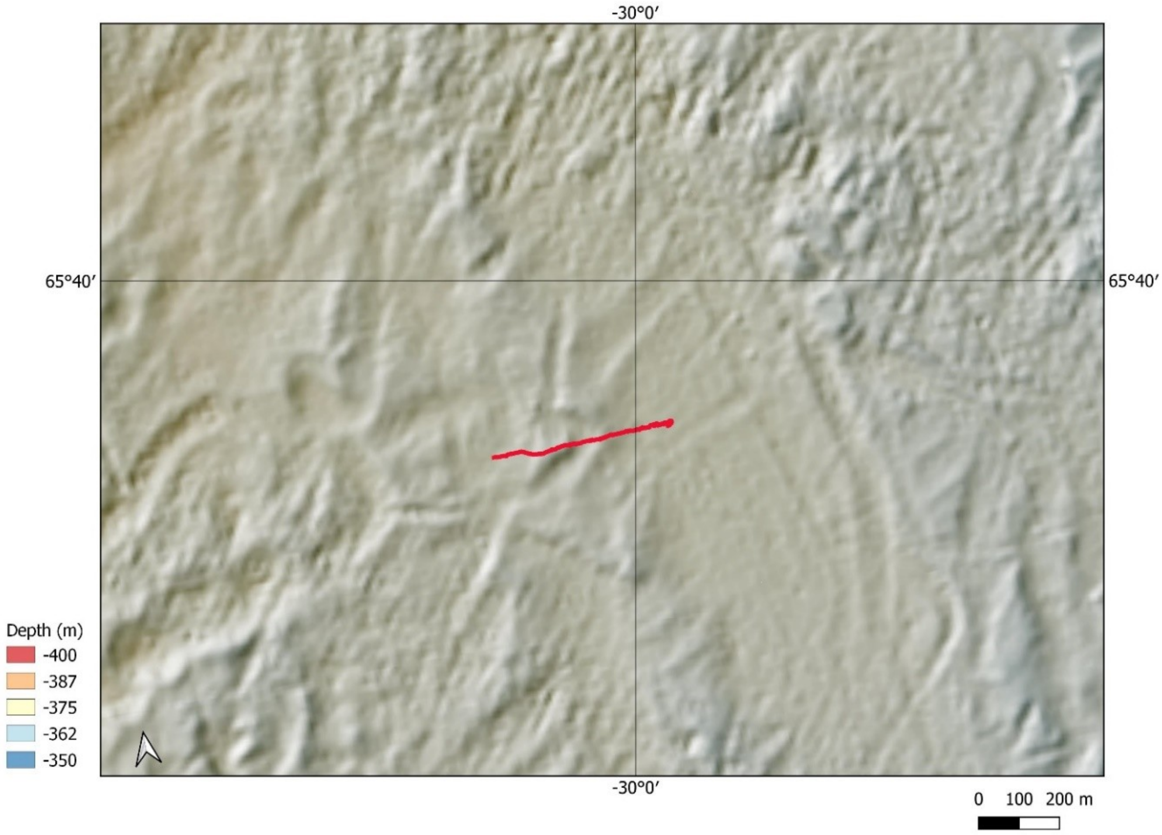

Figure 22: Track of dive 445, crossing iceberg plough marks.

Figure 23: Dense aggregation of sea anemones (Actinauge) and a cauliflower coral.

Dive 446 also crossed iceberg plough marks (figure 24). Here the sediment was soft and muddy, characterized by the large seapen *Umbellula encrinus* and and the carnivorous sponge Cladorhizidae (figure 25). Marks on the seabed were observed, potentially caused by iceberg movement or bottom trawling (figure 26).

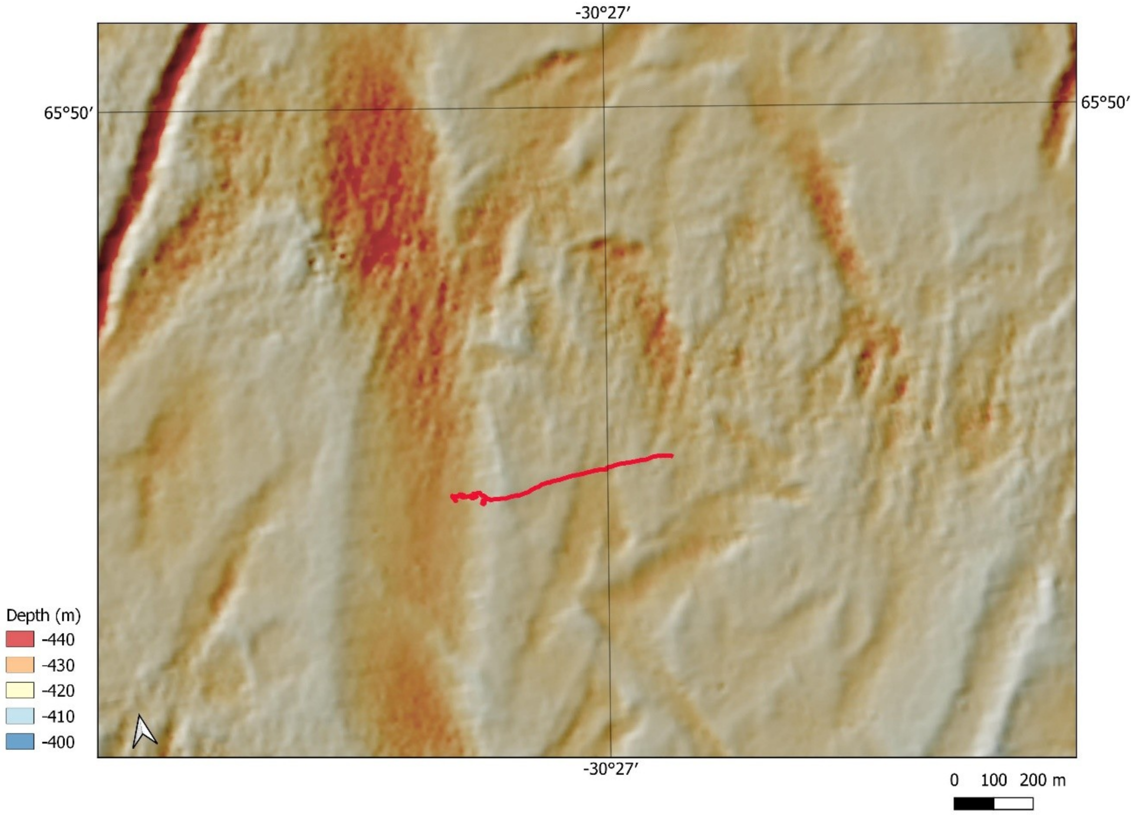

Figure 24: Track of dive 446 on the Kangerdlugssuaq trough, on the Greenlandic shelf.

Figure 25: Mark on the seabed observed during ROV dive. It is not clear if this was caused by iceberg movement, or by the otter board of a bottom trawler.

Figure 26: Umbellula encrinus. Cladorhizidae sponges can be seen in the background.

Dive 447 was carried out deeper in the Kangerdlugssuaq Trough, at a depth of 404 m (figure 27). Here the seabed was characterized by very soft bottom, where parallel trawl mark lines where clearly observed (figure 28). In this area we observed small sponges (*Stylocordyla borealis*, *Asbestopluma* sp.), cauliflower corals, and a single *Umbellula encrinus* (figure 29).

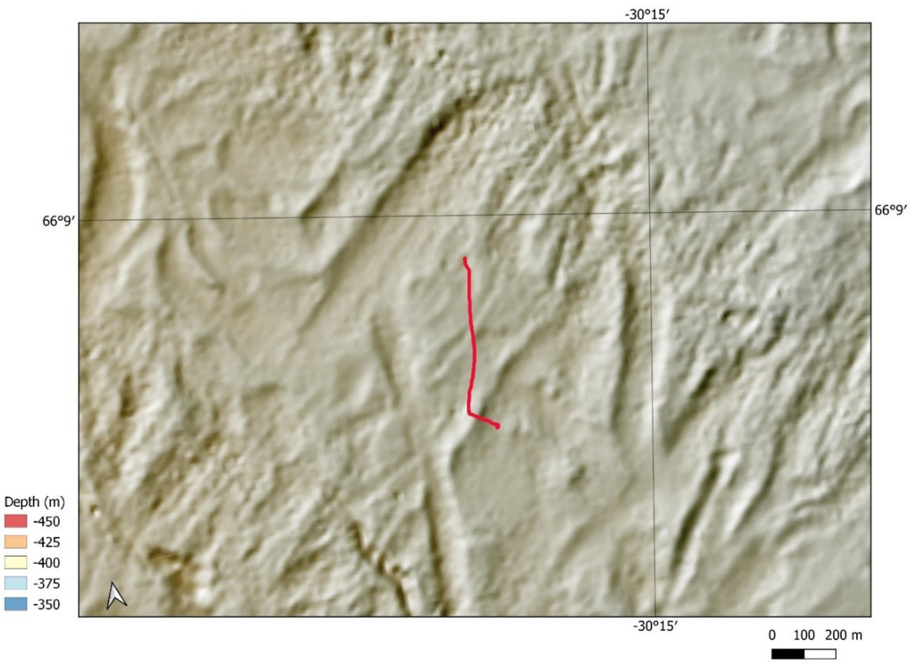

Figure 27: Track of dive 447 on the seafloor. Iceberg plough marks are crossing the region.

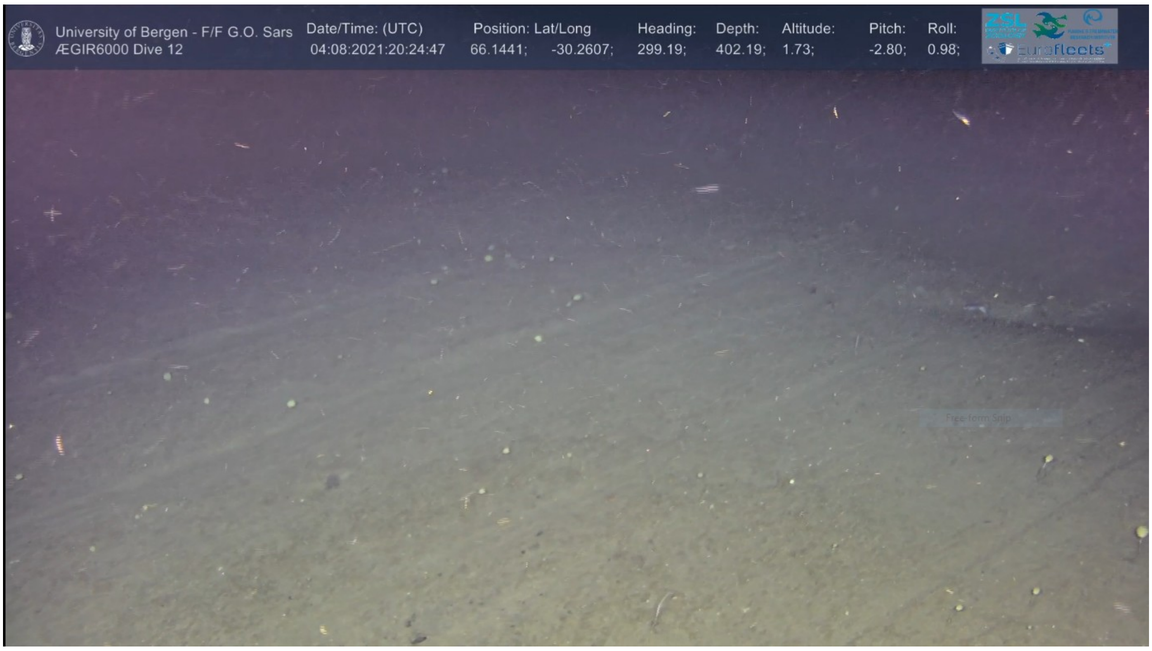

Figure 28: Trawl marks on the seabed observed during dive 447.

Figure 29: Umbellula encrinus, approximately 1 m hight, anchored in the soft sediment. High density of krill were observed, attracted to the ROV lights.

Center transect

Dohrn Bank: Dives 448 and 449

Dives 448 and 449 were carried out on the Dohrn Bank, on the Greenland shelf. As in the Kangerdlugssuaq Trough, this area was also characterized by multiple iceberg plough marks visible in the multibeam bathymetry. Dive 448 took place at a depth of ~320 m (Figure 30). The seabed here was comprised by mixed soft and hard sediment, with high density of sponges on the cobbles and on the hard ground (figure 31). The depth during dive 449 was similar (figure 32). Here we observed cobbles and boulders with attached or semi-attached benthic fauna like crinoids, bryozoans, ophiuroids, *Gersemia* and porifera (figures 33 and 34).

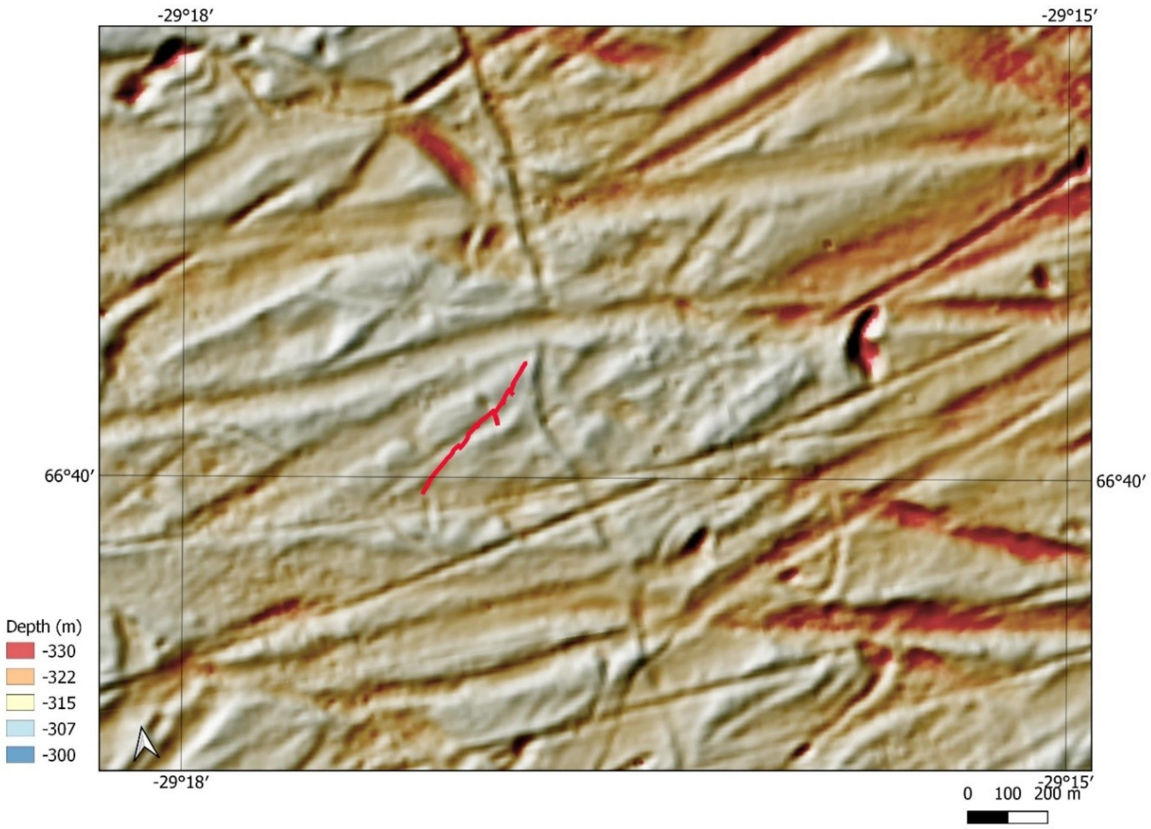

Figure 30: Dive 448 on the seafloor. Iceberg plough marks can be seen crossing the region.

Figure 31: Thin layer of soft sediment on hard bottom observed during dive 448. Various types of sponges and crinoids are attached to the cobbles.

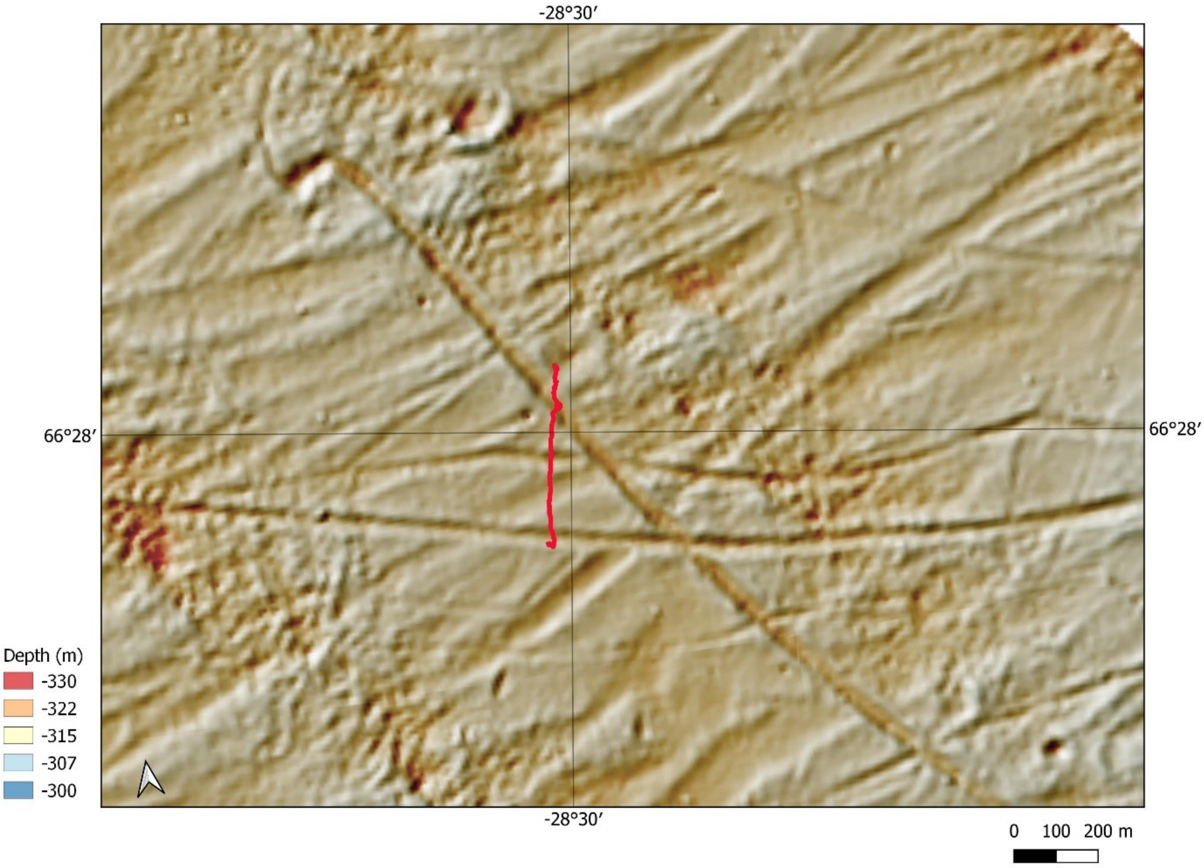

Figure 32: Dive 449 on the seafloor. Iceberg plough marks are visible crossing the region.

Figure 33: White branching Bryozoa.

Figure 34: Large boulder with sponges and other attached fauna.

Greenland-Iceland Ridge: Dives 450 to 454

Five dives were carried out to characterize benthic habitats on the Greenland-Iceland Ridge. Dive 450 was carried out at a depth of 493 m, on the northwest flank of the channel that bisects the ridge (Figure 35). Here we found hard bottoms with gravel, cobbles and boulders, with aggregation of sponges and cauliflower corals (figures 36 and 37).

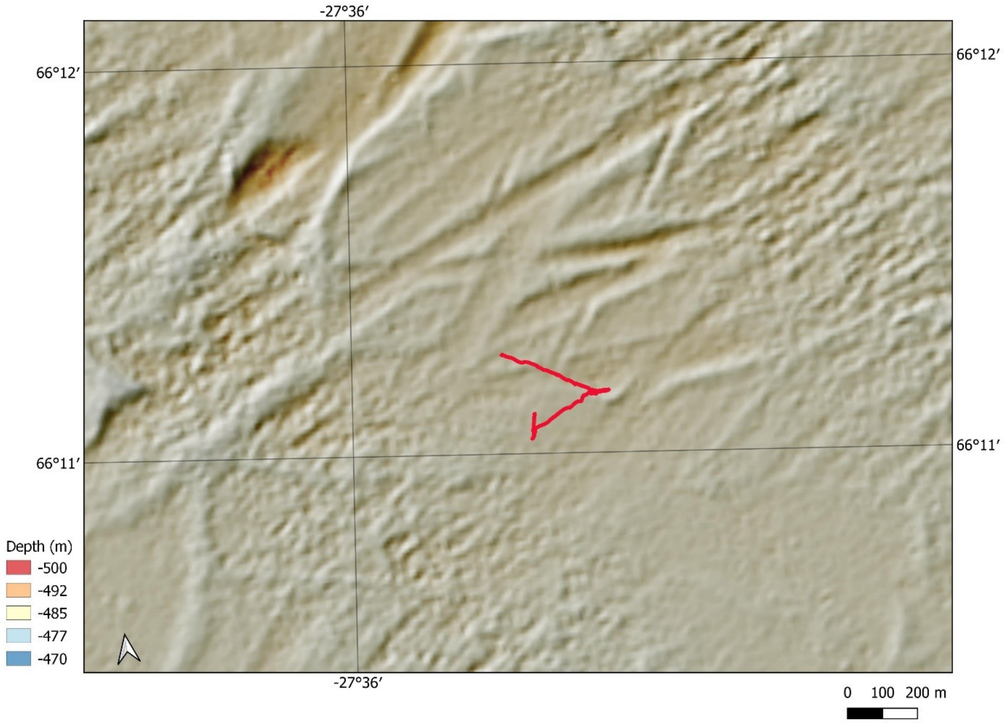

Figure 35: Dive 450 on the Greenland-Iceland ridge.

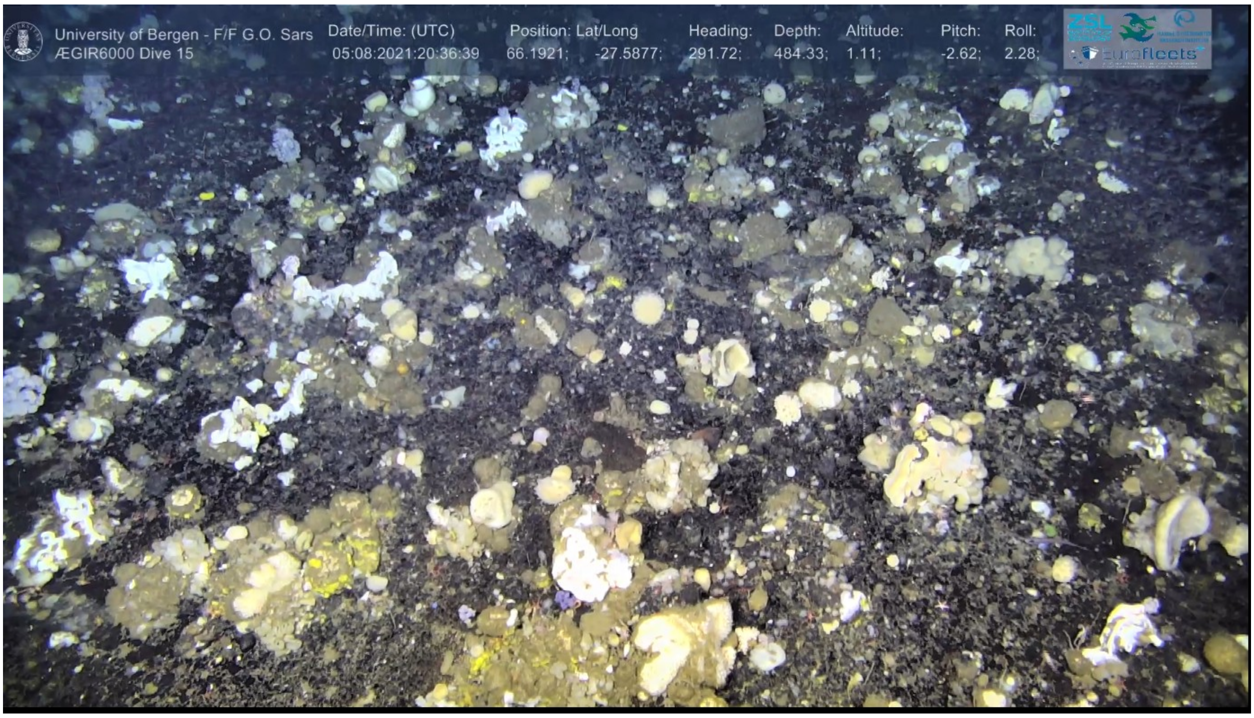

Figure 36: Aggregation of sponges and cauliflower corals observed during dive 450.

Figure 37: Fan shaped sponges and other fauna on a large boulder observed during dive 450.

Dive 451 was carried out on the within the Greenland-Iceland ridge channel, at 650 m depth (figure 38). This location was characterized by hard bottoms and a high diversity of benthic organisms (figure 39).

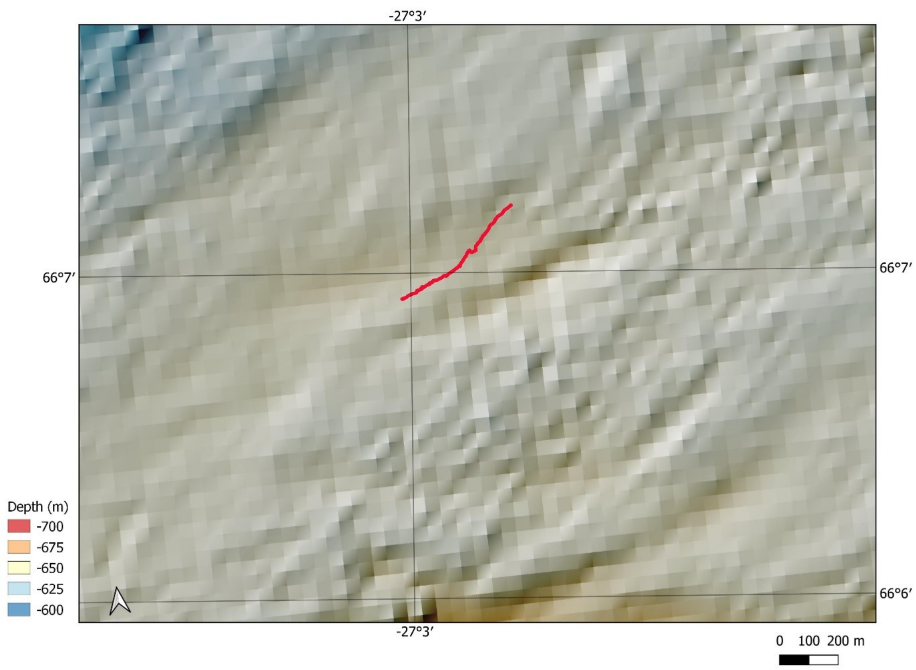

Figure 38: Dive 451 on the channel that bisects the Greenland-Iceland ridge.

Figure 39: Octopus among diverse sponge types observed during dive 451.

Dive 452 was carried out on the north flank of the channel, at depth of 522 m. In this site we did not collected multibeam data, due to time constraints. Nevertheless, it is expected that this area will be surveyed by the Marine and Freshwater Research Institute in the near future. In this location we observed hard bottom with various types of sponges and other fauna including numerous basket stars (*Gorgonocephalus* sp.) (figure 40).

Figure 40: Sponges and basket stars (Gorgonocephalus sp.) observed during dive 452.

The dive 453 was conducted on the Greenland-Iceland Ridge, in the slope area off the Icelandic shelf (figure 41). This dive was planned to be broadcasted live through the Facebook page of the Zoological Society of London (https://www.facebook.com/officialzsl/videos/983927399096891/?t=2303). The location of the dive was selected to be in proximity with a previous dive carried out by MFRI that showed the presence of a high diversity of benthic organisms, to ensure the presence of interesting images for the viewers of the broadcast. During the dive the images revealed a high density of colorful sponges and cauliflower corals with other faunal groups on hard bottom. The broadcast was narrated by Emmeline Broad and other members of the scientific crew, who also answered questions posted by the public.

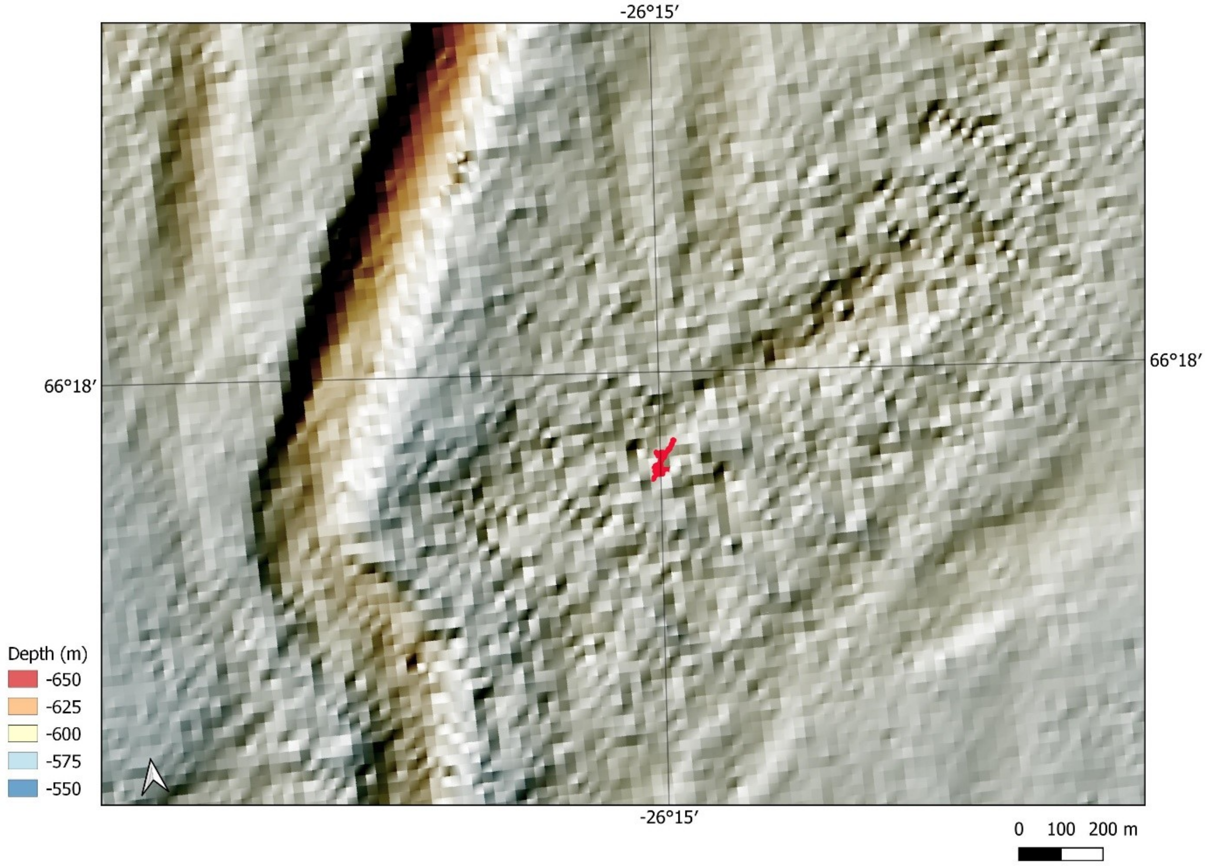

Figure 41: Track of dive 453 on the slope off the Westfjords, Iceland. A large iceberg plough mark is visible west of the transect.

Figure 42: Dense and diverse community of sponges and caulflower corals observed in dive 453.

Dive 454 was and additional dive included to the cruise plan to explore the benthic communities of an area on the northern slope of the Greenland-Iceland ridge (figure 43). This area is known as the “potato garden” by Icelandic fishermen, because of the sponges captured as by-catch in this location. This area has been an increase of fishing effort in recent years. Contrary to what was expected we did not observed a high density of sponges, but we did saw a variety of benthic organisms on boulders and soft sediments (figure 44).

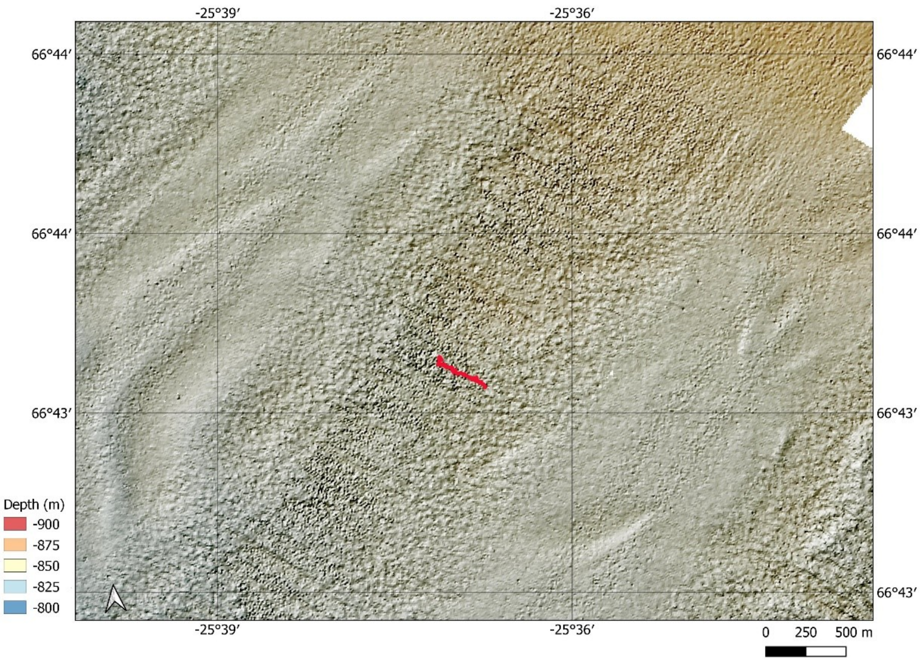

Figure 43: Track of dive 454 on the area known as the "potato garden". The roughness of the topography is artifacts from the multibeam data.

Figure 44: Boulders and cobbles on soft sediment with attached fauna observed in dive 454.

Northern transect

Greenland slope and Blosseville Basin: Dives 455 to 459

A series of five dives were carried out to describe benthic habitats on the Greenland slope towards the Blosseville Basin, north of the Greenland-Iceland Ridge. The first dive, numbered 455, was located on the Greenland shelf at ~ 308 m deep (figure 45). Similar to other locations on the Greenland shelf, multiple iceberg plough marks were evident on the multibeam bathymetry. Here the seabed consisted of a mixture of mud and hardened bottoms. Here we observed two types of sponge communities:) a diverse community comprised of multiple types of sponges on the hard ground (figure 46), and a more homogenous sponge garden with round sponges (figure 47).

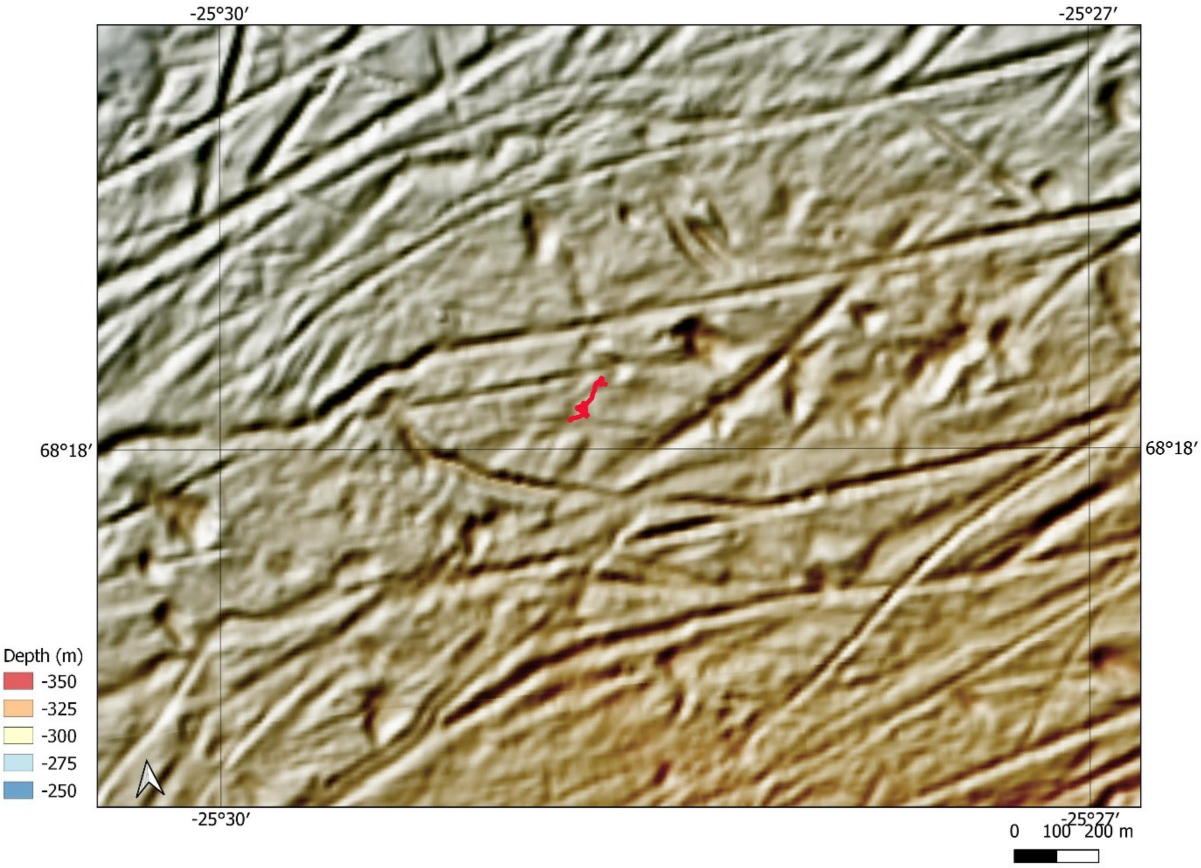

Figure 45: Track of dive 455 on the Greenland shelf.

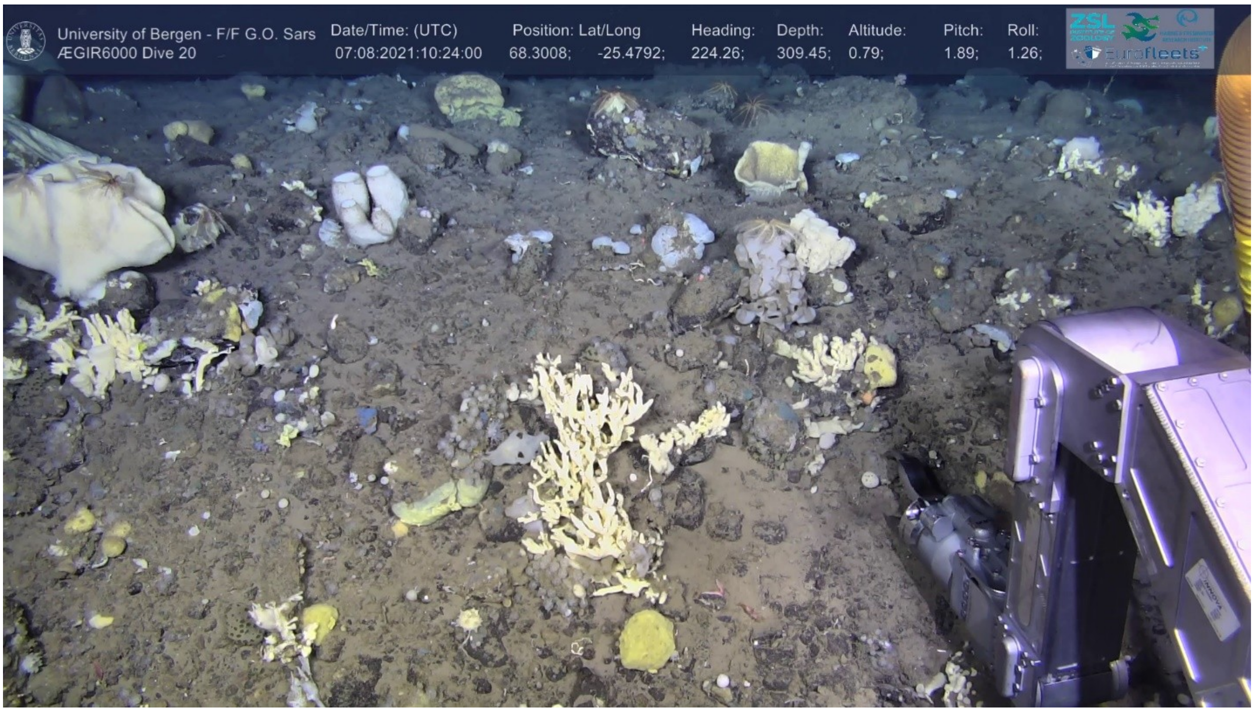

Figure 46: Sponge communities comprised of hexactinellids and demosponges observed during dive 455.

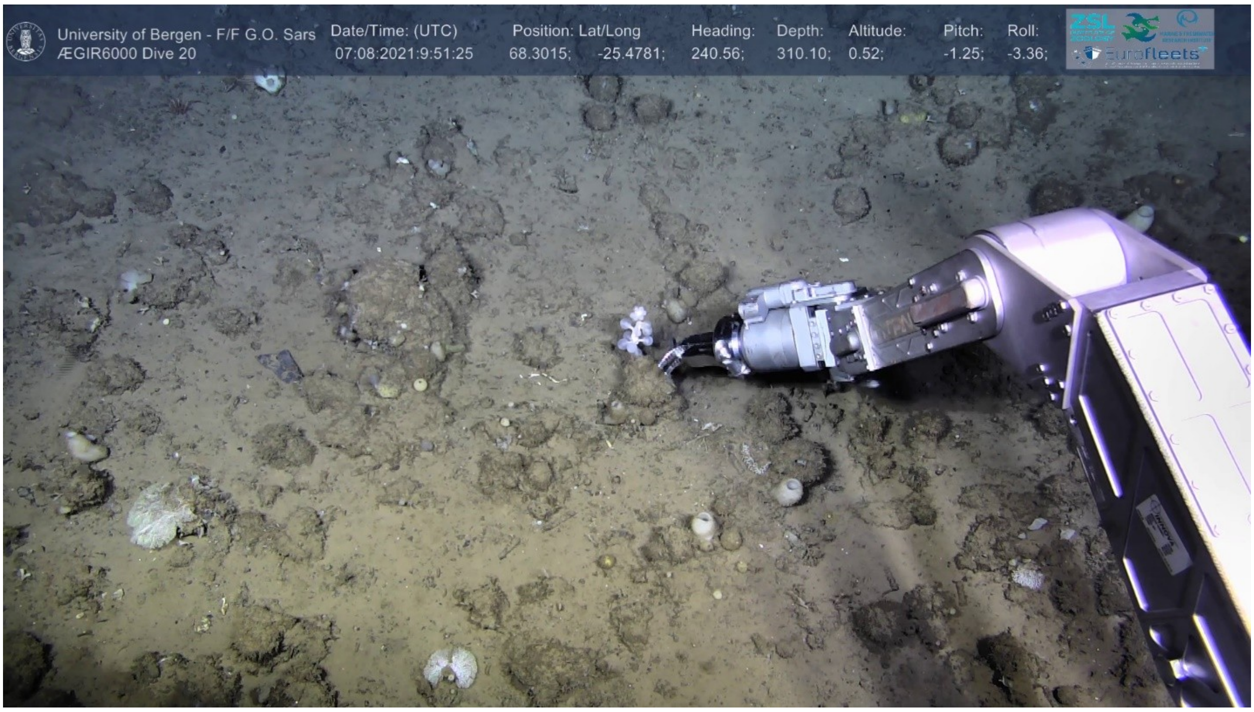

Figure 47: Round, large sponges on soft bottom observed in dive 455.

Dive 456 was conducted on the shelf break off the Greenlandic shelf, at 521 m deep (Figure 48). Hard sandy gravelly bottom with cobbles and boulders were observed, with relatively low density of benthic organisms (Figure 49).

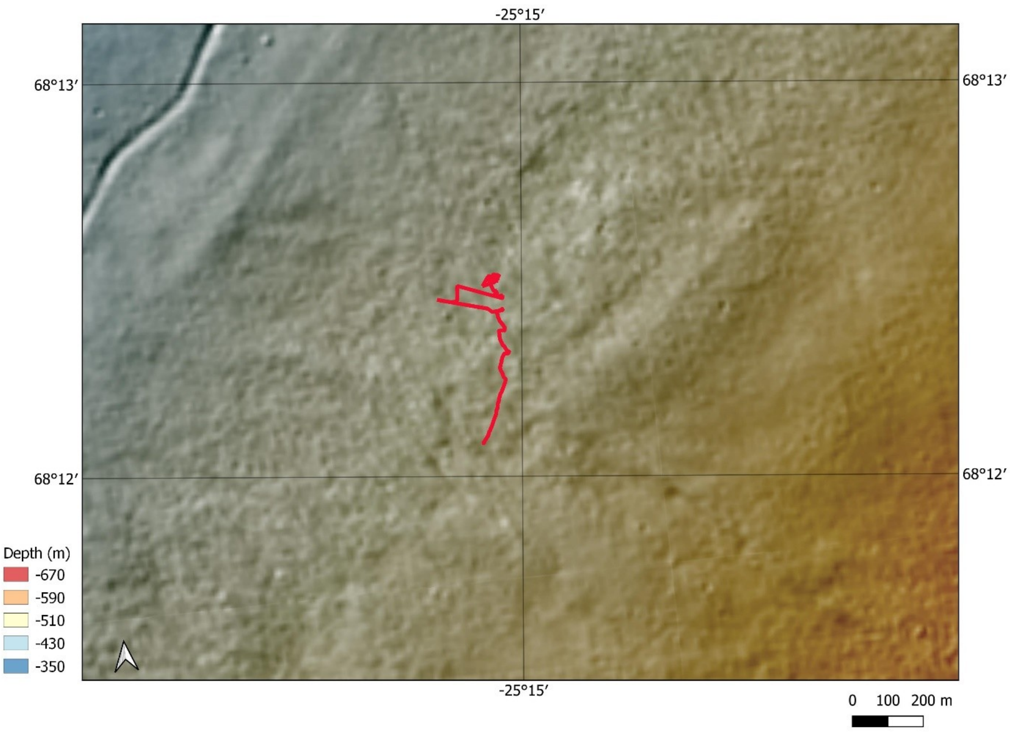

Figure 48: Track of dive 456 on the Greenland shelf break.

Figure 49: Hard bottom with sand gravel and cobbles.

Dive 457 was carried out on the Greenlandic shelf north of the GIR, at a depth of 1158 m (figure 50). Here soft sediment were dominant. Sea pens like *Umbellula* and the cold-water sponges *Chondrocladia grandis*, and *Cladorzia* sp. were observed. Other benthic fauna included the sea spider *Colossendeis proboscides (figure 51)*.

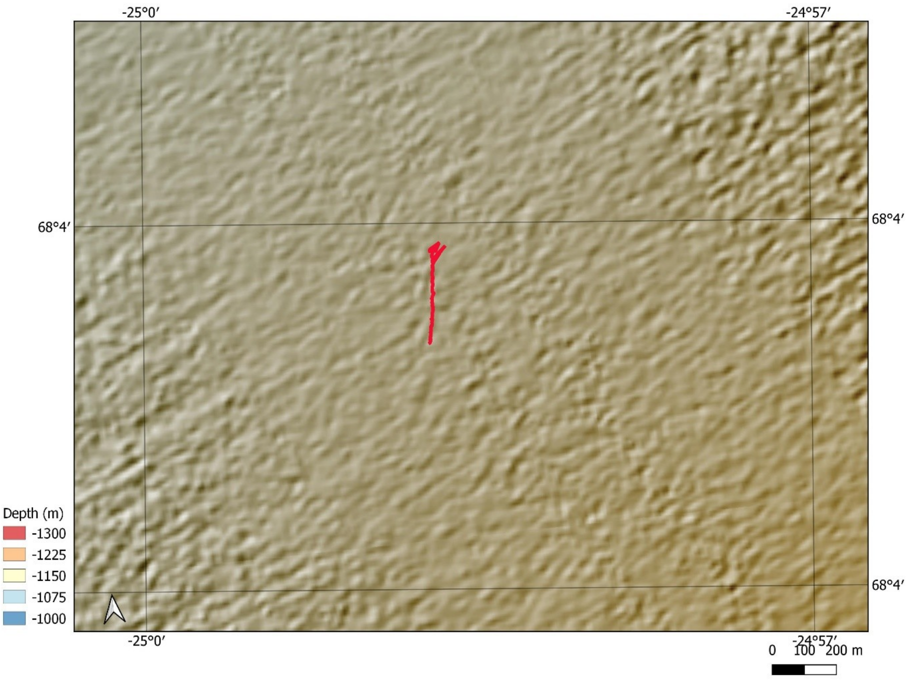

Figure 50: Dive 447 on the slope of the Greenland shelf, north of the Greenland-Iceland rige.

Figure 51: Sea spider Colossendeis proboscides.

Dive 458 replaced a planned dive at 900 m could not be carried out because of the presence of icebergs. Because at the time of the dive there were icebergs still present in the area, we did not obtained multibeam data in this location. Images from the dive indicated that the area is dominated by soft sediments. Sponges were observed on pebbles and cobbles or in the soft sediment like *Chondrocladia grandis* (figure 52).

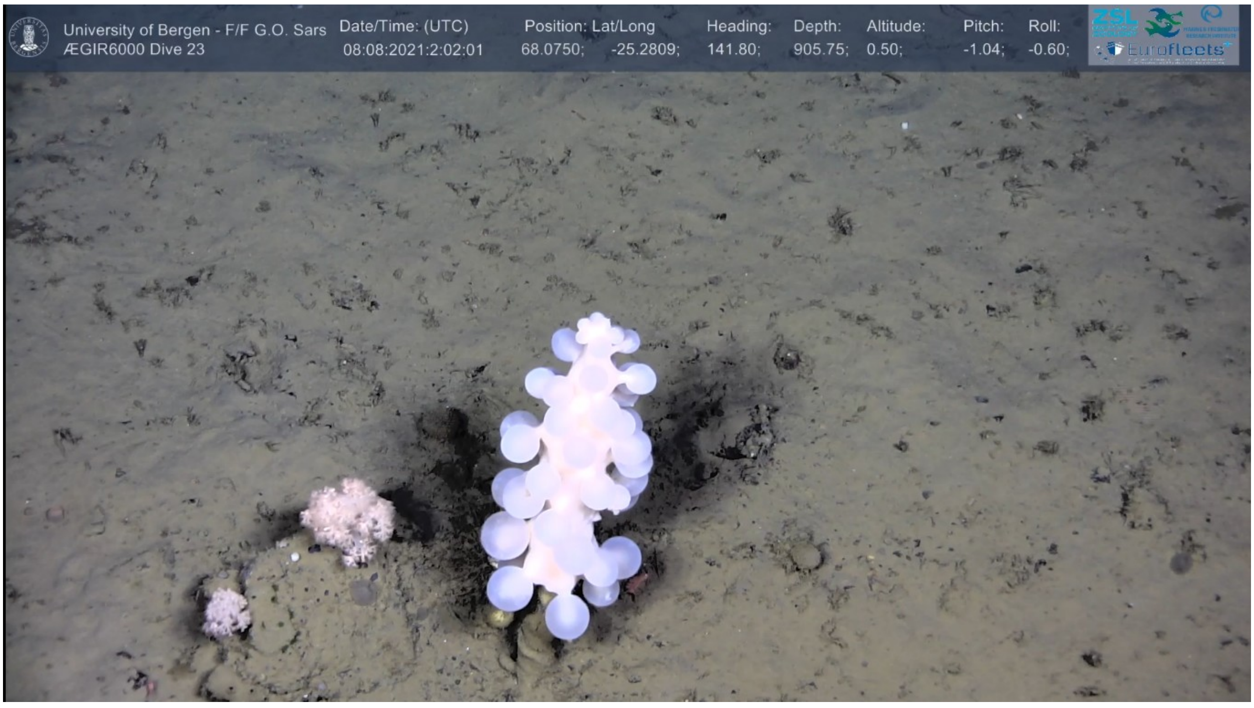

Figure 52: Cold water sponge Chondrocladia grandis.

Dive 459 was the deepest dive in the northern transect, and the second deepest in the entire survey. The dive was carried out on the Bloseville Basin at 1471 m deep (figure 53). The area was covered with very soft sediments, with scattered drop stones and gravel where sponges and other fauna were observed (figure 54).

I

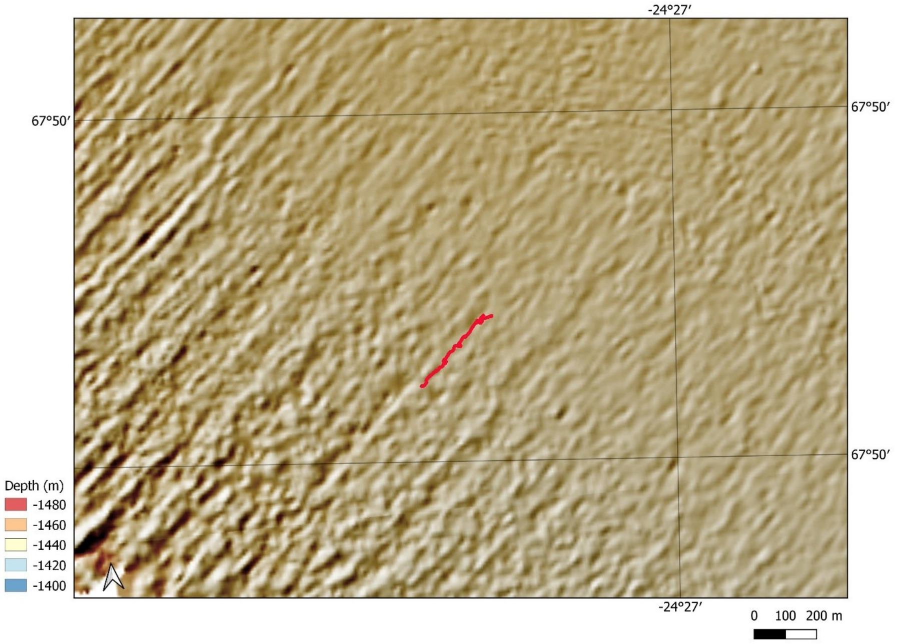

Figure 53: Dive 459 on the bottom of the Blosseville basin at 1471 m deep.

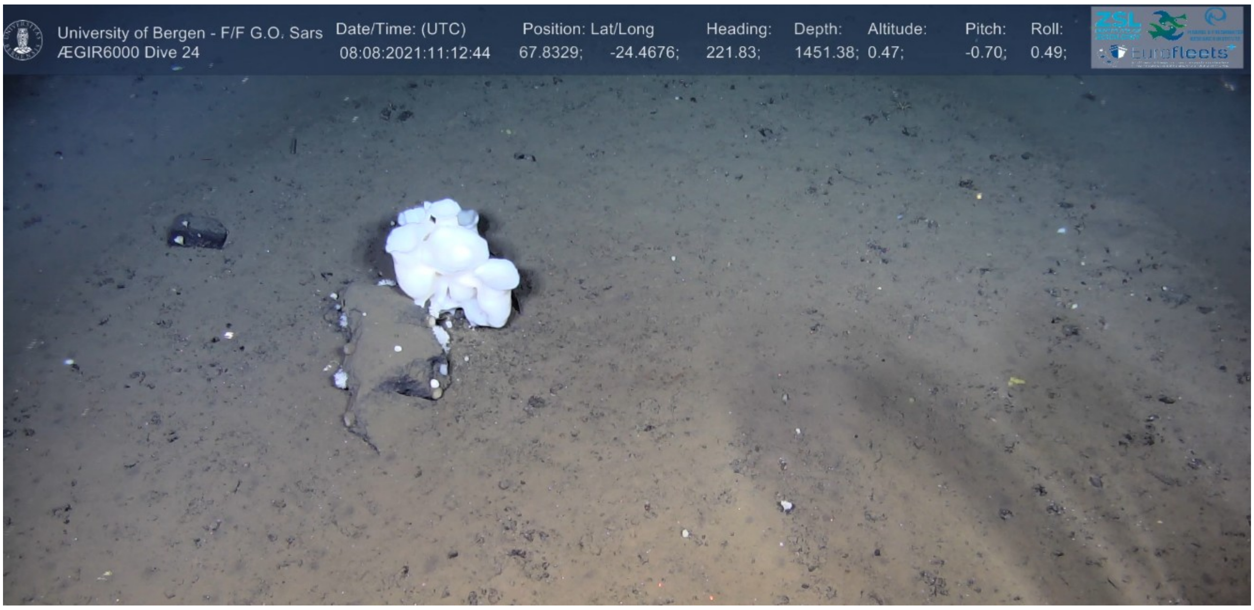

Figure 54: Soft bottom with gravel and attached fauna observed during dive 459.

Iceland slope: Dives 460-463

The last four dives were located on the Icelandic slope, north of the Greenland-Iceland ridge. The first three dives completed the transect that was initiated in dive 456. Dive 460 was located at a depth of 979 (figure 55). The seabed was characterized by soft bottom with pebbles and relatively low densities of attached epibenthic organisms (figure 56). Similar observations were carried out during dive 461 at 695 m deep (figure 57), and during dive 462 at 334 m deep (figure 58).

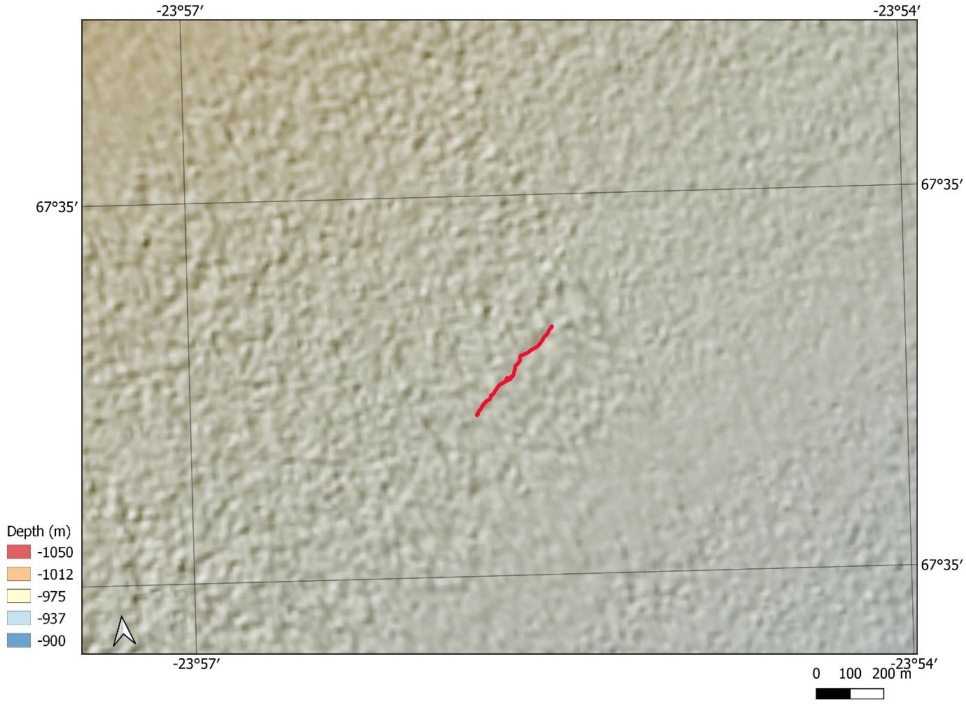

Figure 55: Track of dive 460 on the Icelandic slope.

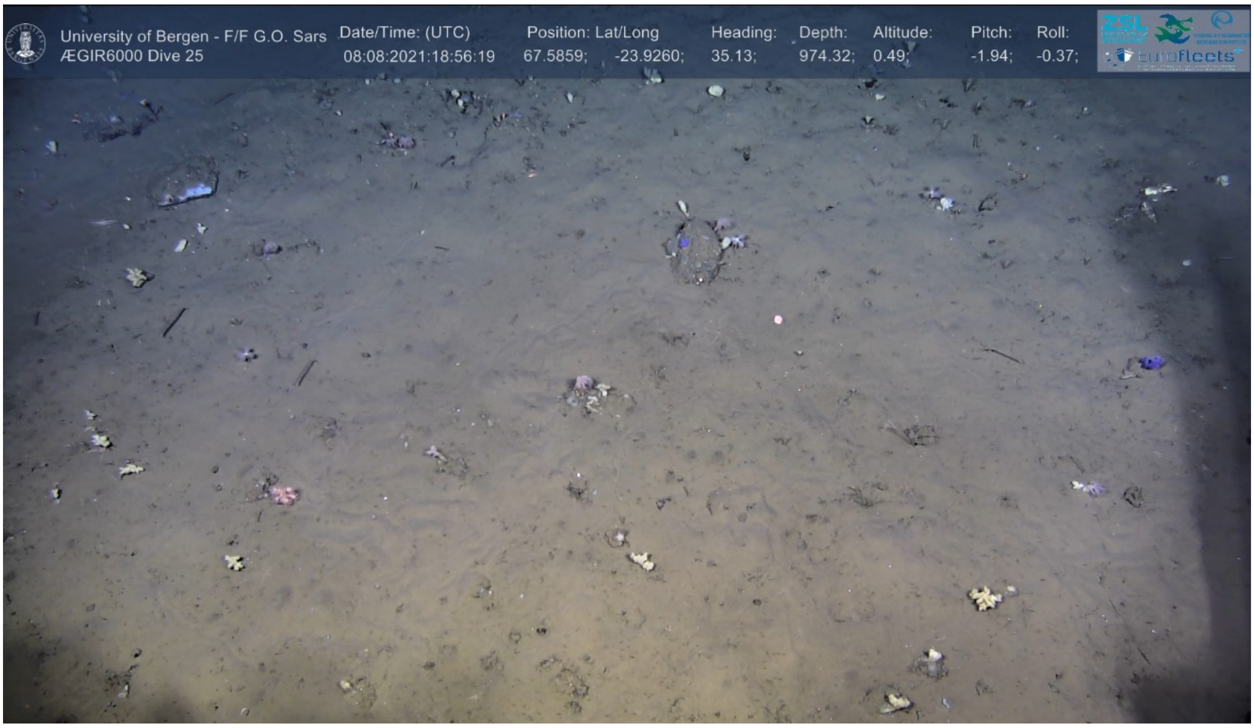

Figure 56: Soft bottom and pebbles with attached fauna observed during dive 461.

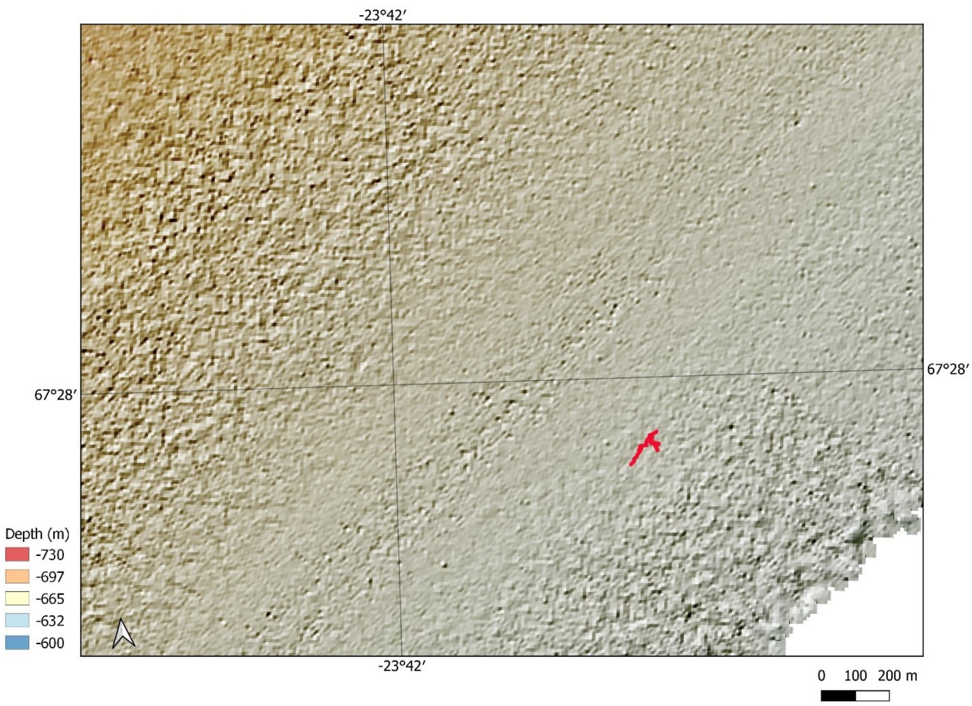

Figure 57: Video track of dive 461.

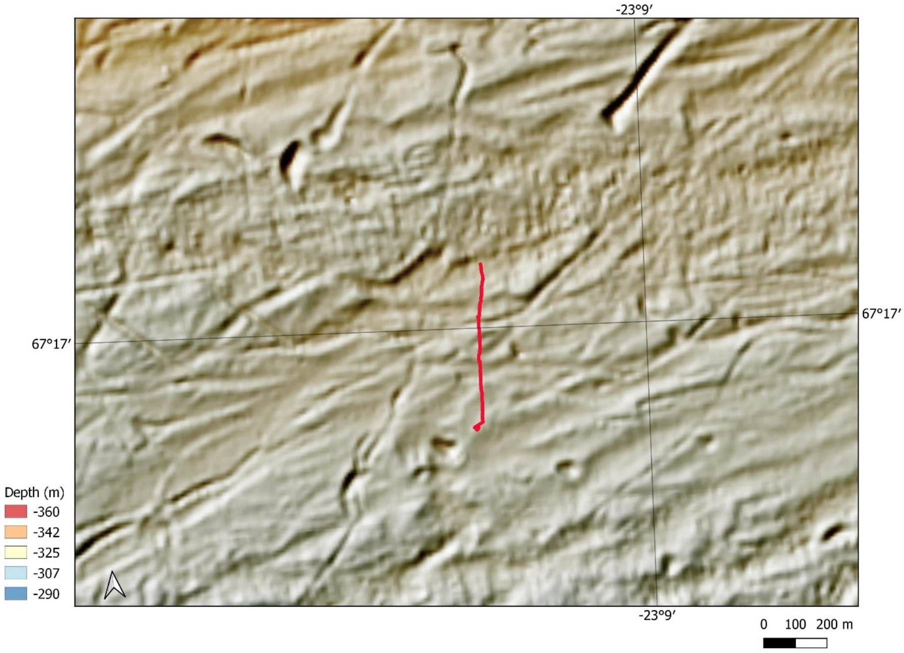

Figure 58: Track of dive 462 on the Icelandic slope.

The last dive of the survey was conducted in the northern part of the slope off the Westfjords (figure 59). Two separate communities were observed in this location. One was comprised of a diverse group of sponges, basket stars and sea lilies (figure 60), on the hard bottom with thin layer of fine sediment with dense cover of diverse sponges and other animal groups, including basket stars and sea lilies. This community alternated with other dominated by sea pens in areas with soft sandy bottoms (figure 61). This dive was streamed live through the Facebook page of Eurofleets+, albeit without live commentary (https://www.facebook.com/eurofleets/videos/225176132722781/).

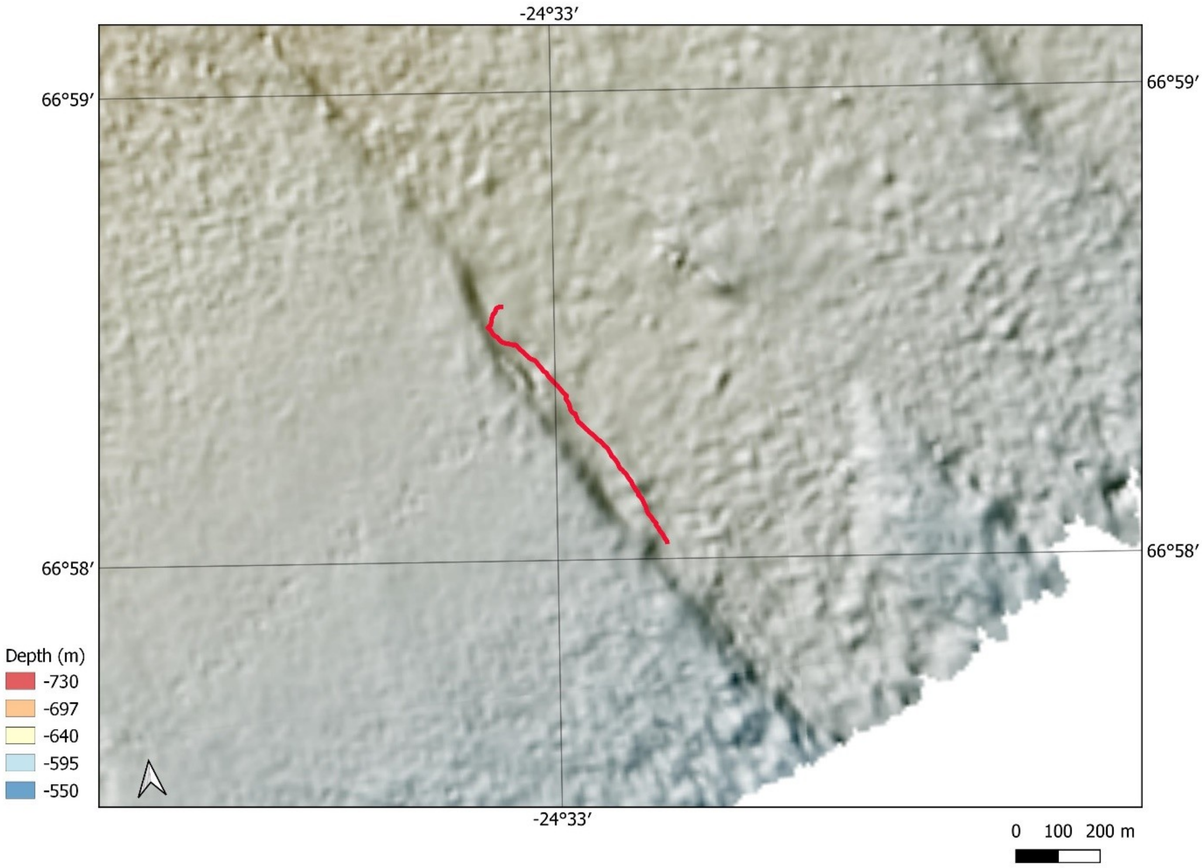

Figure 59: Track of dive 463 on the slope off the Westfjords, Iceland. The dive followed a channel on the seabed.

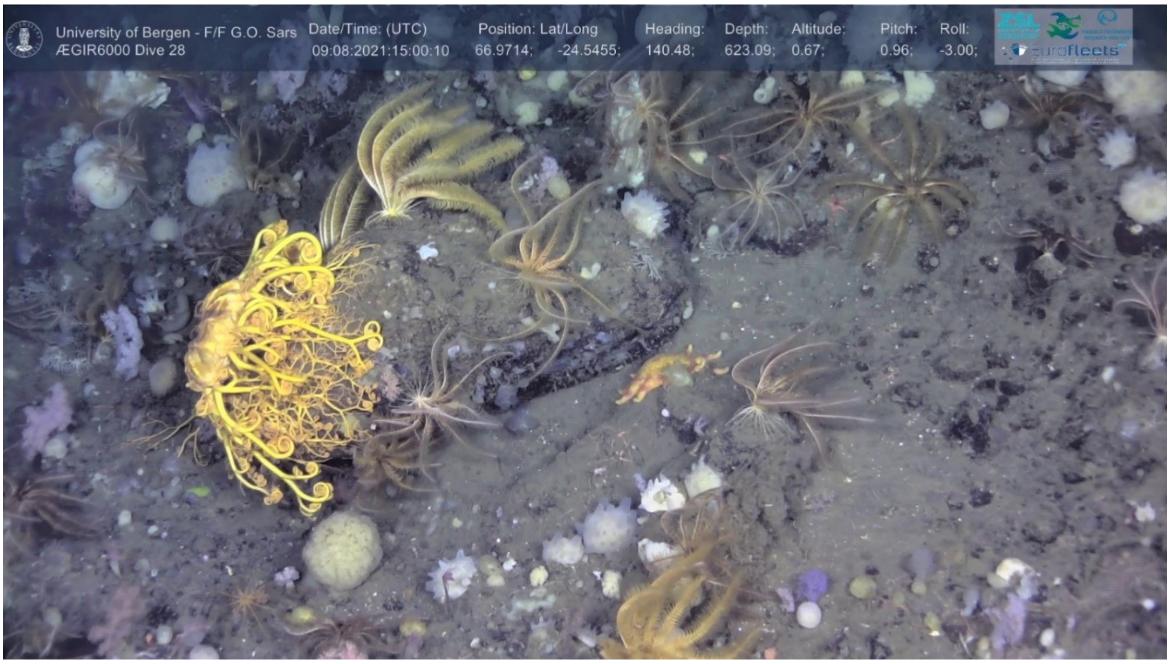

Figure 60: Diverse hard-bottom community observed in dive 463.

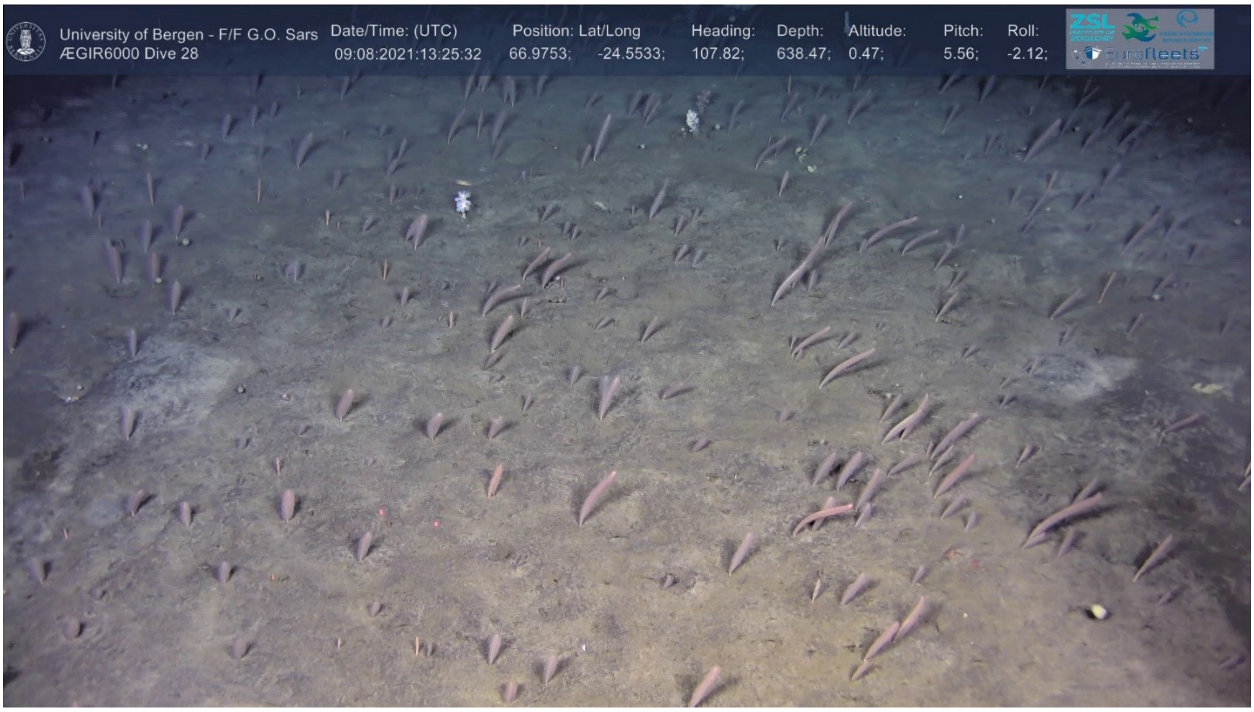

Figure 61: High density of sea pens observed during dive 463.

Cruise participants

No.	Name	Early career (Y/N)	Gender	Affiliation	On-board tasks
1	Julian M. Burgos	N	M	MFRI	Cruise leader
2	Andreas Macrander	N	M	MFRI	CTDs, hydrography
3	Davíð Þór Óðinsson	N	M	MFRI	CTDs, multibeam mapping
4	Steinunn H. Ólafsdóttir	N	F	MFRI	Video annotation, sample processing
5	Bylgia Sif Jónsdóttir	Y	F	MFRI	Video annotation, sample processing
6	Laure de Montety	N	F	MFRI	Video annotation, sample processing
7	Petrún Sigurðardóttir	Y	F	MFRI	Video annotation, sample processing
8	Nanette Hammeken	N	F	GINR	Video annotation, sample processing, hydrography
9	Chris Yesson	N	M	ZLS	Video annotation, sample processing
10	Emmeline Broad	Y	F	ZLS	Video annotation, sample processing, live feeds
11	Roeland Develter (*)	Y	M	VLIZ	ROV trainee

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Station List

Station ID	Gear	Date (2021)	Time (UTC)	Latitude	Longitude
198	CTD	2/8	02:35	64°50,46	-28°52,36
436	ROV	2/8	06:28	64˚50,45	-28˚52,36
199	CTD	2/8	09:59	64°46,12	-28°51,62
437	ROV	2/8	12:02	64°46,79	-28°51,73
438	ROV	2/8	15:55	64°43,05	-29°06,23
200	CTD	2/8	19:24	64°43,07	-29°14,66
439	ROV	2/8	21:08	64°43,07	-29°14,66
201	CTD	2/8	01:37	64°58,35	-29°20,34
440	ROV	3/8	03:50	64°58,38	-29°20,41
202	CTD	3/8	09:24	65°18,99	-28°46,85
441	ROV	3/8	11:12	65°18,98	-28°46,93
203	CTD	3/8	15:24	65˚26,79	-29°13,76
204	CTD	3/8	16:38	65°28,58	-29°18,91
205	CTD	3/8	19:30	65°30,02	-29°24,04
206	CTD	3/8	20:52	65°32,03	-29°31,01
207	CTD	4/8	01:47	65°34,28	-29°37,72
208	CTD	4/8	05:04	65°40,31	-29°59,92
445	ROV	4/8	05:59	65°40,31	-29°59,90
209	CTD	4/8	11:18	65°48,69	-30°27,05
446	ROV	4/8	13:42	65°48,97	-30°27,51
210	CTD	4/8	17:47	66°08,68	-30°15,65
447	ROV	4/8	20:20	66°08,65	-30°15,65
211	CTD	5/8	02:00	66°39,76	-29°16,25
448	ROV	5/8	02:49	66°39,75	-29°16,84
212	CTD	5/8	10:05	66°28,06	-28°30,07
449	ROV	5/8	10:47	66°28,06	-28°30,07

213	CTD	5/8	16:10	66°11,43	-27°35,33
450	ROV	5/8	18:57	66°11,46	-27°35,31
214	CTD	5/8	23:36	66°06,58	-27°02,94
451	ROV	6/8	00:43	66°06,55	-27°03,04
452	ROV	6/8	06:30	66°23,59	-26°41,78
215	CTD	6/8	09:36	66°17,88	-26°14,90
453	ROV	6/8	10:35	66°17,86	-26°15,02
216	CTD	6/8	17:31	66°43,28	-25°36,74
454	ROV	6/8	19:06	66°43,39	-25°37,03
217	CTD	7/8	07:29	68°18,06	-25°28,64
455	ROV	7/8	09:47	68°18,08	-25°28,69
218	CTD	7/8	13:01	68°12,14	-25°15,12
456	ROV	7/8	15:25	68°12,00	-25°15,12
219	CTD	7/8	19:52	68°04,13	-24°58,74
457	ROV	7/8	21:25	68°05,36	-24°58,67
458	ROV	8/8	01:28	68°04,69	-25°16,96
220	CTD	8/8	06:36	67°50,05	-24°27,85
459	ROV	8/8	10:21	67°50,05	-24°28,16
221	CTD	8/8	16:26	67°35,06	-23°55,75
460	ROV	8/8	17:57	67°35,05	-23°55,80
222	CTD	8/8	22:14	67°27,48	-23°40,95
461	ROV	8/8	23:12	67°27,49	-23°40,91
223	CTD	9/8	04:17	67°17,24	-23°09,75
462	ROV	9/8	04:47	67°16,90	-23°09,76
224	CTD	9/8	10:21	66°58,92	-24°33,31
463	ROV	9/8	13:15	66°58,52	-24°33,19

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