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CCGS Amundsen 2021804 expedition: video sampling and coring on the Northeast Newfoundland slope, Labrador Sea

V.E. Kostylev, L.M. Broom, A.G. Robertson, L. Campbell,
K. MacKillop, and E. Patton

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Canada

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1. BACKGROUND AND OBJECTIVES

The Marine Geoscience for Marine Spatial Planning (MGMSP) Program lead by Natural Resources Canada (NRCan) provides regional geoscience products to support the Department of Fisheries and Oceans (DFO) Marine Spatial Planning and evidence-based decision-making. In August 2019 a joint Geological Survey of Canada (Atlantic) and Canadian Hydrographic Service team carried out multibeam bathymetry mapping and sub-bottom profiling on board the Canadian Coast Guard ship *Louis S. St. Laurent* (LSSL) in the northern part of Orphan Basin, as well as along the shelf break and slope from Orphan Spur to Notre Dame Trough. The multibeam survey gave new insight into surficial geology, geohazards and benthic habitats of the northeast Newfoundland slope, northern part of Orphan Basin and Orphan Spur (Kostylev et al. 2021).

The work in the area continued in 2020 with a *CCGS Amundsen* 2020804 expedition (Kostylev et al. 2020) scientific objectives of which included geological and habitat mapping, identification and dating of geological hazards, and gaining better understanding of geological controls on ecological processes. The sites of interest were located in the West Orphan Basin and northeast Newfoundland slope (Labrador Sea), and included the Northeast Newfoundland Slope Closure - an area known for high-density populations of deep-sea corals, sponges and sea pens.

In summer 2021, the GSC (Atlantic) team continued work on mapping seabed habitats and marine geohazards in the same region. Objectives of the third year of this study were to ground-truth and date several submarine failures through piston coring, and to image unique habitats using the DeepImager – an upgraded underwater video system developed in-house. The work was carried out along the northern part of Orphan Basin and on Orphan Spur.

The expedition was supported by Amundsen Science - the not-for-profit corporation responsible for the management of the scientific mandate of the research icebreaker CCGS *Amundsen*.

2. PARTICIPANTS

For the Geological Survey of Canada purposes, six participants led the different operations on board the ship (Table 1, Figure 1).

Table 1. Participants for the Geological Survey of Canada Amundsen expedition 2021804.

First name	Last name	Organization	Role
Vladimir	Kostylev	Geological Survey of Canada	Chief Scientist
Laura	Broom	Geological Survey of Canada	Physical Scientist
Lori	Campbell	Geological Survey of Canada	Sampling
Angus	Robertson	Geological Survey of Canada	Technician
Eric	Patton	Geological Survey of Canada	Hydrography, GIS
Kevin	MacKillop	Geological Survey of Canada	Sampling

Figure 1. GSC participants of the Amundsen 2021804 expedition. Left to right: Vladimir Kostylev, Eric Patton, Lori Campbell, Kevin MacKillop, Laura Broom, Angus Robertson. Photograph by L. Campbell. NRCan photo 2021-505.

3. SUMMARY OF ACTIVITIES

The *Amundsen* 2021804 expedition took place in the northeast Newfoundland slope and northern Orphan Basin (Figure 2) region between Latitudes 50.2 – 51.5 N and Longitudes 50.5 – 48.5 W.

The expedition departed from St. John's, Newfoundland on the 8th of July, 2021 and returned to St. John's on the 13th of July 2021 (Figure 3). Inclement weather and sea state persisted through most of the trip, which have substantially shortened the time available for deck operations. The cruise activities consisted of sampling the seabed by collecting piston cores, one box core, and bottom camera imagery (Figure 4, Table 2) during daylight hours (approximately 6 am – 6 pm) and surveying the seabed using a sub-bottom profiler and multibeam echosounder during night hours.

The highest priority targets were sampled successfully, and approximately 2000 km^2 of multibeam data and 500 NM of sub-bottom profiler data were acquired (including during transit). The DeepImager camera system was successfully deployed with a new fibreoptic cable and new winch, and effective troubleshooting was carried at sea to overcome communication errors between the winch and the camera.

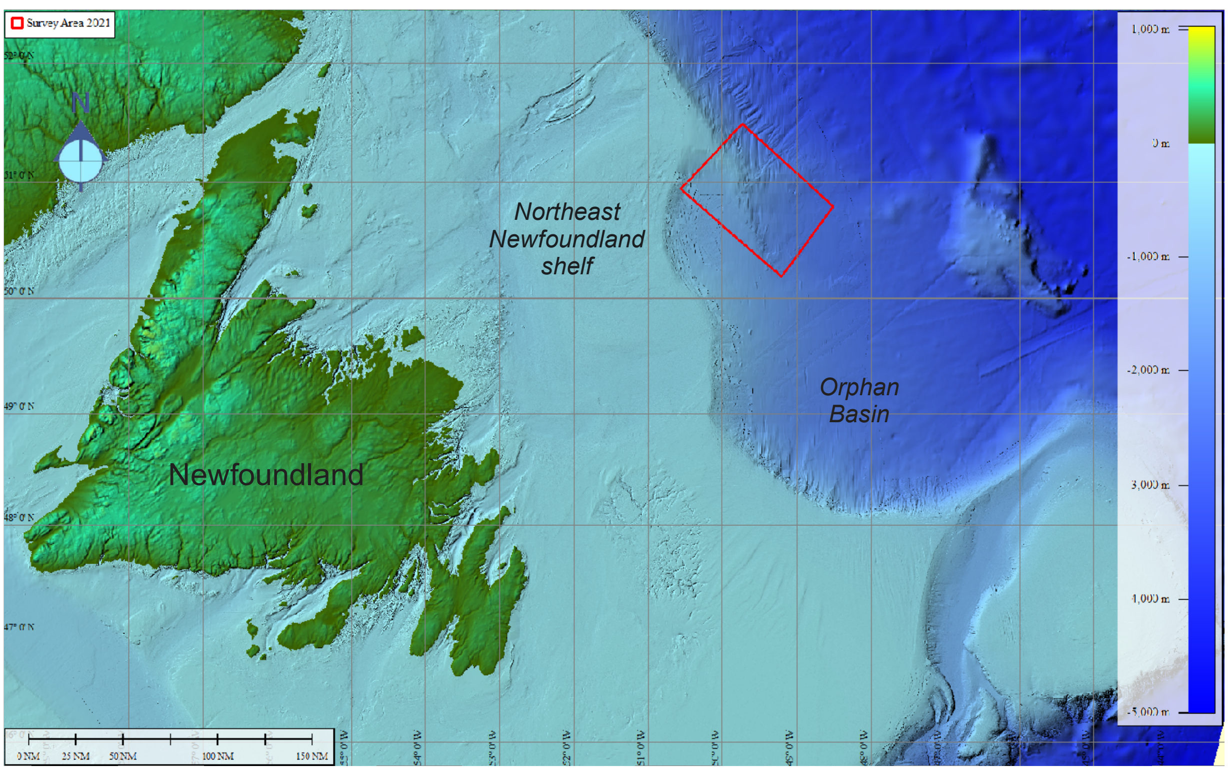

Figure 2. Survey area for CCGS Amundsen 2021804 expedition, July 8th – 13th 2021, indicated with a red polygon.

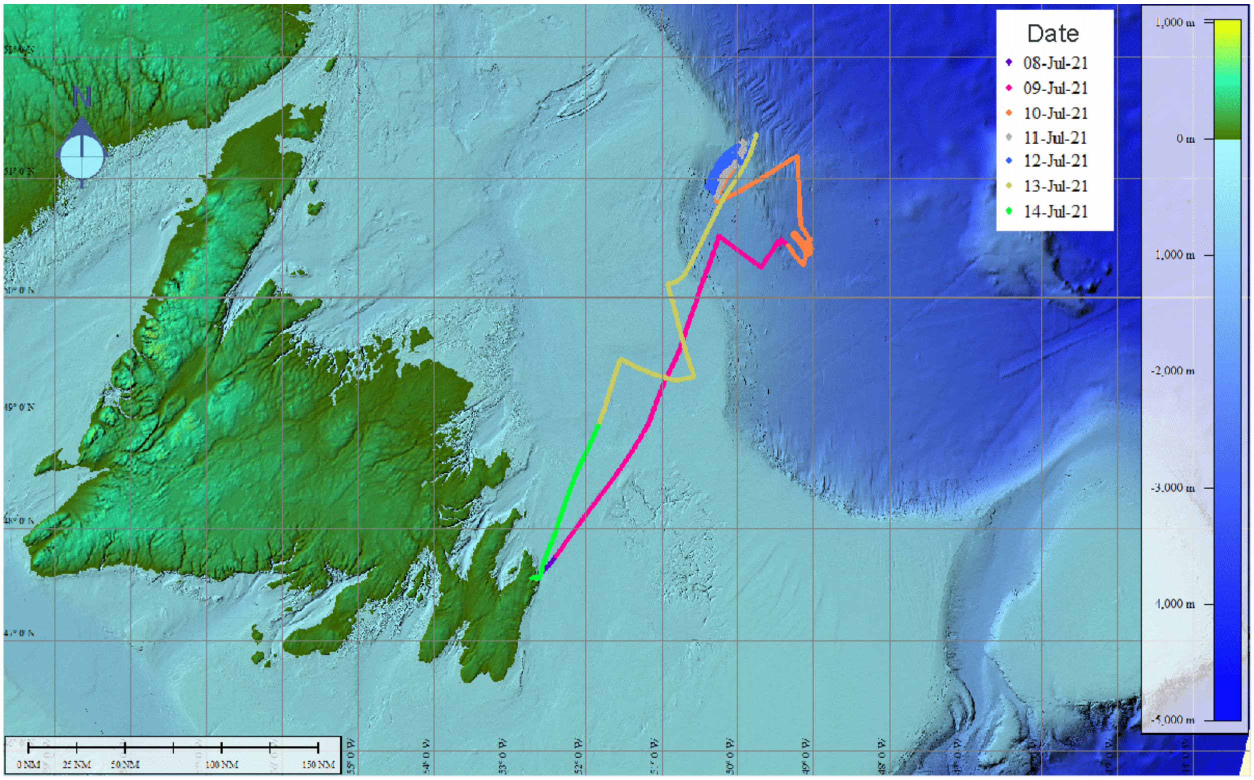

Figure 3. Ship tracks identified by date. Geophysical survey and sampling took place between July 10 and 13th .

During the expedition 6 sampling locations were occupied (Table 2).

Table 2. Names, types, position and depth of seabed sampling stations.

Station	GSC-A station	Station type	Latitude	Longitude	Depth (m)
MSP21-30	0001	Box core	51.22469	-49.83103	962
MSP21-32	0002	Piston core	51.3073	-49.93453	1087
MSP21-31	0003	Piston core	51.27058	-50.01411	688
MSP21-10	0004	Camera	51.11363	-49.93532	759
MSP21-09	0005	Camera	51.11846	-49.91434	742
MSP21-13	0006	Camera	51.37059	-49.75216	1864

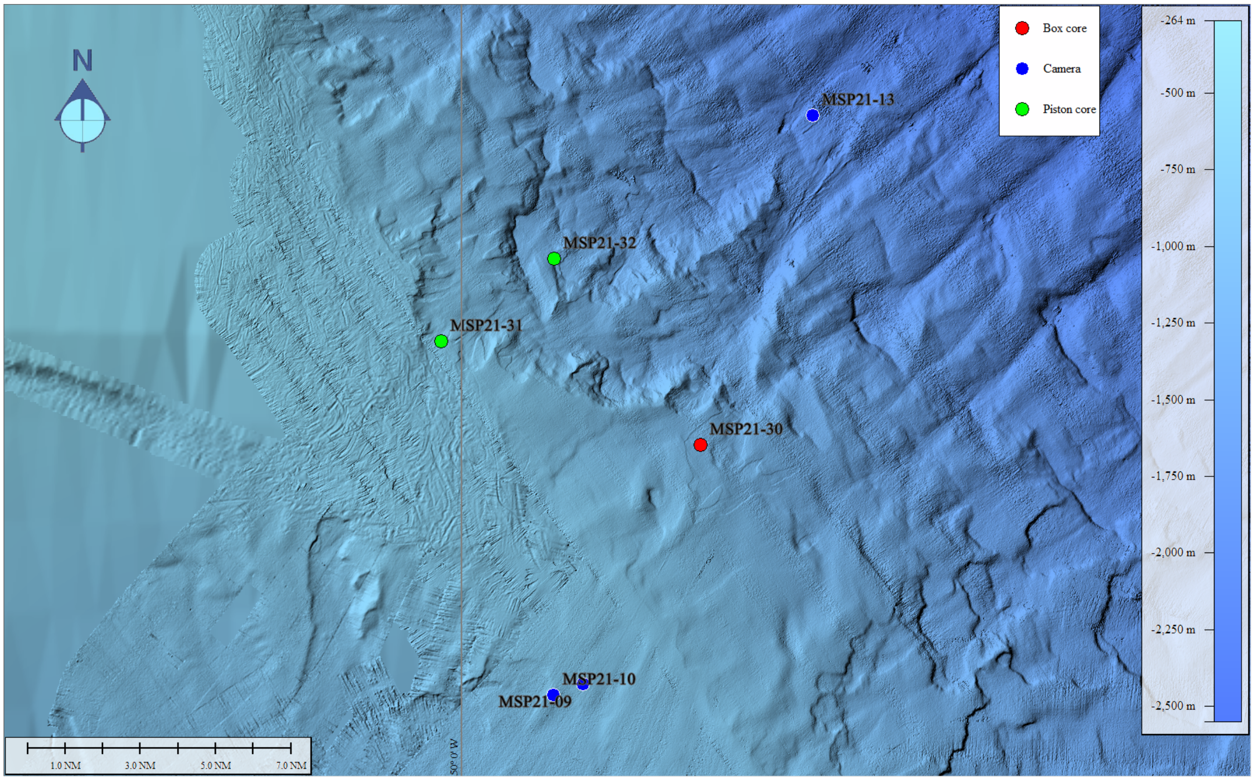

Figure 4. Sampling locations within the survey area.

4. EQUIPMENT AND PROCEDURES

4.1 Knudsen 3260 Echo-Sounder

Since May 2016, a new Knudsen 3260 deck unit has been installed onboard the *Amundsen*. Sub-bottom profiles were acquired continuously at a frequency of 3.5 kHz to image the near surface stratigraphy of the seafloor. Approximately 500 NM of data were acquired during this expedition. The original Knudsen .keb files were converted to SEGY and JP2 on board using tools developed by Bob Courtney (GSC Atlantic). Data logging started when CCGS Amundsen left the dock in Quebec City, on the 5th of July 2021 (Julian Day 186) and continued during crossing to St. John's. Due to good weather conditions, excellent quality data were collected. Julian days 189 to 195 data were collected over the area targeted by the current expedition (Newfoundland shelf and slope), under worse weather conditions. Thumbnail (low resolution) images of the sub-bottom profiler sections are shown in Appendix E.

4.2 Simrad EK80 echo sounder

The Hull-mounted Simrad EK80 wide band scientific echo sounder was collecting water column data continuously during the expedition. The Simrad EK80 is the most modern "high end" split beam scientific echo sounder in the scientific market. The system is controlled through a dedicated Microsoft Windows computer. Data were collected at 25 kHz to 50 kHz by ES38-7c transducer, 85 to 170 kHz by ES120-7c transducer and 150 to 300 kHz by ES200-7c transducer and stored as .idx and .raw files.

4.3 EM-302 multibeam echosounder

The *Amundsen* is equipped with an EM302 multibeam sonar operated with the Seafloor Information System (SIS). Attitude is given by an Applanix POS-MV receiving RTCM corrections from a CNAV 3050 GPS receiver. Position accuracies were approximatively < 0.8 m in planimetry and < 1 m in altimetry. Beam forming at the transducer head is done by using an AML probe. All the data acquired during the expedition were post-processed in real-time using the MB-System 5.7.9 software. Approximately 2000 km^2 of new multibeam data was acquired (Figure 5, Figure 6).

We have attempted to use Lockheed Martin MK21 Expendable sound velocity system to collect sound velocity profiles for sound speed corrections using XSV-02 probes. Unfortunately the probes malfunctioned. Instead, sound velocity profiles were calculated from historical water column data based on the World Ocean Atlas salinity models (https://www.ncei.noaa.gov/products/world-ocean-atlas).

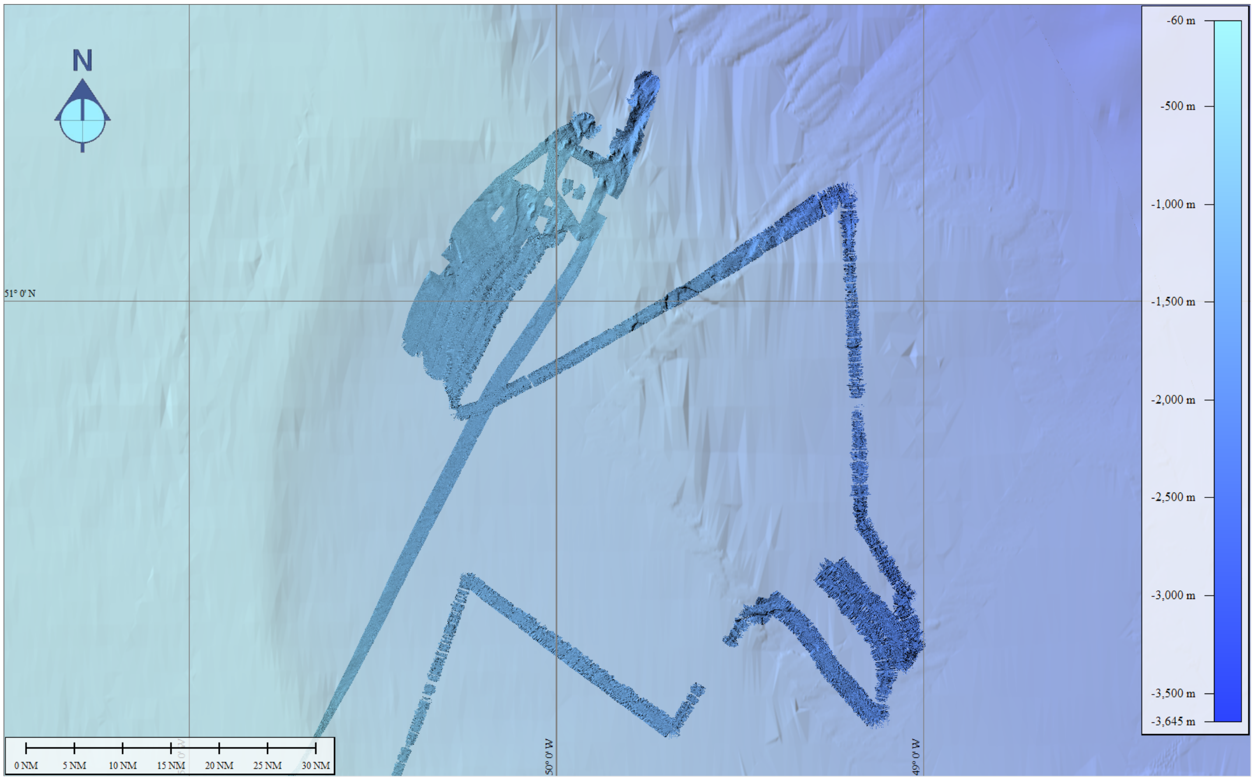

Figure 5. MBES coverage within survey area (saturated colors) overlaid on generalised bathymetric model.

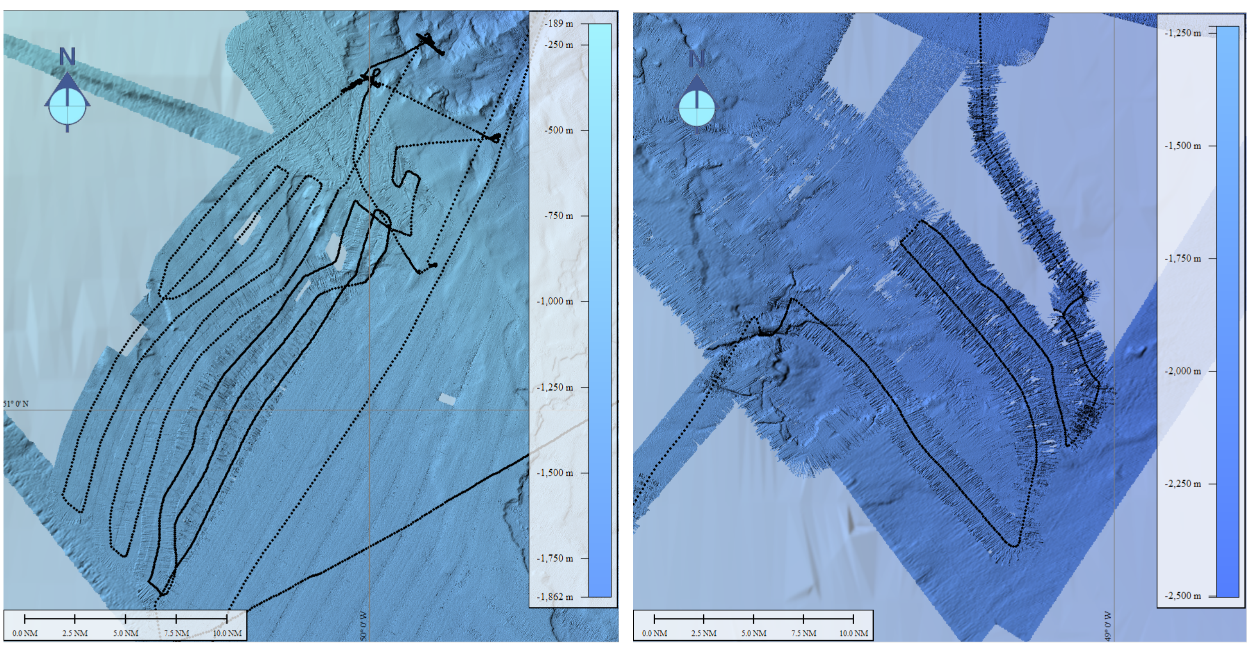

Figure 6. Additional coverage resulting from 2021 survey (color saturated areas) added to previously existing MBES data. 2021 ship tracks are shown.

4.4 Piston and gravity coring

The piston corer used onboard the Amundsen is designed using the specifications of the AGC-Atlantic long corer system. The core head is 800 kg and 2 meters in length. The core barrels that attach to the core head are 305 cm (10 ft) long and attached to each other using external couplings. The configuration of the Amundsen's foredeck only allowed for the deployment of the piston corer with three barrels, approximately 9 m. The core barrels are supported by jacks as the coring system was rigged.

The core liner is made of CAB plastic, and contains the recovered sediments. The core liner has an internal diameter of 9.9 cm. The core liner is inserted inside the core barrels and each length (305 cm) is held together with clear tape.

A split piston with 2 O-rings and a variable orifice size is used to allow for greater sediment penetration and reduced sampling disturbance. The split piston is connected to the winch cable that is inserted through the core head and is placed inside the last core liner. A core cutter which houses a core catcher and allows for the sediment to be retained during recovery is attached to the lowermost core barrel.

The trigger weight corer (TWC) has a dual function. It acts as a trigger to lease the piston corer to free fall from a predominated height above the seafloor. In addition, the TWC acts as a gravity core, which supplements the data obtained from the piston corer by collecting an undisturbed surface sample. The trigger weight core used on the end of the trip wire was the standard Murphy Corer composed of a 3 m aluminum barrel to house the liner, cutter, catcher, one way plunger valve and an upper head weight stand of a steel clasp, lead weights and fins. The head weight stand weighted 150kg.

All GSC Atlantic piston and TWC cores were processed according to standard GSC Atlantic core procedures (Mudie et al., 1984). The cores were identified alphabetically by section at the time of removing the core liner from the core barrels. Removing the core liner required dismantling individual core barrels from the bottom to the top, commencing with the bottom-most core barrel and proceeding to the uppermost barrel containing sediment. Each 302cm length of liner was extruded from the barrel and cut in half on the foredeck, using a GSCA pipe cutter. The sediment in the liner was cut using a wire saw and the section ends were carefully capped to minimise disturbance to the sediment surface. The top end cap was labelled with the cruise number, station number, section label and top. The base of the core is designated with the letter A and the top of the base section is designated as B. The base section is AB. Each section was brought into the Geotechnical Lab stored horizontally on the bench. The core liner was labelled with an up arrow, cruise number, station number, section label and the top and base of the section were labelled with the appropriate letter. End caps were removed if the sediment was not too fluid, and the section length was recorded.

Issues involved with the piston coring operation included the malfunction of the depth counter on the large ArcticNet Humboldt winch, and the lack of a taper at the end of the core barrels. Due to the issue with the winch depth counter a USBL was attached to the winch cable to indicate water depth. However this also malfunctioned on the first piston core deployment and the piston core was recovered prior to impacting the seafloor. The lack of taper at the end of the core barrels prevented the external coupling from "sliding up the barrel" and the barrels had to be pulled apart prior to separating the core liners (Figure 7). This resulted in extensive disturbance at the bottom and top of the liners which were taped together, corresponding to barrel breaks. In core 2021804001 approximately 5 cm of sediment was extruded onto the deck between sections CB and CD while pulling the barrels apart.

Figure 7. Piston core barrels separated on CCGS Amundsen forward deck, showing separated core liner. Photograph by V. Kostylev NRCAN photo 2021-506.

4.5 Physical Property Sampling

Undrained Torvane shear strength (S_u) measurements and constant volume samples were taken at the ends of each section if the condition of the sediment allowed. The constant volume sampler was inserted into the end of the section, the undrained shear strength measurement was taken and then the constant volume sampler was removed.

The undrained shear strength was measured using a hand-held Hoskin Scientific Torvane. The dial on the Torvane was zeroed, the fins on the vane were completely inserted into the sediment. The dial was rotated at a constant rate until the sediment failed. The Torvane reports values in kg-force/cm^2 units (1 kg/cm^2 = 98.07 kPa). The Torvane has three adapter vanes of different size areas which can be used for various sediment strengths. The large sensitive vane is used for soft sediments (< 0.2 kg/cm^2), the medium regular vane for moderate strength sediments (< 1.0 kg/cm^2)

and the small high capacity vane for stiff sediments (< 2.5 1 kg/cm^2). Note that the readings on the torvane dial face should be recorded as decimal numbers from 0.0 to 1.0 for all three vane sizes. If the dial reading is the maximum reading (i.e. 1.0) for that vane a second measurement should be made using the next smaller vane. The following are used to present the S_u in kPa.

<u>Large Sensitive vane</u>: S_u (kPa) = dial reading * 0.2 kg/cm^2 * 98.07 kPa
<u>Medium Regular vane:</u> S_u (kPa) = dial reading * 1.0 kg/cm^2 * 98.07 kPa
<u>Small High capacity vane:</u> S_u (kPa) = dial reading * 2.5 kg/cm^2 * 98.07 kPa

Constant volume samples for bulk density and water content determinations were taken by inserting stainless steel samplers of a known volume. Prior to insertion, the sampler was lightly sprayed with Pam cooking oil and gently wiped with a small Kimwipe tissue. The bevelled edge of the sampler was placed on the flat sediment surface and carefully inserted into the sediment at a constant rate using two flat headed spatulas. The sampler is inserted at a constant rate to minimize compression of the sediment within the sampler. The sampler was then carefully removed and the sediment was trimmed using a wire saw and extruded into a pre-weighed 1 oz screw-top glass bottle. The bottle cap was then labelled and sealed using electrical tape to prevent the lid from loosening. The samples will be weighed, dried at 105°C for 24 hours and re-weighed to determine bulk density, dry density and water content according to ASTM Test Method D 2216-90 (revision of 2216-63, 2216-80) Standard method for laboratory determination of water (moisture) content of soil and rock. All relevant information for the Torvane measurements and constant volume samples was recorded on data sheets and input into Excel spreadsheets and will be incorporated into the GSCA physical property database.

4.6 Box core sampling

A standard Benthos style box core owned by *Amundsen* Science was used and gave very good results considering the substrate contained some gravel in every sample. One deployment was undertaken and received a reasonable amount of recovery (38 cm). The box core sample was sub-sampled upon retrieval with two push cores (34 and 37 cm recovery) when a sufficient amount of relatively undisturbed sediment was retrieved (Figure 8). A battery operated vacuum pump (Laerdal Medical vacuum) was used to prevent compression during the push. This appeared to work well and eliminated the need for an electrical cable on the deck. A surface layer (approximately 5 cm thick) was also saved as a separate sample for bulk grain size measurements.

Figure 8 Surface, push cores and side view of the Box core sample. Photograph by V. Kostylev NRCAN photos 2021-507, 2021-508, 2021-509.

4.7 Camera stations

GSC Atlantic - designed and owned DeepImager (Figure 9) was used as a platform for acquiring images of the seafloor. A GSC-A drop camera (4k Cam) was taken on board as backup.

The DeepImager system consisted of a camera, connected to a winch via Kevlar-armoured fibreoptic cable and from the winch to ship-side computer running navigation and deep imager control software. Before departure from St Johns the system was tested. DeepImager was connected through the winch to computer controls. Amundsen Navigation, Mixer and Deep Imager software worked as designed. Communication with the DeepImager was established, the depth sensor turned on, the camera was turned on, both sounders, lights and lasers were working too. All the initialization procedures passed and all systems were "go".

On Thursday afternoon, deck crew moved the camera from the initial location on the starboard side to under the A-frame on the port side to prepare it for the upcoming deployment. The camera was moved along the deck. Then the winch was used to spool about 30 feet of cable in order to put it through the specially designed block. Angus helped with disassembling the rollers on the sides of the winch in order to pull the wire through them. A lot of deck crew were assisting with the process. They were warned about the fragility of the fibreoptic cable and there was no observation of excessive bending.

When everything was in place and ready for deployment, the ship-side software was tested again, but resulted in communication errors (no Ethernet connection between the camera system and the desktop console). No combinations of rebooting the camera, software, cleaning connectors, or using a freshly charged camera battery helped establish the communication. Unplugging and re-plugging power to the winch modem made Deep Imager Ethernet link alive for 10 seconds, after which it always disconnected. Later this was explained as the time-out for LAN communication.

Connecting the cable to the camera bypassing the winch worked well - communications were OK and camera controls were working. It was concluded that either the fibreoptic cable was broken or modems (winch or camera side) were malfunctioning.

The camera side modem in the pressure case was relatively securely held in place by hot glue and foam pads. The winch modem on the other hand is just sitting on top of multiple wound wires in the project box. No outside damage to the modem or disconnected wires was observed. Very thin fibreoptic wires were not protected by anything but they did not appear damaged.

As only one of four fibres in the cable were used for data communication, it was decided to try a different fibre with a hope of eliminating the broken one. Fibreoptic wires on the camera modem side were the same colour and labeled 1 - 4. The wires on the winch modem side were gray, black, purple, and blue and not numbered. The initial configuration was violet to #3. Assuming the current violet wire was damaged there were 9 combinations of colors vs numbers to try.

Fortunately detailed information on modem and wire setup was provided by Patrick Meslin, who greatly assisted with troubleshooting of the communication issues.

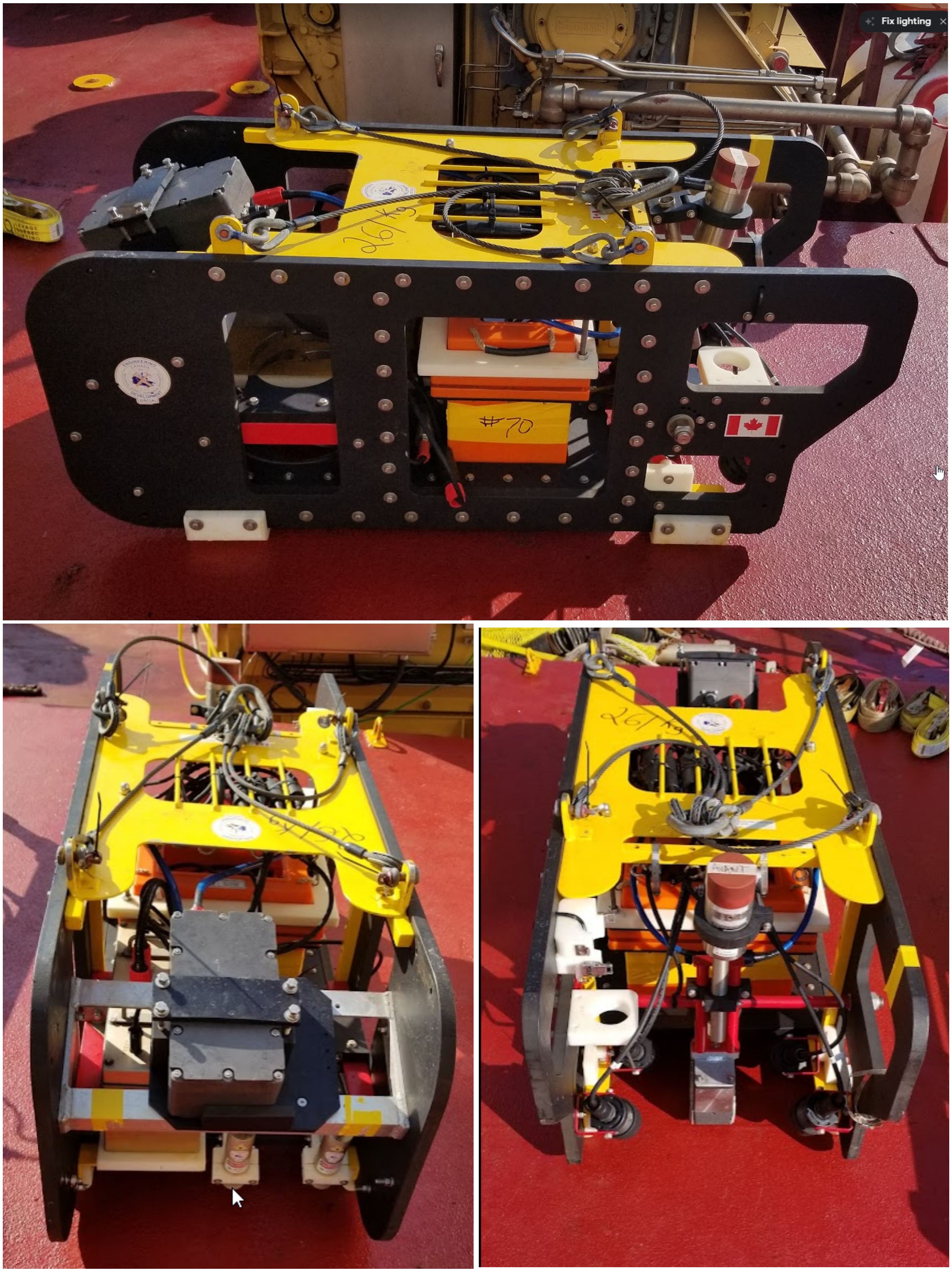

Figure 9 Side, front and back views of the DeepImager. Photograph by V. Kostylev NRCAN photos 2021-510, -511 and -512.

Camera and winch side modems are identical. For troubleshooting and indicating if the link is 'live', the fibre modems have 6 LEDs in two columns of 3, 'left' of the fibre connector when the network connector is on the right side (Table 3).

Table 3. Status of LED indicators on fiberoptic modems for troubleshooting communication.

Top-left LED is power indicator:	**Top-right is copper speed indicator:**
If it's on solid, it indicates the unit is powered on properly. If it's blinking slowly, it indicates the unit is in loopback mode If it's blinking fast, it indicates there's a hardware failure with the modem	Green is 1000Mbps Yellow is 100Mbps Off is 10Mbps or no link
Middle-left is fibre duplex mode:	**Middle-right is copper duplex status:**
On is full-duplex Off is half-duplex	On is full-duplex Off is half-duplex
Bottom-left is fibre link status:	**Bottom-right is copper link status:**
On is fibre link present Off is no fibre link detected Blinking slow is fibre link present but no copper link Blinking fast is fibre link present and receiving data	On is copper link present Off is no copper link present Blinking slow is copper link present but no fibre link Blinking fast is copper link up and receiving data

A fully functional communication status would show the four top LEDs on both modems lit up solid, and the two bottom ones either on solid of blinking quickly. If one of the modems has a hardware failure, the top-left ('PWR') LED should be blinking rapidly. If there's an issue with one of the copper links but the fibre works, the bottom-right would be off and the bottom-left would be blinking slowly. If there's an issue with the fibre but the copper link works, the bottom-left would be off and the bottom-right would be blinking slowly.

The inspection of powered-up modems has shown that was the case, indicating the broken fibre link. The configuration of fibre connections was the following:

1 goes to black
2 goes to blue
3 goes to purple
4 goes to grey

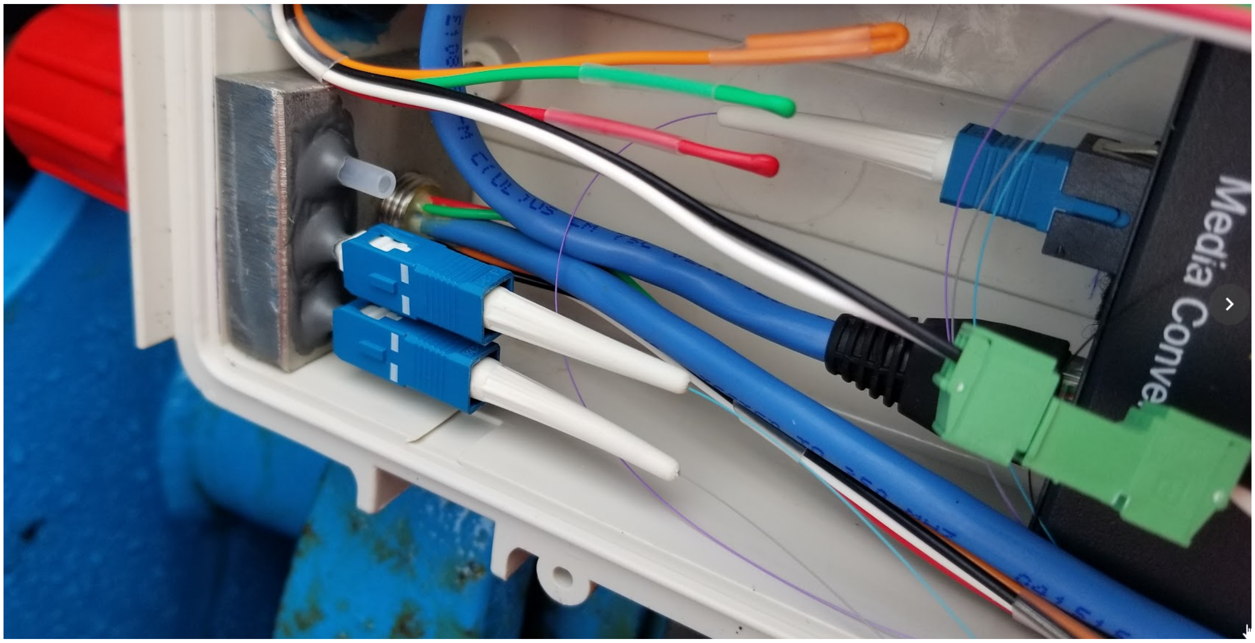

Figure 10. Fibre optical connectors within winch modem. The purple fiber is connected to the modem on the right. The spare (unused) fibers are connected to the side of the modem on the left. Photograph by V. Kostylev NRCAN photo 2021-513.

Testing wires has shown that violet and black were internally damaged somewhere inside the cable. The blue wire was visibly broken within winch modem (Figure 10). The grey wire worked, and was used to establish successful communication.

The DeepImager was tested during three dives, about 30 minutes each. The first two at 740 - 900 m water depth and the last around 1860 m. The system worked really well. Winch was great, however sometimes there was not enough tension to kick the tilt in for level wind, but manual adjustment worked. Remote control for the winch was tested successfully as well, and DI operator would take winch control over from deck operator when the seabed was within 10 m of the camera (as identified from Imagenex multibeam data). A Valeport pressure data logger was very pertinent, and compared to the HiPAP beacon, showed that at 1860 m water depth the measurements were within 5 m of each other. We left the HMR & Valeport on during ascent, and eventually the HMR shut down, but it was nice to see that the Valeport was still giving valid data that agreed very closely with the USBL and gave us some caution for the deck crew before surfacing. The quadrant block for fibreop cable worked flawlessly. We have tried to install the bat fin on the DeepImager before the first dive but it looked like the angle on the strut was going to encounter the new fibre-modem case so we carried the dive without it. The heading of the camera would move at times but did not seem to rotate fully.

The acquired test photographs and videos were not available on the external data pod for on-deck download. They were however, saved on the internal memory in the Sony camera. The potential interfering issue was the lack of charge in the Sony camera battery. The battery was charged overnight, however the issue was not resolved. We changed the camera setting, e.g. time zone, date and time. Selected both photos/video and selected external memory storage. After the first dive we saw that date/time were retained in the camera memory but the external memory pod, which has the correct folder directories had no data. We had to open the camera again to be certain the internal memory had the data and all was good. Rather than potentially further disturb electronics on the foredeck/electronics van, with the camera inside the pressure case we bottled it back up and carried out dives 2 and 3. From dive 2 onwards, we had lost the date/time stamp again. We had also switched out the main deep-sea battery on the last dive as the first died during the ascent of the second dive.

During the DeepImager deployments video was recorded continuously and photographs were obtained automatically at interval of 15 seconds. Imagenex profiler and sounder data were recorded at each deployment. 270 underwater images (Figure 11) and 3.3 GB of high-resolution video were acquired during 3 dives. Thumbnails of the collected images are shown in the Appendix D.

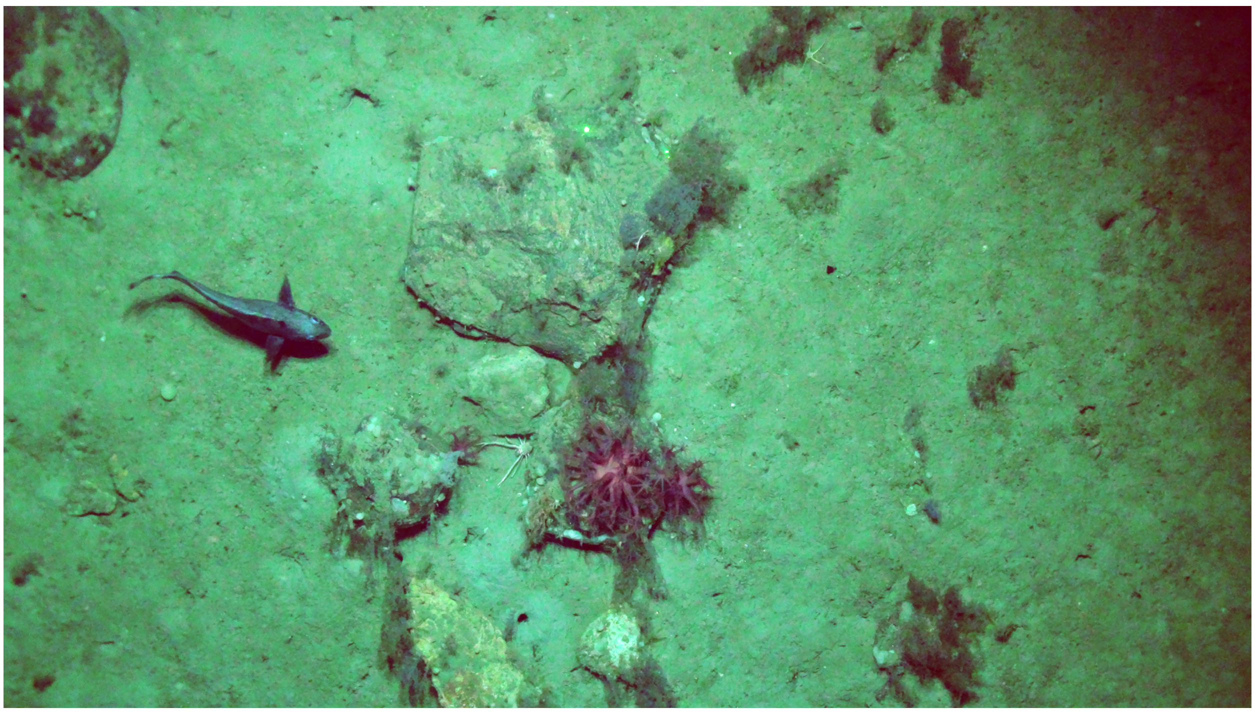

Figure 11. An example underwater photograph acquired with the DeepImager system. Photograph by V. Kostylev NRCAN photo 2021-514.

5. PRELIMINARY RESULTS

5.1 Piston coring

Two piston cores were collected off of the slope of Orphan Spur. Core 2021804 0002 was collected from 51.27058, -50.01411 at a water depth of 688 m. The trigger weight core (TWC) came up empty and the piston core (PC) had a recovery of 339 cm. Core 0002 targeted a mass transport deposit (MTD) downslope from station 0003. The station ended up retrieving sediment above the failure. This core could provide sedimentological or geotechnical results to explain why the sediment below failed. It also has the potential to capture sediment travelling downslope from failures closer to the shelf break (Figure 12).

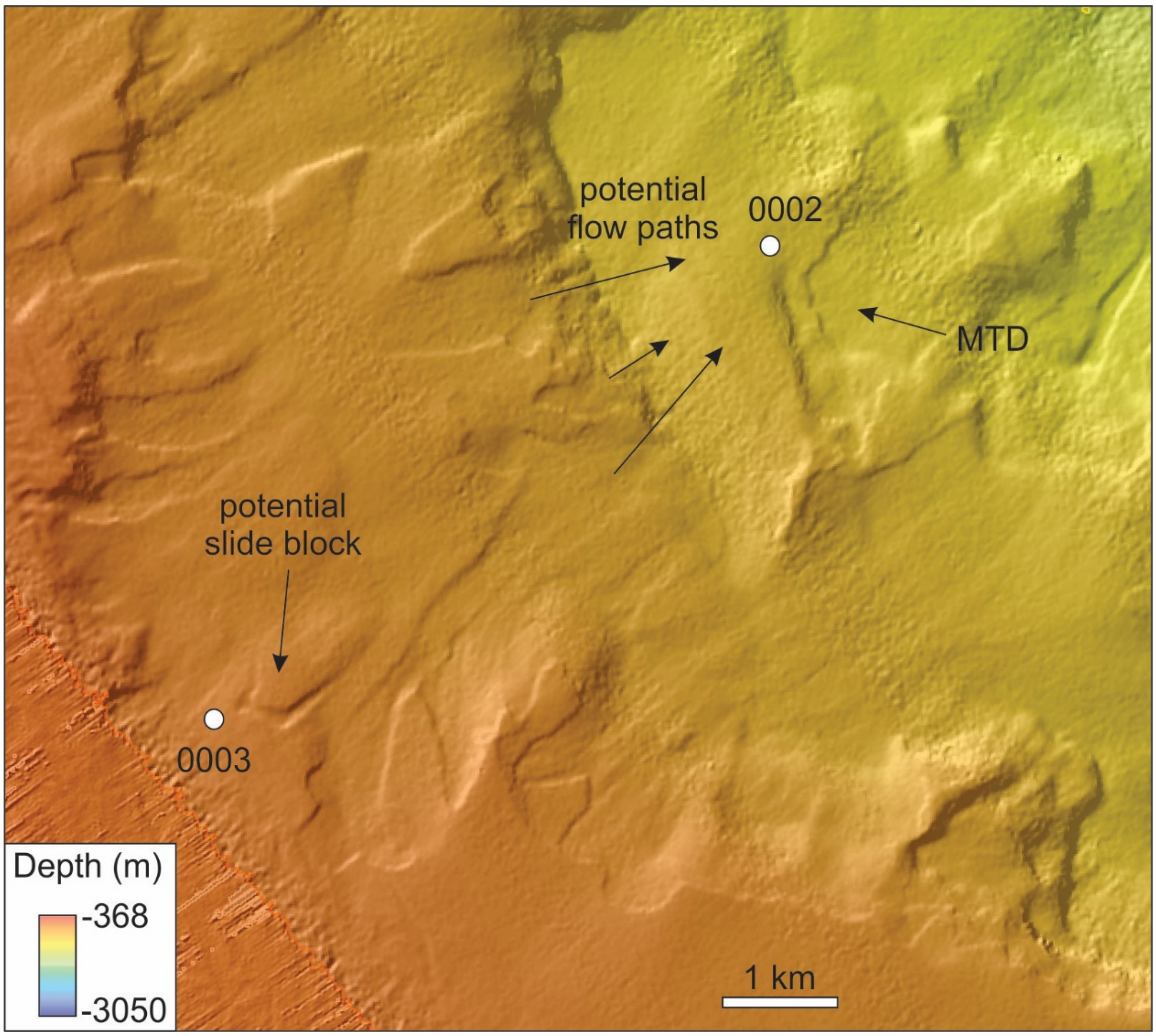

Figure 12. Piston core locations 0002 and 0002 showing the potential slide block target and MTD target.

Core 2021804 0003 was collected from 51.3073, -49.93453 at a water depth of 1087 m. There was no recovery in the TWC, while the PC recovered 498 cm. Core 0003 was sampled to retrieve undisturbed sediment above a potential slide block observed in multibeam bathymetric data (Figure 12), where the sediment below station 0003 appears to have partially moved downslope. This core was collected for the purpose of determining if the recovered material had any geotechnical and/or sedimentological characteristics that could explain why the material below failed.

5.2 Physical Property Measurements

A total of 5 Torvane measurements and constant volume samples were taken at the top and base of the sections from the 2 piston cores (Table 4 and Table 5). The undrained shear strength S_u values are higher in piston core 20218040002pc which was taken in a MTD and may indicate the sediment is overconsolidated. Note that two Torvane measurements were taken at the top of section AB using two different size vanes which produced different values.

Table 4 Summary of Physical Property sampling

Station Number	Sample Type	Section	Top/Base	Sampler ID	Bottle id	Comment
0002	PC	AB	Top	A9	A190	Some IRD made a small hole
0002	PC	BC	Base	A4	A148	Some IRD
0003	PC	AB	Top	A4	A58	
0003	PC	BC	Base	A4	A74	
0003	PC	BC	Top	A4	A34	

Table 5 Summary of Torvane measurements.

Sample No.	Type	Section	Top/Base	Vane used	Torvane Reading	Shear strength (kPa)	Comment
0002	PC	AB	Top	Large	0.50	9.81	Questionable
0002	PC	BC	Base	Med	0.20	19.61	
0002	PC	AB	Top	Med	0.20	19.61	
0003	PC	AB	Top	Large	0.30	5.88	Questionable
0003	PC	BC	Base	Large	0.48	9.41	

5.3 Box coring

One box core (2021804 0001) was collected from 51.22469, -49.83103 at a water depth of 962 m in attempt to retrieve the surface of a MTD (Figure 13). This was the location of a piston core station (2020804 0018) during cruise 2020804 which targeted a potentially recent MTD with no sediment cover in 3.5 kHz sub-bottom profiler data. This MTD appeared to occur at the top of the piston and trigger weight cores, therefore a box core was deployed during cruise 2021804 in attempt to recover an undisturbed surface sample of the top of the MTD. The box core had 38 cm of recovery. Two push cores (0001A and 0001B) were taken from the box core sediment (Figure 8) with recoveries of 37 cm and 34 cm. This core was taken with the aim to date the top of this MTD.

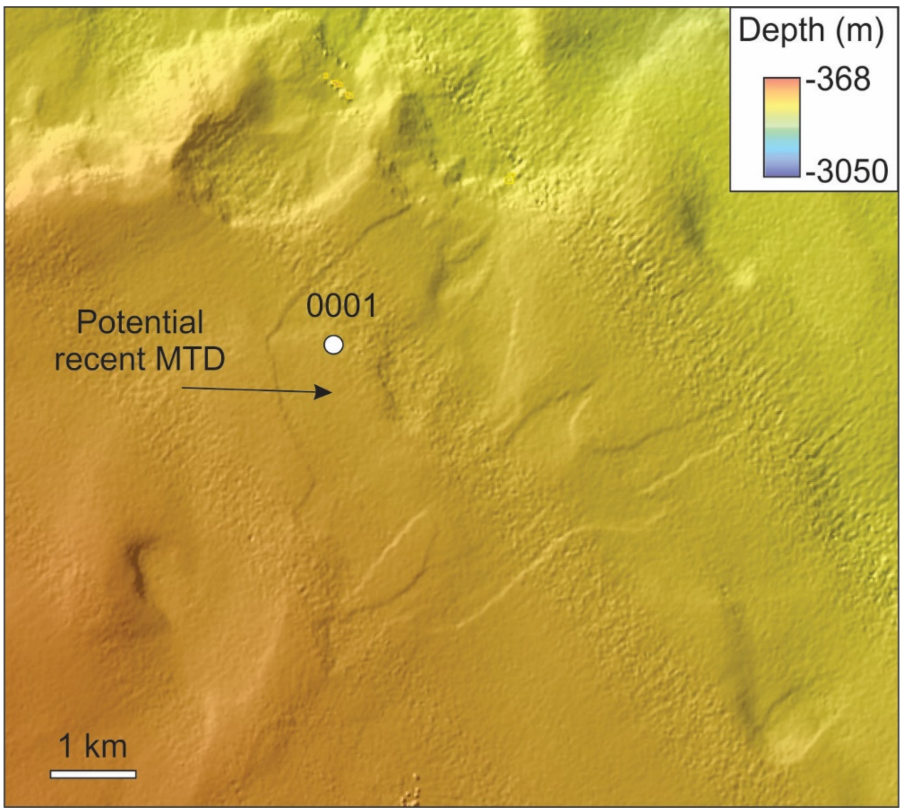

Figure 13. Location of box core 0001 targeting a potentially recent MTD.

5.4 Multibeam echosounder and 3.5 kHz sub-bottom profiler data

A sub-bottom profiler survey was completed downslope from core 0003 targeting a track that ran parallel across the two failures that cores 0002 and 0003 attempted to sample. Transect A (Figure 14; Figure 16) starts from the shelf, crosses the shelf break and ends close to core site 0003. Preliminary observations from this transect shows a strong bottom reflection and no clear internal reflections. This is likely due to the hard surface of the shelf and shelf break. Transect B (Figure 14; Figure 15) continues the transect from the potential slide block down to the lower MTD that was the target of core site 0002. Preliminary observations show a strong sea bed reflection and relatively weak, likely stratified reflections below. This transect also shows the escarpment above the lower MTD.

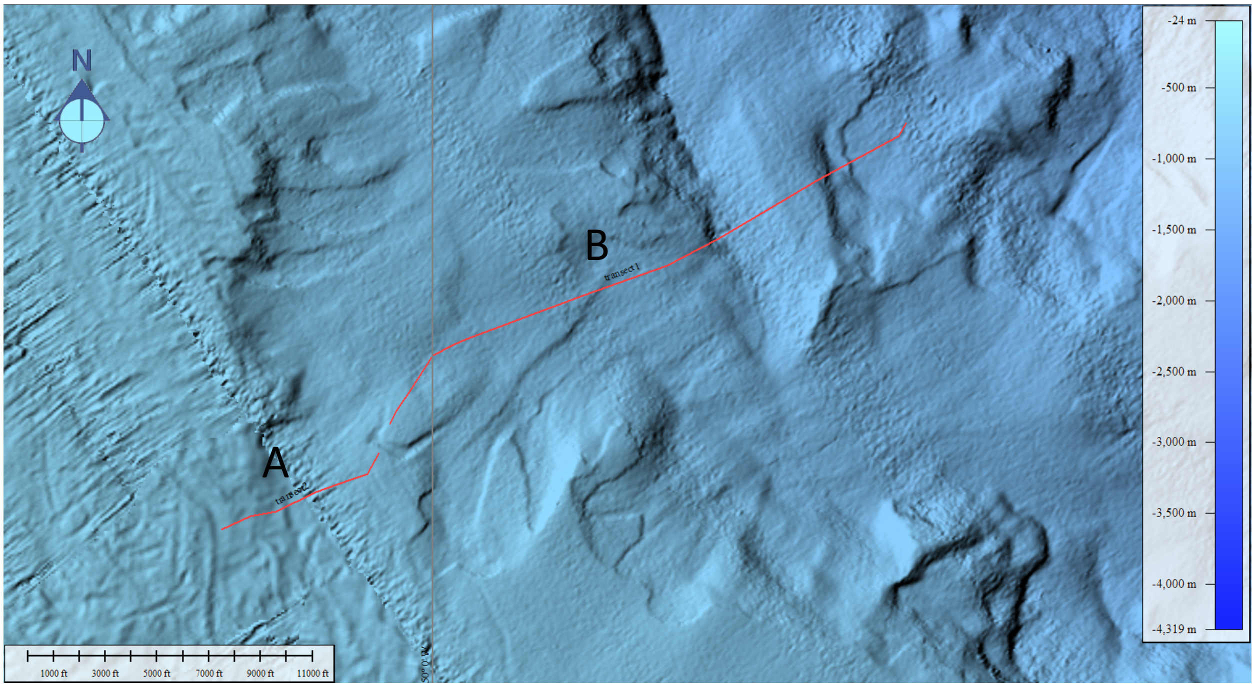

Figure 14. Sub-bottom profiler sections over the recent failures. Cross-sections for transects A and B are shown below.

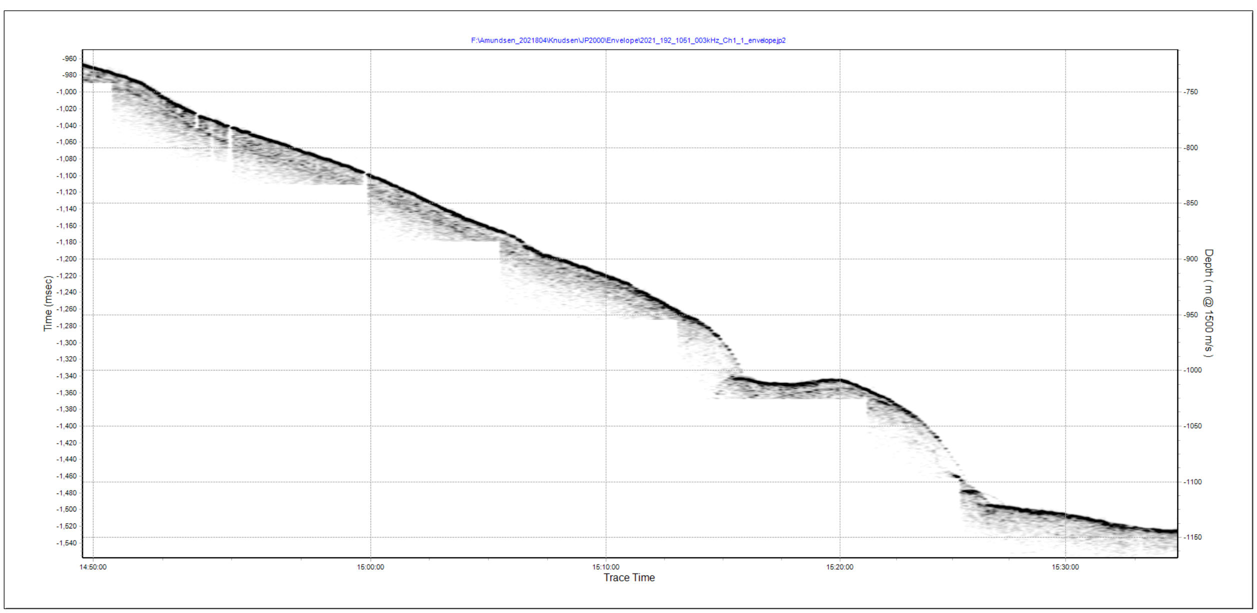

Figure 15. Sub-bottom profiler data, Transect B, Day 192, 14:50 – 15:35

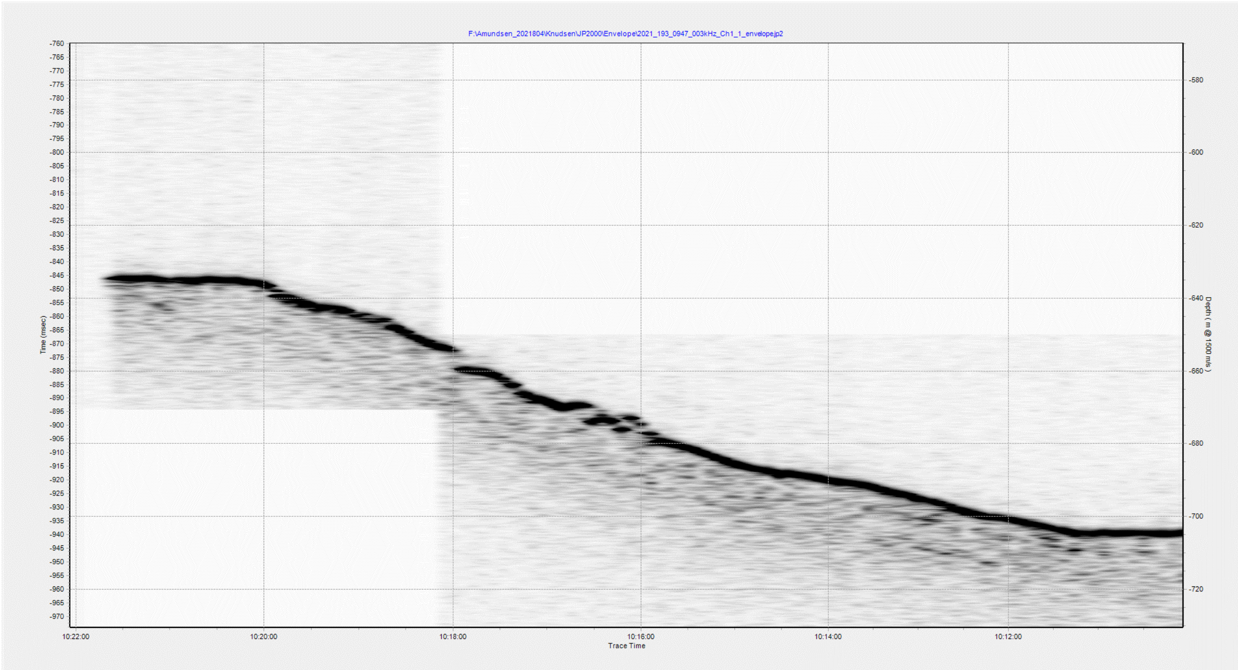

Figure 16. Sub-bottom profiler data, Transect A, Day 193 10.10 – 10.22

Even though the amount of multibeam collected during this expedition was not great, we have managed to fill in several gaps in the previously existing data. Most importantly we have imaged the southern side of the shallow part of the Orphan Spur to establish the location of the shelf break and identify the deepest extent of relic iceberg scours (Figure 17). The data showed that the deepest extent of the iceberg scours is approximately 680 m, and that the southern slope of the Orphan Spur (into the Orphan Basin) has erosional features (gullies) similar to the eastern side, however more infilled with sediment (Figure 18).

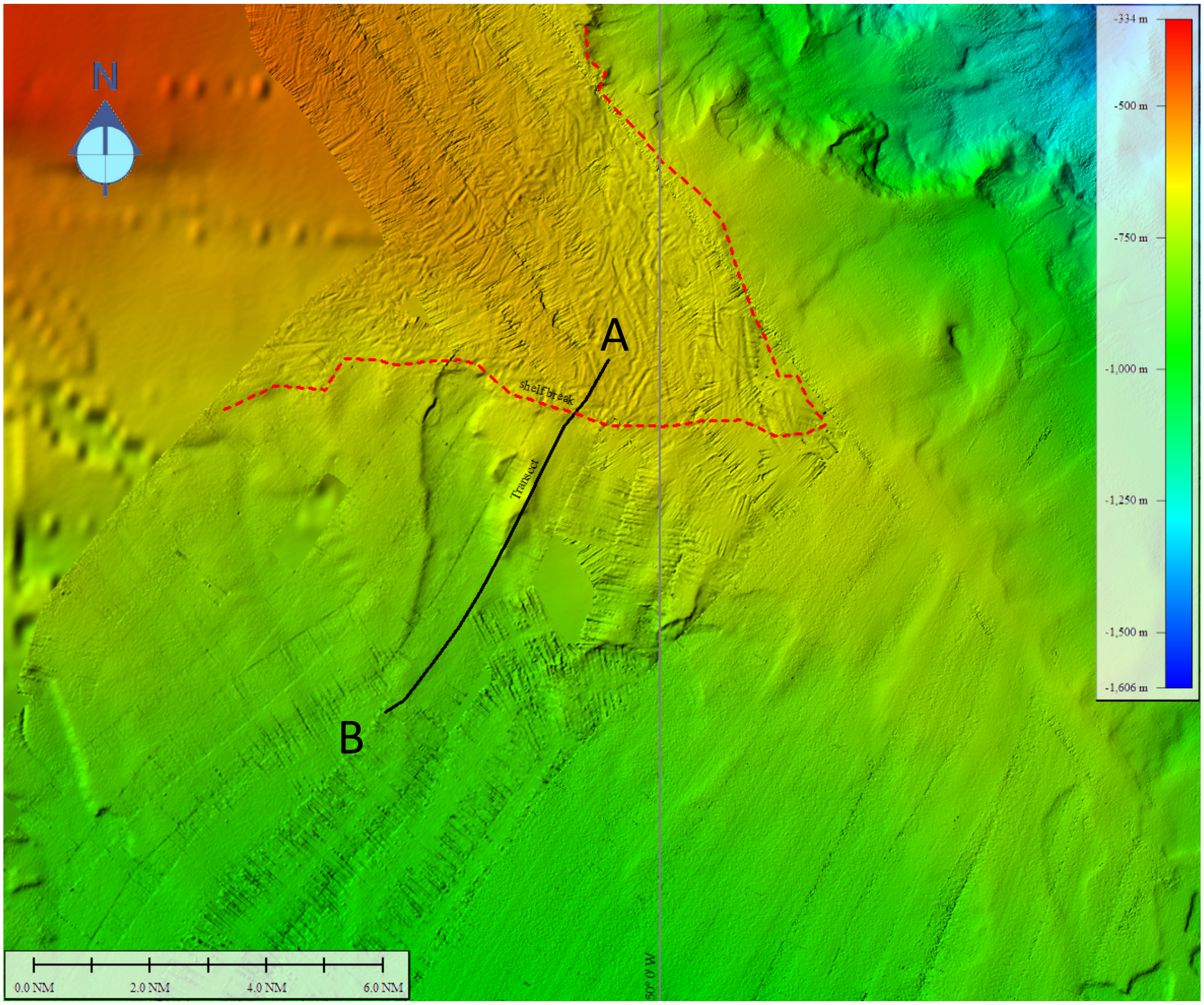

Figure 17. The shallow part of the Orphan Spur, showing the approximate location of iceberg-scoured shelf break (dashed red line).

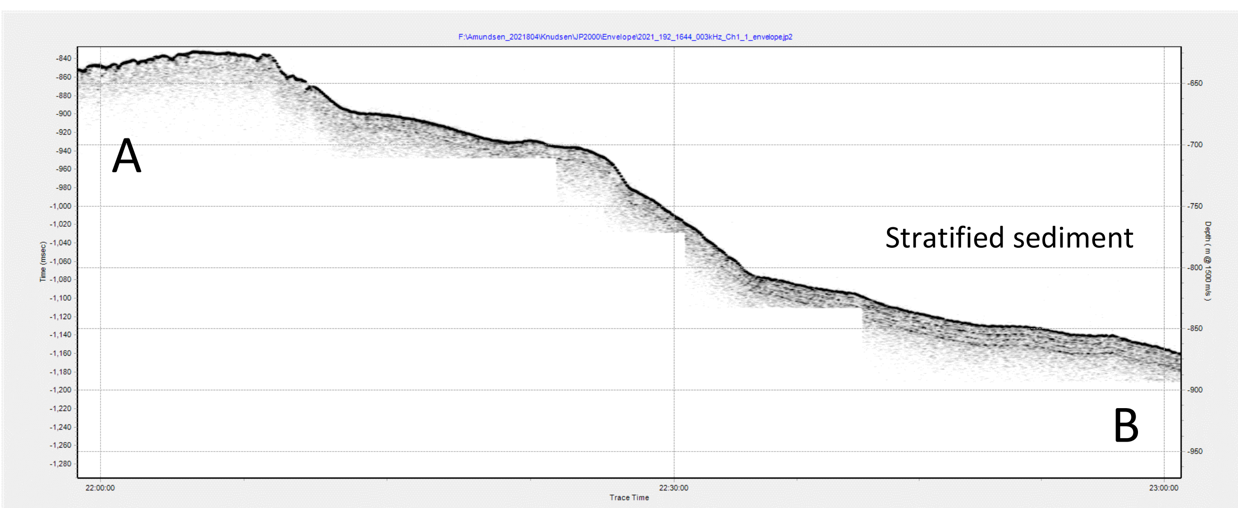

Figure 18. Sub-bottom profile downslope from Orphan Spur, as shown on Figure 19.

5.5 DeepImager camera stations

Deep water camera sampling yielded 249 high-resolution photographs and 92 minutes (3.3 GB) of hi-resolution video of seabed. Locations of the target structures were originally identified on the archival seismic data (Figure 19). However, the video observations and photographs did not show presence of unusual seabed structures or unique habitats. Because the size of the identified structures was at scale of 100 m, it is likely that we were not able to observe them because of the uncertainty in navigation of the archival seismic observations, positioning of the ship and time constraints on sampling.

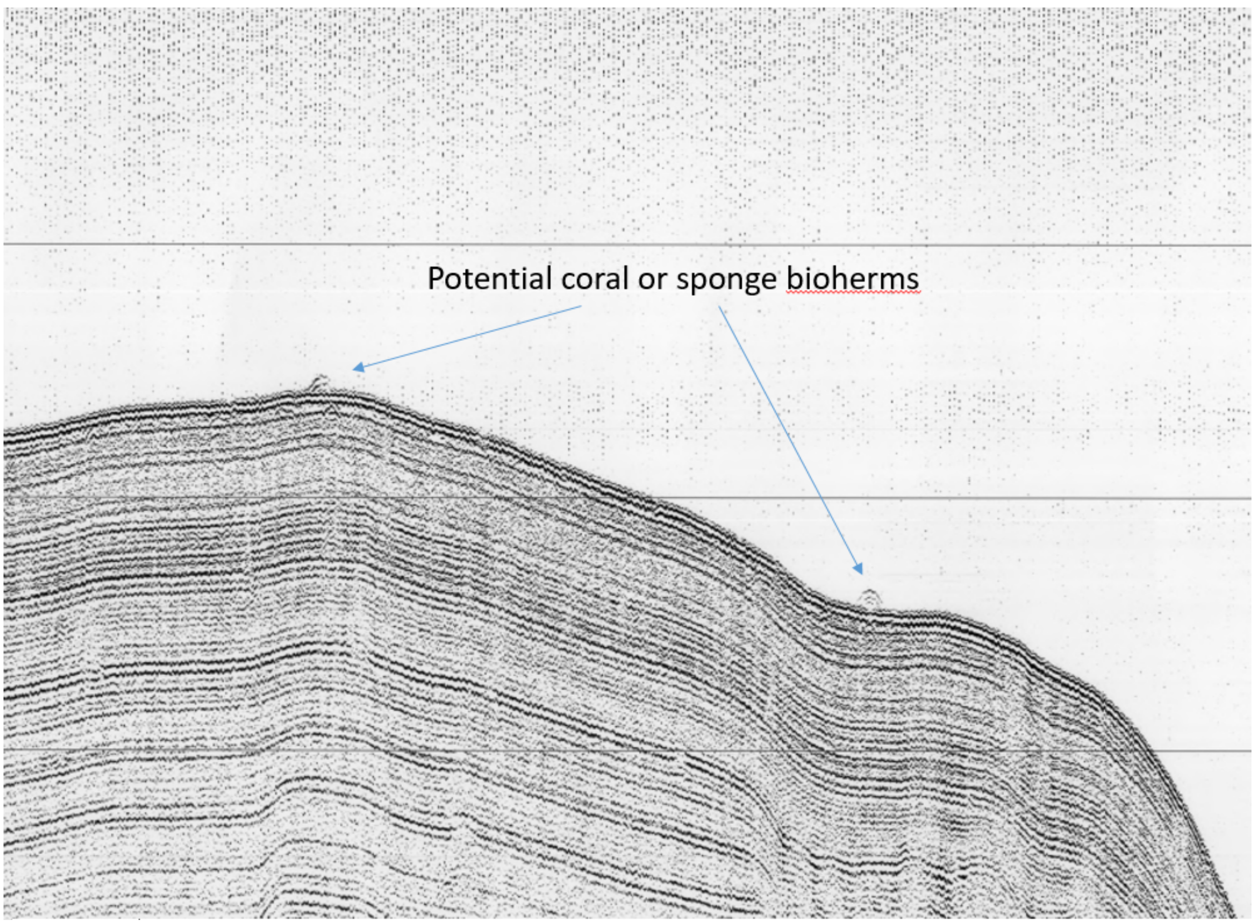

Figure 19. Archival seismic profile (cruise 2005033B, JD213, approximate time 2:45 – 3:15) showing potential bioherms on Orphan Spur. These locations were targeted during video surveys.

The third location was chosen for the uniquely high seabed backscatter (Figure 20). Video observations showed relatively homogeneous muddy seabed, which may imply that the coarser sediment is covered with thin mud veneer. The area showed presence of the small bamboo corals, *Acanella arbuscula*, one of the common species of gorgonian corals in the region (Figure 21). A detailed image analysis and comparison with neighbouring locations, imaged previously, will be carried in order to evaluate the uniqueness of the habitat in this area.

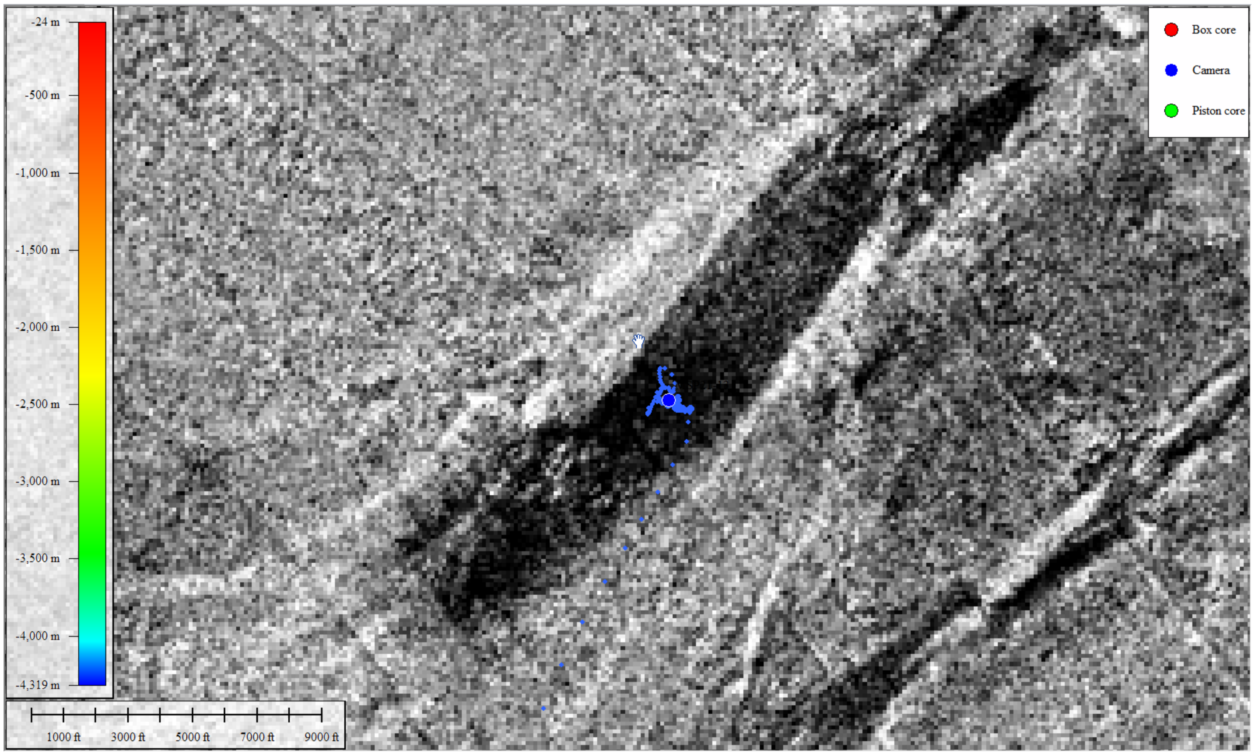

Figure 20. Multibeam backscatter and the track of the video transect over station 006.

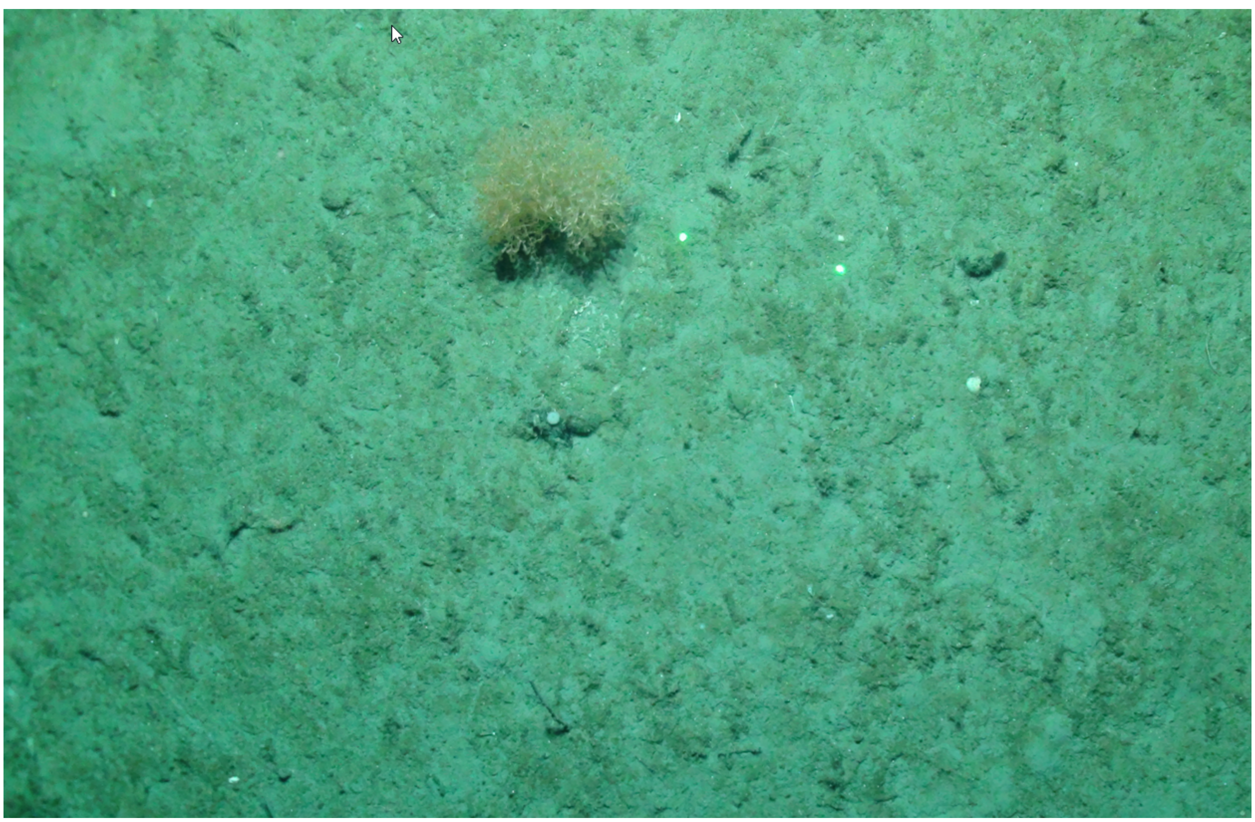

Figure 21. A small bamboo coral (Acanella arbuscula). Green laser pointers are separated by 7 inches distance. Photograph by V. Kostylev NRCAN photo 2021-515.

6. ACKNOWLEDGEMENTS

We are thankful to Captain Pascal Pellerin for ensuring a safe and successful expedition. The officers and deck crew were most helpful and engaged in our work. We also thank Amundsen Science for helping us organise the expedition, plan the cruise schedule, and mobilise scientific gear. Anissa Merzouk was instrumental in liaising with the commanding officer and the crew. The Amundsen Science team on board the ship was extremely helpful with operation and troubleshooting of scientific gear.

7. REFERENCES

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Kostylev, V.E., Broom, L.M., Robertson, A.G., Carson, T.E., Hayward, S.E., 2020. CCGS Amundsen 2020804 expedition: seabed habitats and marine geohazards in Northeast Newfoundland Slope, Labrador Sea. Geological Survey of Canada, Open File 8749, 68 pages, https://doi.org/10.4095/327425

Kostylev, V.E., King, G., Manning, D., Meslin, P., Graham, S., Nunn, S., Levy, D., Fizzard, J., 2021. CCGS Louis S. St. Laurent 2019 expedition: multibeam mapping and sub-bottom profiling in Northeast Newfoundland slope, Labrador Sea. Geological Survey of Canada, Open File 8841, 75 pages

APPENDIX A: Daily log of events

DAY # 1, Date: Tuesday 2021-07-06

Angus Robertson (AR), Laura Broom (LB), Lori Campbell, EricPatton (EP) and Vladimir Kostylev (VK) arrived to St. John`s NF by WestJet flight at 14:30. Kevin MacKillop arrived at 23:00. Overnight in the hotel.

DAY # 2, Date: Wednesday 2021-07-07

The team arrived at coastguard base (280 Southside Rd) at 9 am where they were joined by Jennica Seiden (DFO) and Reily Mackay (Amundsen Science). All underwent a rapid COVID-19 test and tested negative. By 10:30 everyone returned to the hotel to pick up gear. Amundsen was scheduled to arrive at the base at 12:30. Kostylev took a taxi to electronics store to purchase a security camera for monitoring winch operation from starboard lab. At approximately 13:00 the team has joined the ship. Due to bad weather forecast the departure of Amundsen was initially delayed from 4pm today to 1pm on the 8th of July 2021. The plan was to let the low pressure system pass eastward, and follow it in the lower seas on the way to the survey area. The wave forecast for the area was 4 – 6 m. At 2 pm 3rd officer carried familiarisation for the crew. After that the team carried mobilisation of scientific gear. At 20:00 Kostylev gave ¨Life on Board¨ presentation for NRCan and Amundsen science crew.

DAY # 3, Date: Thursday 2021-07-08

At 6am Robertson gave a safety briefing regarding operation of piston core. The team continued to sort out the contents of the boxes, assembling deep water imager, and arranging work stations. Robertson and MacKillop assembled the piston core, Patton set up Regulus system, and Kostylev tested the DeepImager. The DeepImager shipside software has successfully connected to navigation data, camera, pressure sensor, multibeam imager and profiler, and camera was tested for zooming in and recording.

The departure was once again delayed from 13:00 until 18:00 because of the combination of weather and preparation considerations. Several essential parts of the piston core equipment appeared missing, and were sent from GSCA on AirCanada flight by Peter Pledge. Kostylev has arranged delivery of the gear from the airport by taxi to the coastguard base by 4pm.

Deck crew has practiced deployment of the piston core, followed by preparation of DeepImager for deployment with port side A-frame. After the system was moved to the port side it lost communication with the computer. The problem was decided to reside either in the broken fiber cable or in the broken modems (winch or camera side).

The crew was seen by the nurse for vitals and health questionnaire. Then the crew tied up all the equipment and by 18:00 we sailed into calm coastal seas, towards the low pressure system.

DAY # 4, Date: Friday 2021-07-09

After a long night of transit we continued into rougher seas, with 2.5-3 m swells. At 10:00 Kostylev gave a safety meeting on deployment and recovery of the camera and box core. The ship moved at 11 knts. Because of the altered route to destination, we have arrived at the first planned station by 16:30. The day was spent troubleshooting the camera without success. Nighttime survey has started at 19:20. Weather forecast – the tail of post-tropical cyclone Elsa is coming up, rough seas (2.7m) and 25 knt wind in the afternoon.

DAY # 5, Date: Saturday 2021-07-10

Plan for box core in the morning and 2 piston cores during the day was cancelled. Deck operations were delayed due to bad weather – 3 m swells and 40 knt winds. Ship in standby mode waiting for weather. At noon time started survey of the western block. Started surveying with following seas, going downwind, which brought comfort to the crew. At 3pm Kostylev and Robertson started working on fixing deep imager. No success. Geophysical survey continued at night.

DAY # 6, Date: Sunday 2021-07-11

Operations started at 6am. Box core deployment at recent failure feature. Full box core obtained, subsampled with two push cores, surface layer saved, and microbiology sample saved. Photos taken.

VK, AR, KM, LC and LB were tested for COVID again at 9am.

At the first piston core station winch counter malfunctioned, resorted to using HIPAP system for monitoring core depth. HIPAP beacon signal was lost at 350m. Finally depth was called by tracking the echo from the core on ADCP sounder. On the first attempt the piston core was retrieved not triggered (did not reach the seabed). Returning to the original position.

The winch software update was requested, and different HIPAP beacon settings were used on the second attempt. Good depth readings were obtained, successful coring operation. Gravity core however was retrieved empty. Proceeded with a short survey transect with 3.5 khz ran over the fresh failure.

Robertson and Kostylev received instructions on wiring scheme for fiberoptic cable from Patrick Meslin. Good weather allowed working on the deck, the DeepImager was successfully fixed by end of day. Core processing finished by 8pm.

DAY # 7, Date: Monday 2021-07-12

Started at 6am with piston core, good penetration. Gravity core empty. Continued with 3.5 khz transect over failure, attempting to connect to yesterday's transect.

EP was tested for COVID.

At 10 am captain Pascal Pellerin informed me that we will be ending the work tonight because of the upcoming storm and because a crew member needs to come on board for crane operation on the 14th, also because of crew fatigue (crew was on the ship for 7 weeks).

The captain considered 3 options – waiting the storm out, heading North or running with the storm to St John's tonight. I preferred the 2nd option – heading North outside the storm, while continuing the geophysical survey. The captain's decision was to head to St. John's with forecasted 4 meters waves tomorrow morning. The captain made deck crew available to work as long as required by us to obtain as much data as we can on this last day of sampling.

Today was the first deployment of the DeepImager after 10 years hiatus. After 4 days of troubleshooting on board, it performed well at depths up to 1860 m. The camera has saved all the videos in internal memory.

2 camera stations were taken over the suspected mounds as previously identified on seismic data. The video however did not show the mounds but rather muddy seabed with infrequent soft corals.

The third, deepwater station, with high multibeam backscatter showed almost barren habitat with mottled appearance, with presence of concretions on the surface.

Robertson and Kostylev finished work at 21:00. Tied up the gear for travel and disassembled the camera for data download. Started transit to St John's.

DAY # 8, Date: Tuesday 2021-07-13

Transit to St. Johns. Demobilizing gear.

DAY # 9, Date: Wednesday 2021-07-14

Arrived to St. John`s at 8 am. Demobilizing gear. Stored at CHS base for tomorrow's pickup.

DAY # 4, Date: Thursday 2021-07-15

At 6am truck was loaded with gear for shipping to BIO. The crew departed for airport at 11 am NF time. Arrived Halifax at 17:30.

APPENDIX B: Summary of bottom sampling events

Time (UTC)	Station ID	Latitude	Longitude	Activity	Event
2021/07/13 00:02:16	MSP21-13	51.3699035	-49.7516545	Camera	Recovery
2021/07/12 22:48:33	MSP21-13	51.3705892	-49.7521577	Camera	Bottom
2021/07/12 21:54:43	MSP21-13	51.3332682	-49.7763578	Camera	Deployment
2021/07/12 19:52:33	MSP21-09	51.1181495	-49.9183585	Camera	Recovery
2021/07/12 19:05:37	MSP21-09	51.1184557	-49.9143390	Camera	Bottom
2021/07/12 18:51:48	MSP21-09	51.1137732	-49.9369500	Camera	Deployment
2021/07/12 18:04:49	MSP21-10	51.1137732	-49.9369500	Camera	Recovery
2021/07/12 17:22:31	MSP21-10	51.1136262	-49.9353183	Camera	Bottom
2021/07/12 17:07:32	MSP21-10	51.1136262	-49.9353183	Camera	Deployment
2021/07/12 12:59:23	MSP21-32	51.2705765	-50.0141078	Piston Core	Recovery
2021/07/12 12:31:11	MSP21-32	51.2705765	-50.0141078	Piston Core	Bottom
2021/07/12 12:14:03	MSP21-32	51.2704813	-50.0147203	Piston Core	Deployment
2021/07/11 19:51:06	MSP21-31	51.3028823	-49.9217242	Piston Core	Recovery
2021/07/11 19:23:24	MSP21-31	51.3073037	-49.9345317	Piston Core	Bottom
2021/07/11 18:58:12	MSP21-31	51.2948935	-49.9089245	Piston Core	Deployment
2021/07/11 11:52:35	MSP21-30	51.2225962	-49.8399718	Box Core	Recovery
2021/07/11 11:26:02	MSP21-30	51.2246927	-49.8310260	Box Core	Bottom
2021/07/11 11:06:07	MSP21-30	51.2230432	-49.8370607	Box Core	Deployment

APPENDIX C: Summary of geophysical survey events

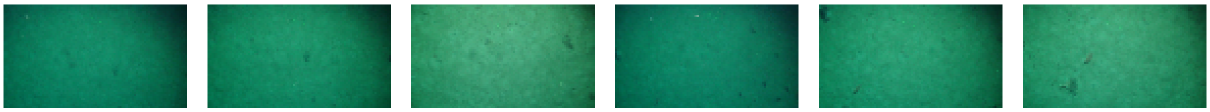
JULIAN DAY	U.T.C. TIME	LATITUDE LONGITUDE	LINE NUMBER	WATER DEPTH (MTR)	COG HEAD	SOG LOG	12kHz	3.5kHz	MBES	COMMENTS
189	20:00	° . ° .						√	√	Departed St. John's en route to main survey area NE of Newfoundland. The transit is expected to be about 20 hours
		° . ° .								Knudsen sub-bottom profiler set to auto gain and auto phase-shifting, With a Tx pulse of 16.0ms, Tx Power 1, Process Shift 0, Sensitivity 5, Draft 7.00m
191	01:07	50° 19.6574 49° 12.0221	SOL 1	1895	141	7.7		√	√	Transiting to start of line after CTD station.
191	01:35	50° 16.9322 49° 08.0553		1922	130	7.8		√	√	Set the Knudsen to manual mode, Gain set to 30dB.
191	01:38	50° 16.6787 49° 07.0775	EOL	1926				√	√	EOL, turning and surveying to the NE to pick up the next NW line.
191	02:21	50° 22.8227 49° 06.0322		2018	347	7.7		Y	Y	3.5kHz gain set to 32dB.
191	02:27	50° 23.5029 49° 06.0627	SOL 2	2024	333	7.6		Y	Y	Gain set to 30dB, Power set to 3, SOL 2.
191	03:53	50° 31.9995 49° 16.7441	EOL2	1880	330	7.6		Y	Y	EOL 2. Large swell, 24kn winds, noisy records on bathy.
191	04:03	50° 33.0276 49° 15.0012	SOL3	1902	49	7.2		Y	Y	SOL 3, Knudsen gain set to 32dB.
191	05:32	50° 25.3385 49° 04.0755		2078	173	6.4		Y	Y	Continuing south to fill a gap in coverage.
191	06:05	50° 21.7719	EOL 3	2060	50	10		Y	Y	EOL 3

		49 ° 03 . 0767								
191	06:28	50 ° 24 . 9510 49 ° 01 . 0120	SOL 4	2160	127	7		Y	Y	SOL4
191	07:00	50 ° 28 . 4868 49 ° 03 . 0842	EOL 4 SOL5	2121	32	7		Y	Y	EOL 4/ SOL5. The swell is fairly high with 24 kn winds. The ship is going to try Surveying a line to the northeast so the wind will be at our stern
191	07:16	50 ° 29 . 3890 49 ° 02 . 0401	EOL 5	2258	33	8		Y	Y	EOL 5. The bridge has informed us we need to divert off this line and begin the transit to the first station location of the day. The transit is about 53nm.
192	00:00	51 ° 07 . 1753 49 ° 59 . 4809	Line 6	870	209	4		Y	Y	On duty. The ship had to postpone station work today due to bad weather (remnants Of tropical storm Elsa). The ship is currently on a survey line which will be called #6.
192		° . ° .						Y	Y	Current Knudsen settings are Tx Pulse: 32ms, Tx Power 3, Gain 32dB, Process Shift:0 Sensitivity: 5, Draft: 7 TX Blanking: 8
192	03:42	50 ° 50 . 9730 50 ° 16 . 4880	EOL 6	1021	145	3.5		Y	Y	EOL 6.
192	04:00	50 ° 51 . 7755 50 ° 17 . 1150	SOL 7	1060	16	5.5		Y	Y	SOL 7. Knudsen set to manual mode.
192	08:07	51 ° 10 . 2760 50 ° 00 . 0978	EOL 7	659	147	5		Y	Y	EOL 7. The ship is close to the first station location for the day, so they are Going to fill some holes and stay in the area.
192	10:08	51 ° 13 . 4307 49 ° 50 . 1326						Y	Y	End of night survey; the ship has reached the box core location.
193	00:00	° . ° .								On duty. The ship is in the midst of running survey line 8, NE to SW along Western edge of the lines run last night.
193	00:36	50 ° 52 . 8067 50 ° 19 . 0631	EOL 8	986	212	5		Y	Y	EOL 8. Turning to run the next line to the NE.
193	00:44	50 ° 53 . 2991	SOL 9	967	353	9		Y	Y	SOL 9.

		50 ° 20 . 2857								
193	02:58	51 ° 10 . 9992 50 ° 03 . 7789	EOL 9	687	21	6.8		Y	Y	EOL 9.
193	03:05	51 ° 11 . 5018 50 ° 04 . 9667	SOL 10	689	231	6.8		Y	Y	SOL 10.
193	05:14	50 ° 54 . 9340 50 ° 02 . 5516	EOL 10		224	7.8		Y	Y	EOL 10.
193	05:22	50 ° 55 . 7665 50 ° 24 . 0872	SOL 11		0	9.2		Y	Y	SOL 11
193	07:10	51 ° 10 . 3775 50 ° 09 . 4470			39	10		Y	Y	The ship needs to make evasive maneuvers to avoid another ship that will be Crossing our survey line.
193	07:22	51 ° 11 . 9932 50 ° 07 . 3260	EOL 11		40	10		Y	Y	EOL 11.
193	07:23	51 ° 11 . 5379 50 ° 06 . 4125	SOL 12		196	10		Y	Y	SOL 12.
193	08:18	50 ° 05 . 7262 50 ° 16 . 5440	EOL 12 SOL 13		16	10		Y	Y	EOL 12, SOL 13, Knudsen gain increased to 29dB.
193	09:06	51 ° 12 . 1961 50 ° 09 . 1400	EOL 13		48	10		Y	Y	EOL 13, Amundsen is steaming to first station location of the day.
194	00:31	51 ° 22 1769 49 ° 45 . 2995	EOS					Y	Y	End of survey, steaming to St. John's as a storm is approaching.

APPENDIX D: Contact sheets for camera stations

Station 2021804004



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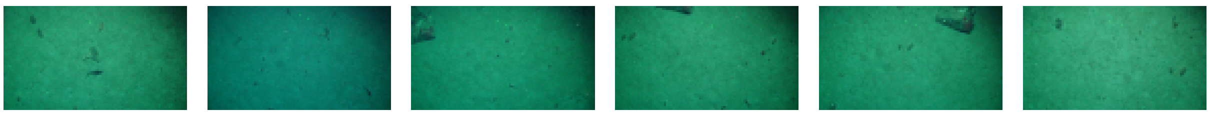

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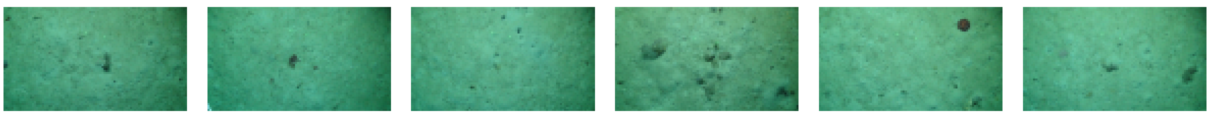

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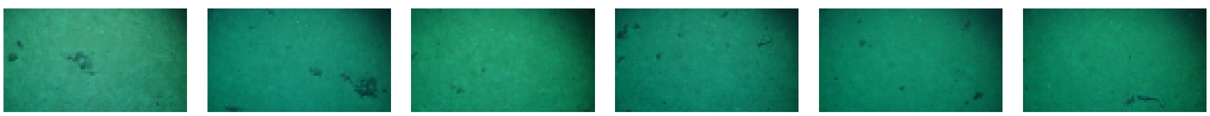
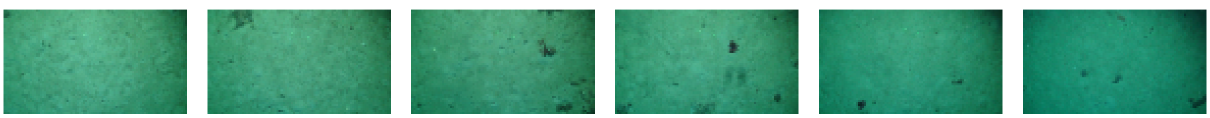


DSC00035.JP DSC00036.JP DSC00037.JP DSC00038.JP DSC00039.JP DSC00040.JP



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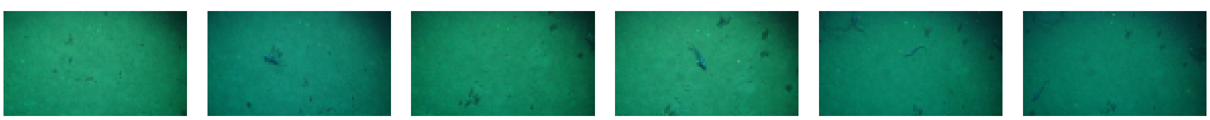

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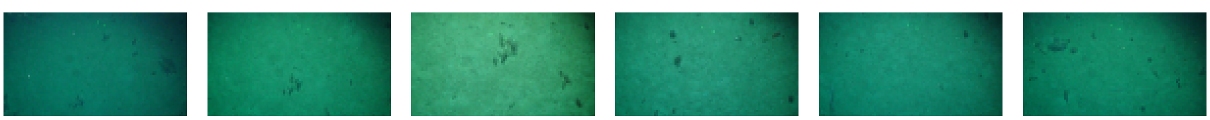

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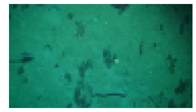
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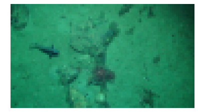
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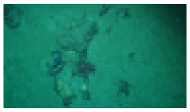
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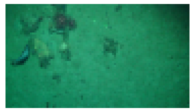
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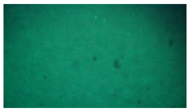
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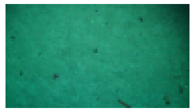
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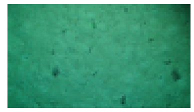
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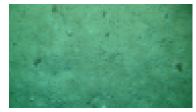
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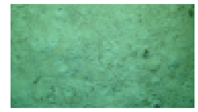
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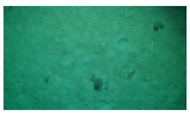
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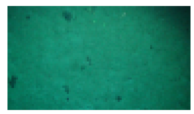
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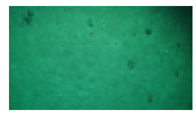
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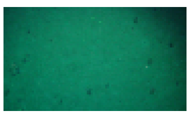
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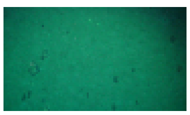
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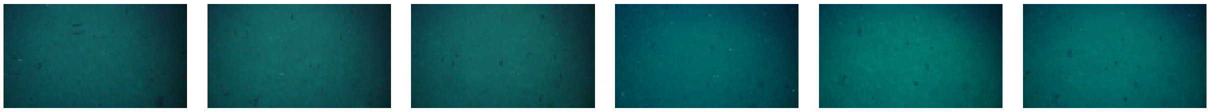

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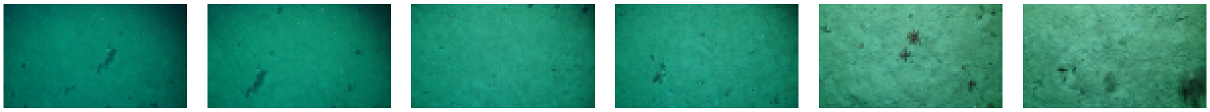

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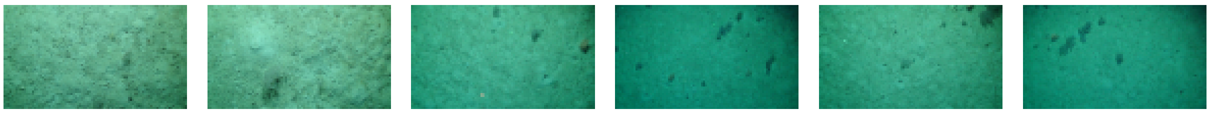

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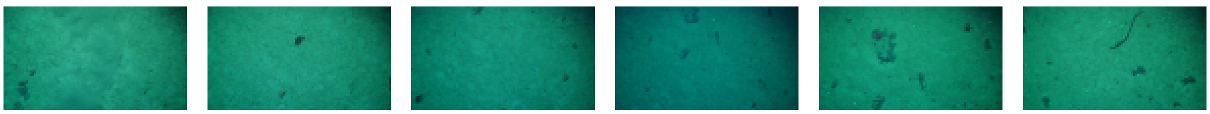

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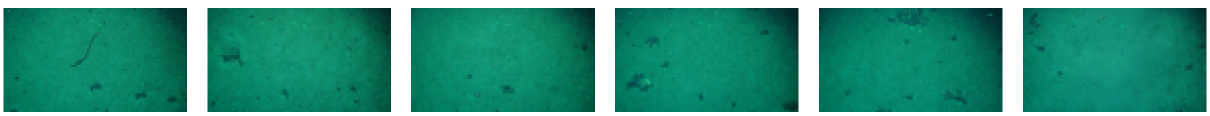

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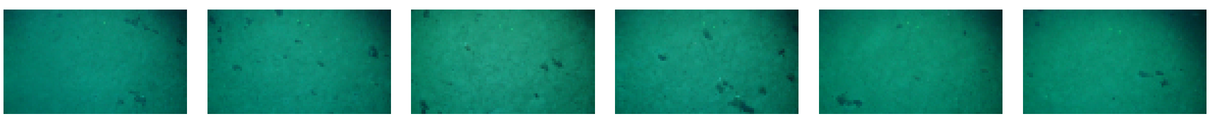

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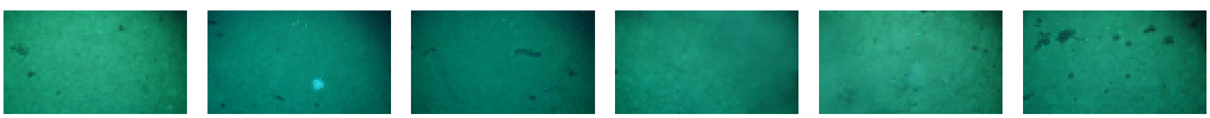

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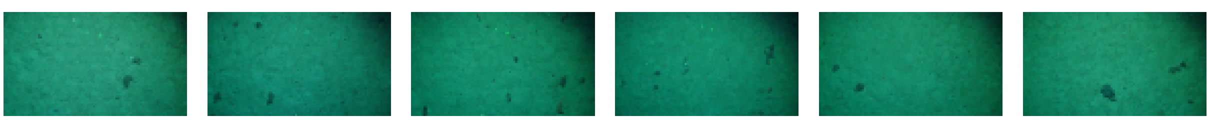

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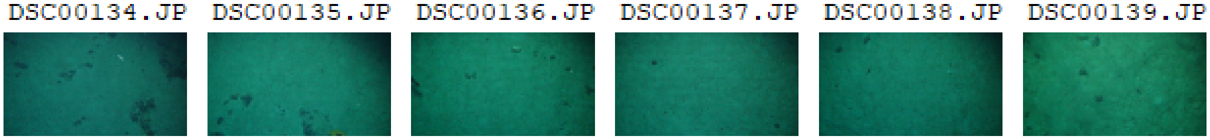

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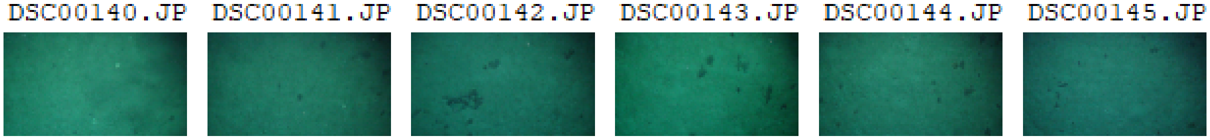

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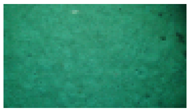
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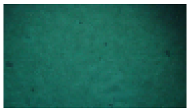
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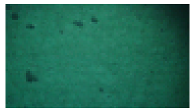
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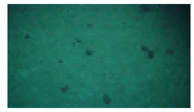
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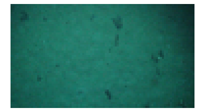
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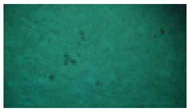
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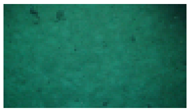
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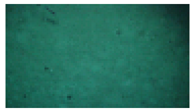
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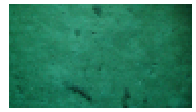
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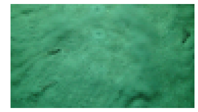
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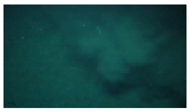
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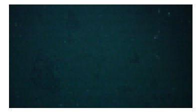
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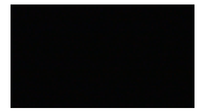
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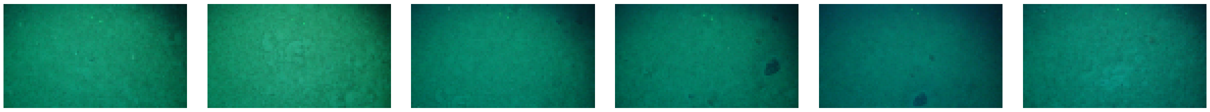

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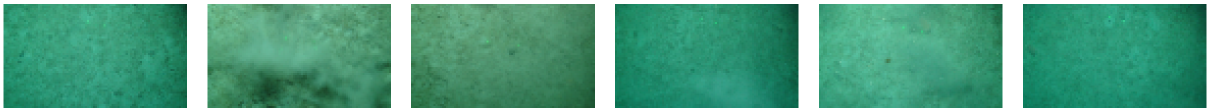

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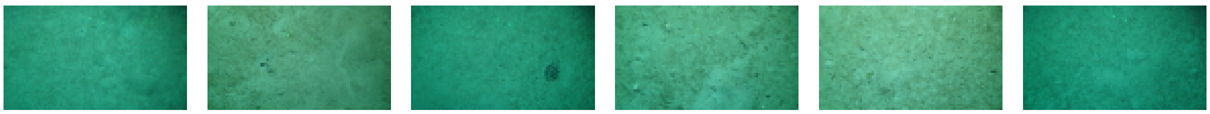

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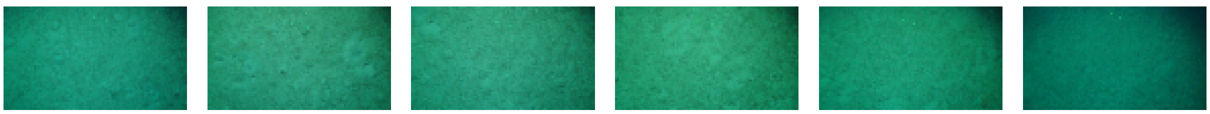

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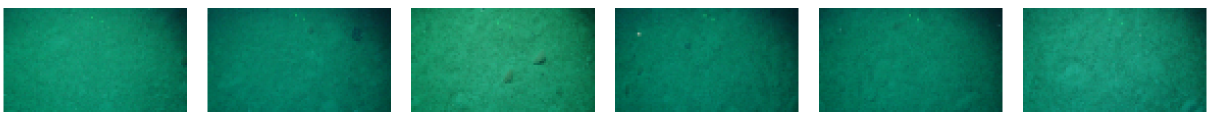

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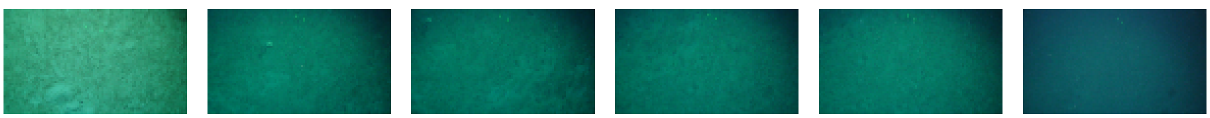

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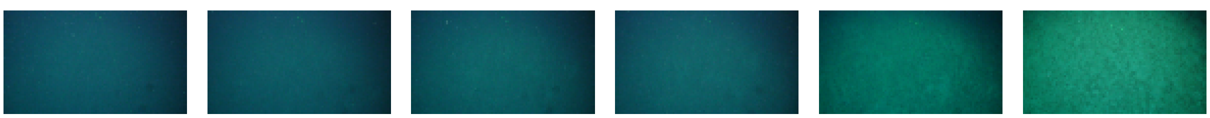

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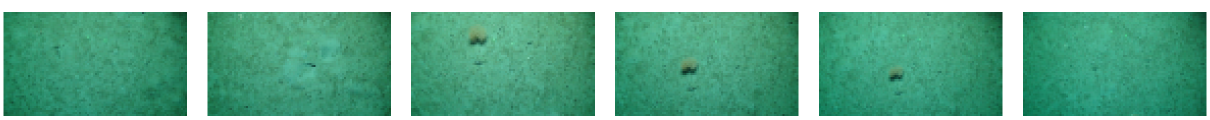

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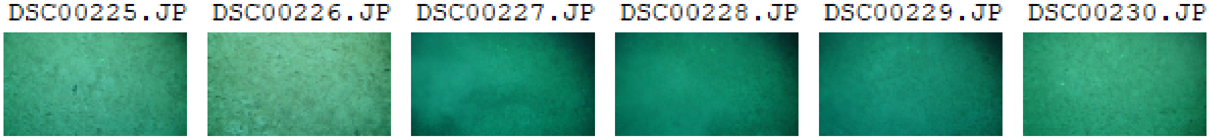

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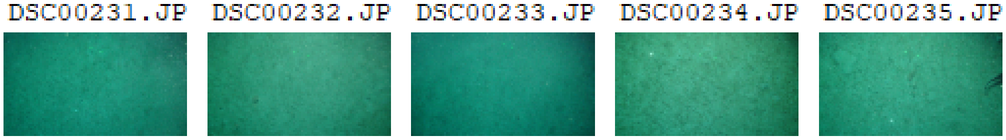

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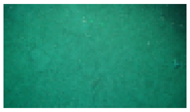	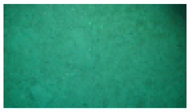		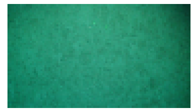	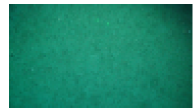	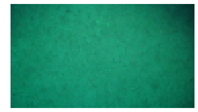
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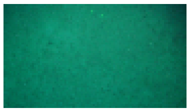	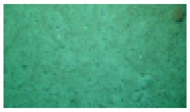	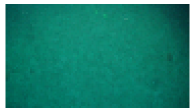	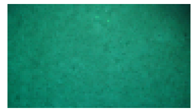	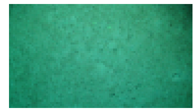	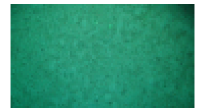
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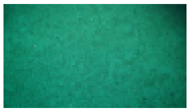	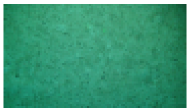	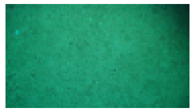	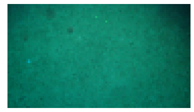	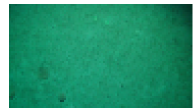	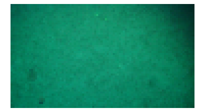
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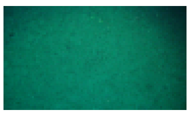			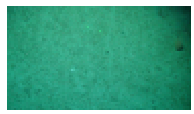	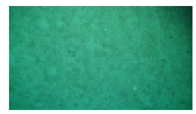	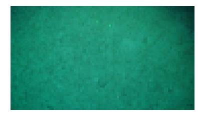
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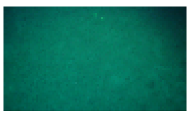	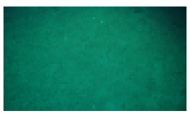		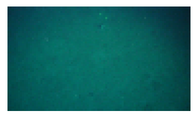		
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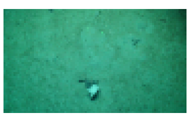	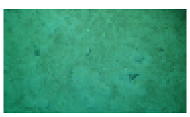	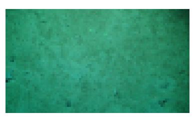	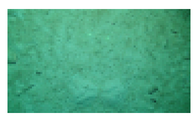	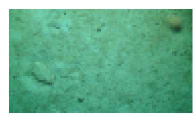	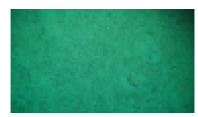
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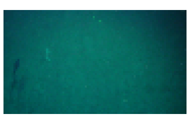	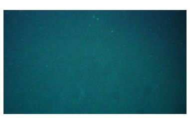	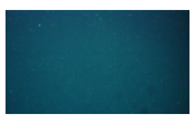			
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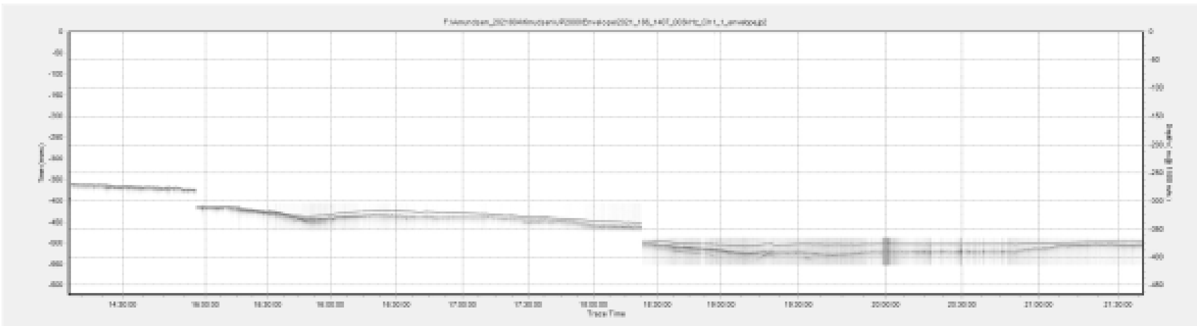
APPENDIX E: Thumbnails of 3.5 kHz segments

The images are titled as the following: yearcruise_julianday_start time.



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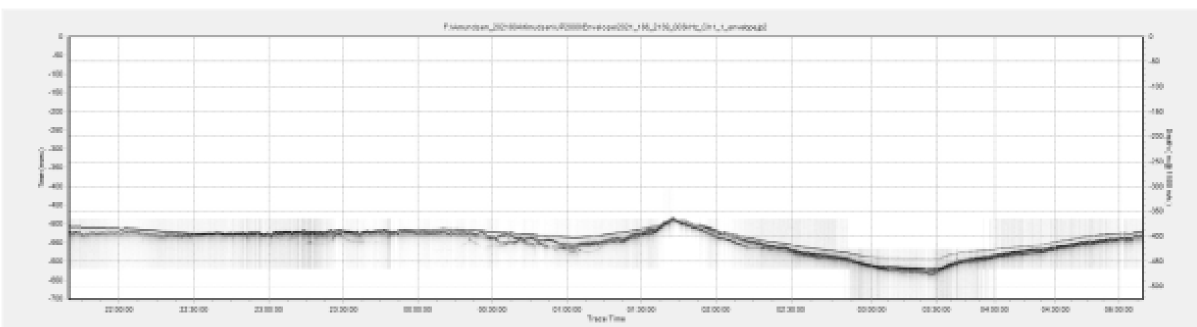

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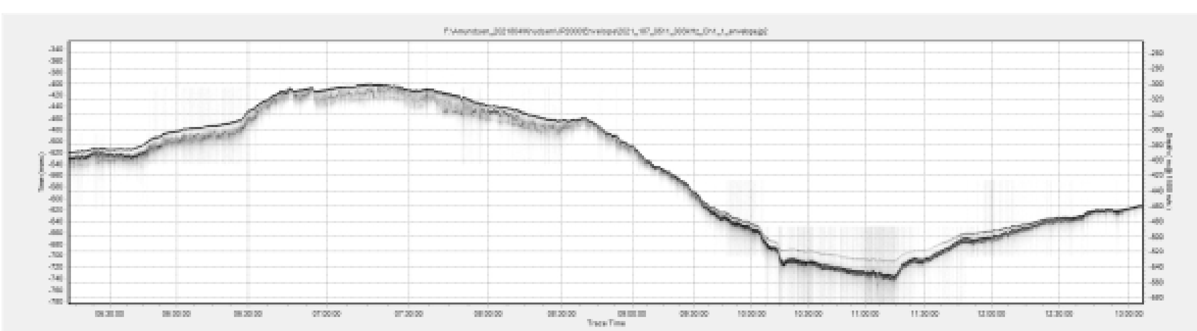

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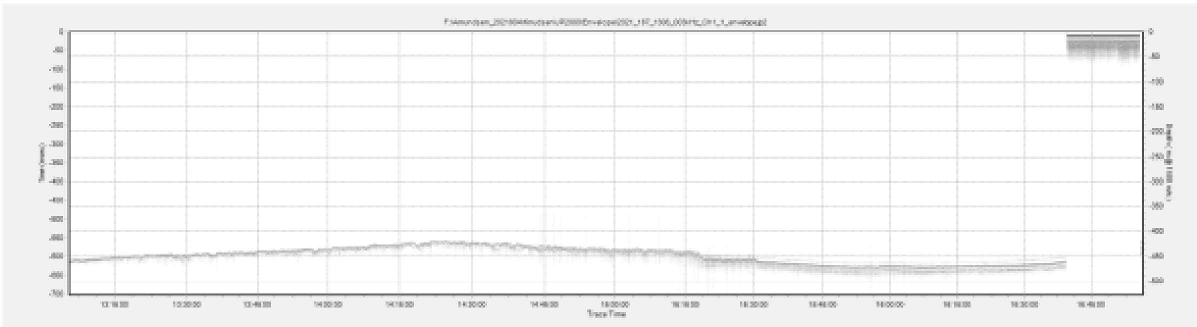

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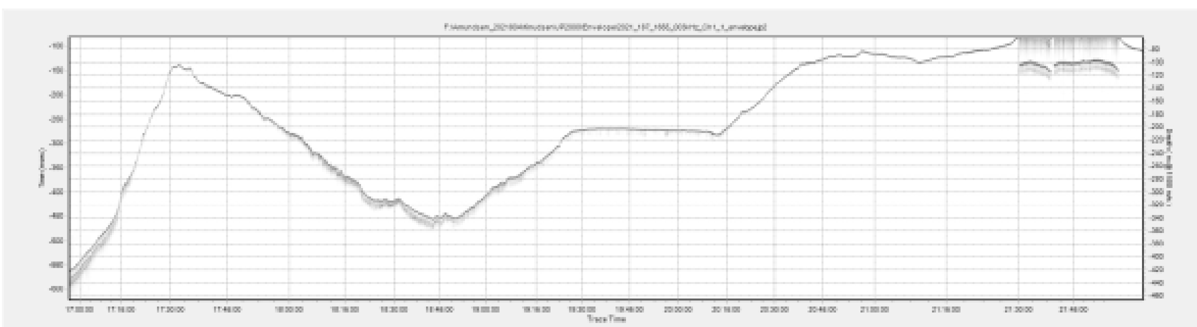

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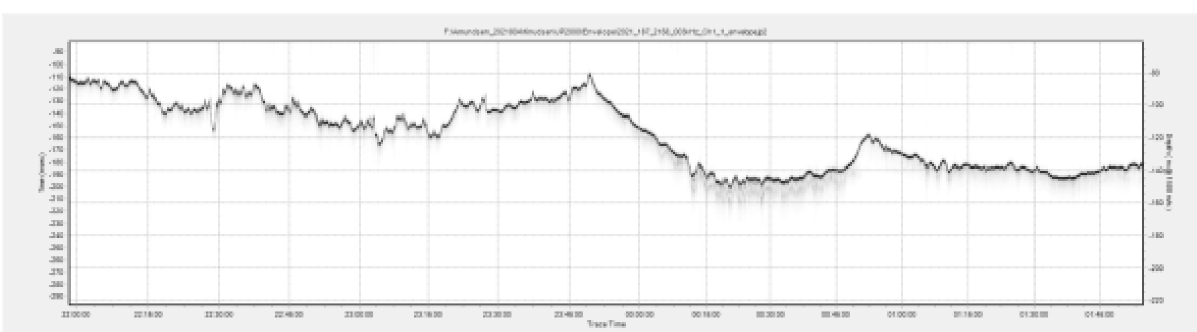

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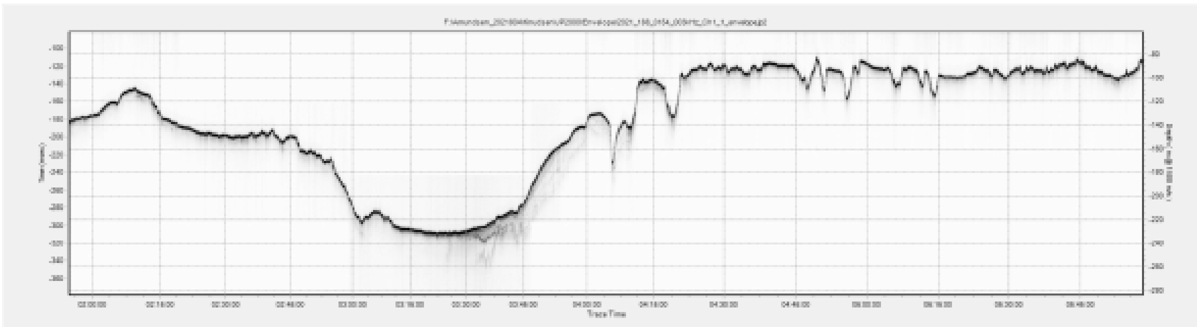

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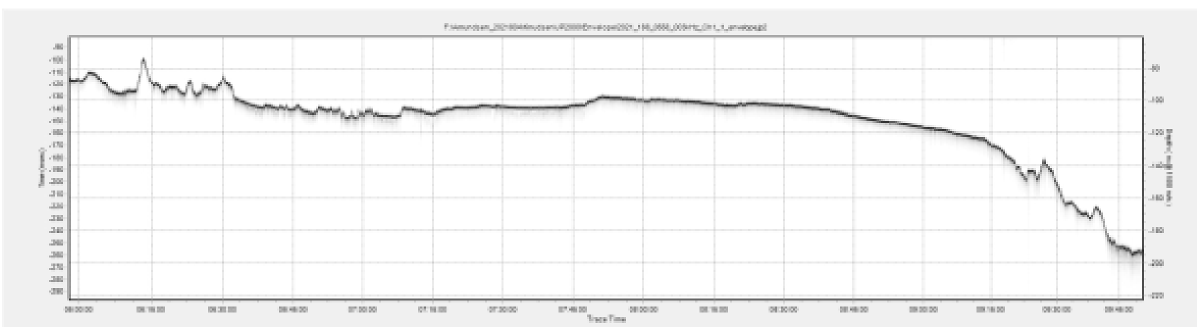

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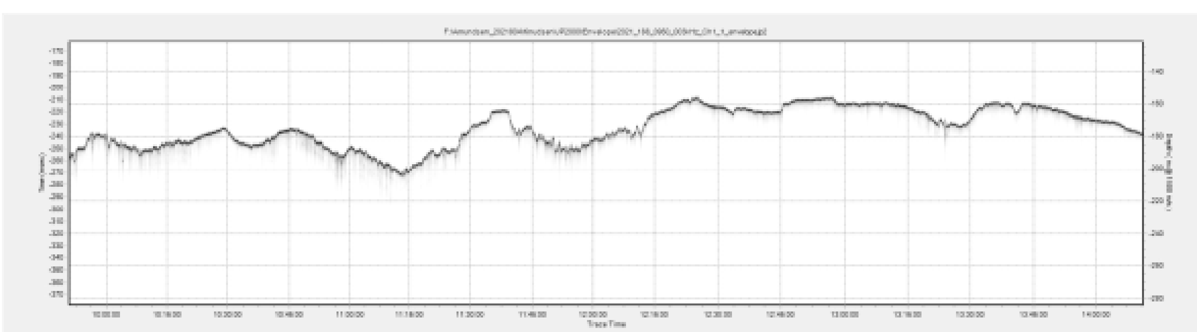

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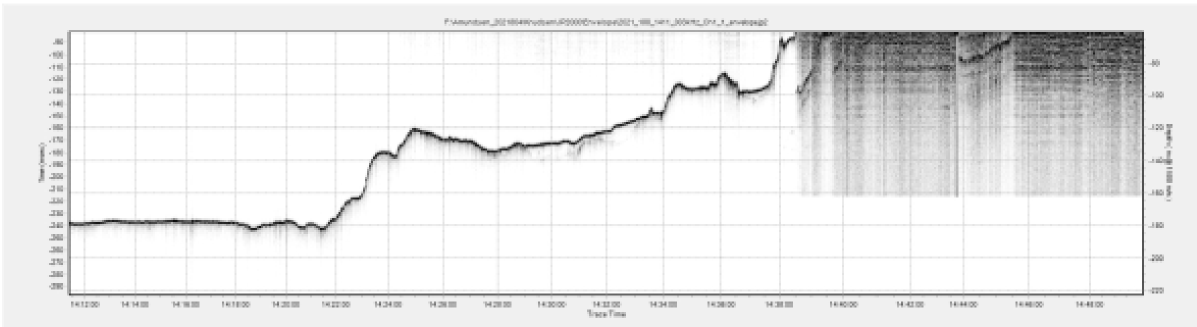

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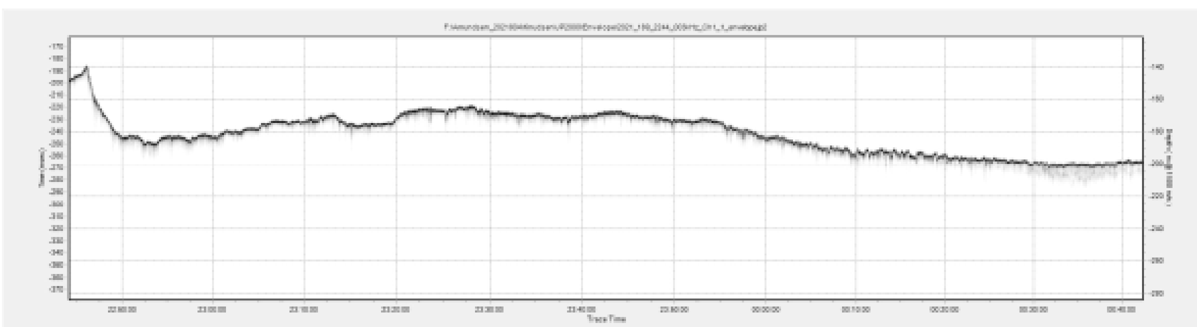

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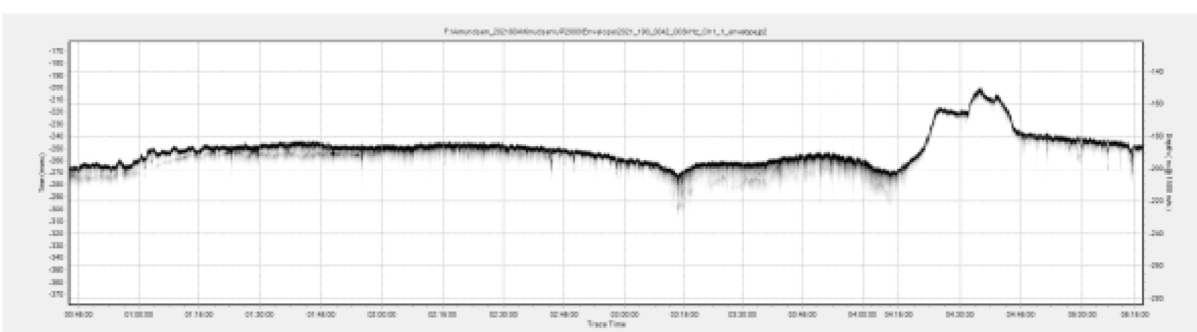

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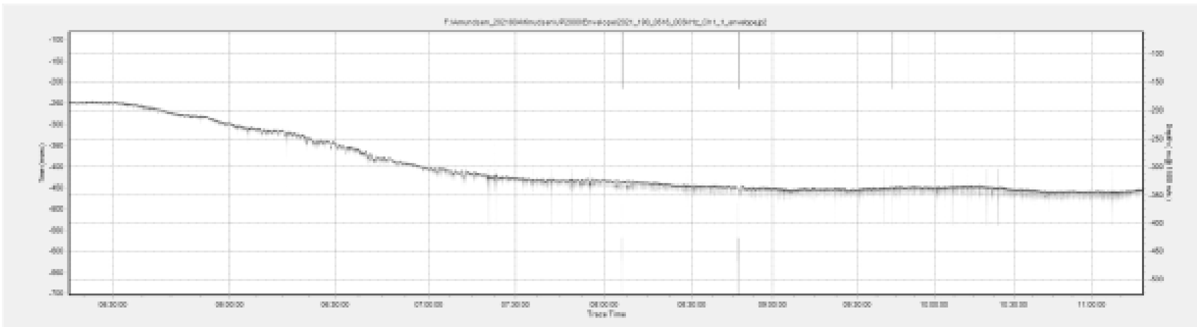

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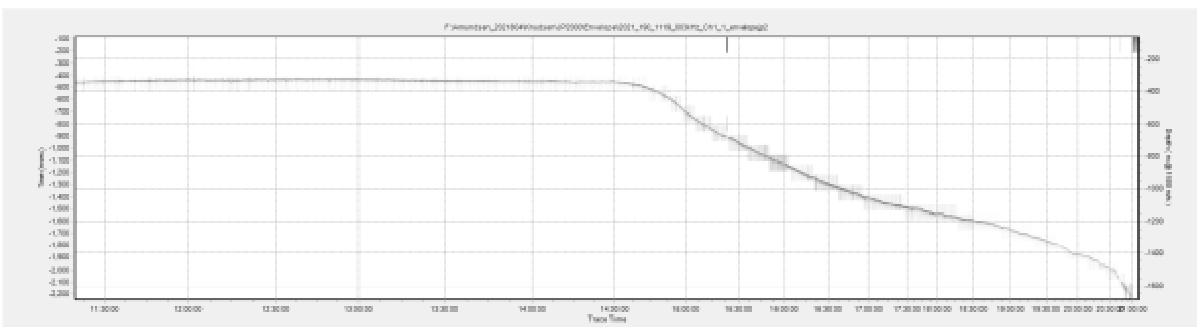

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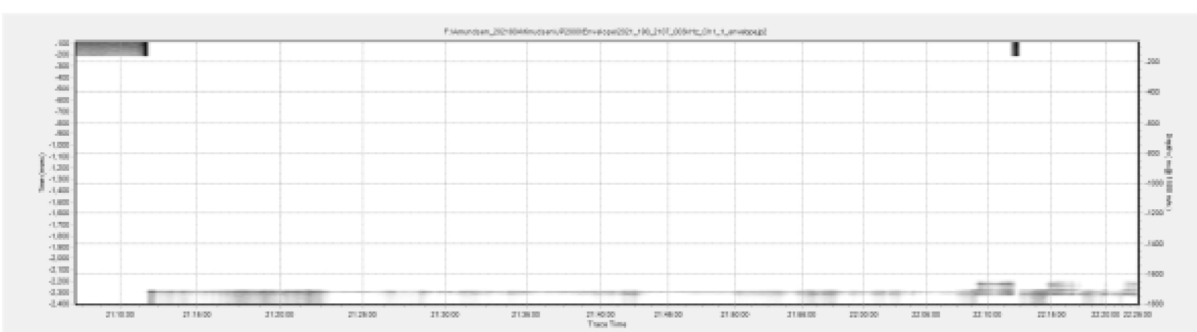

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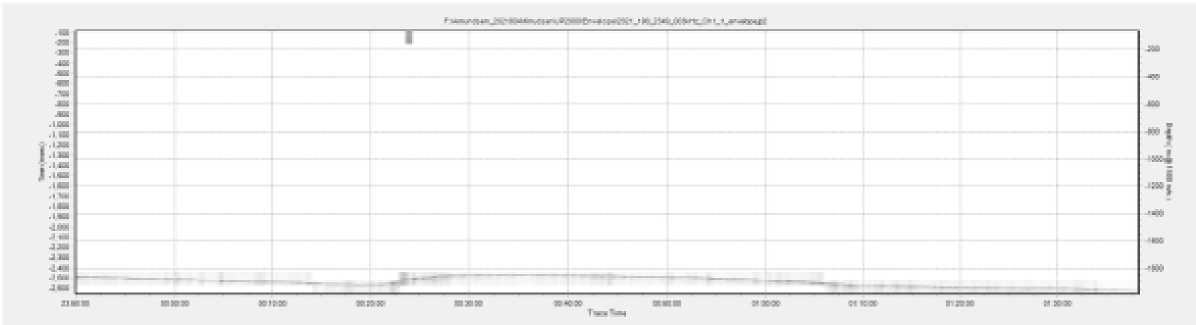

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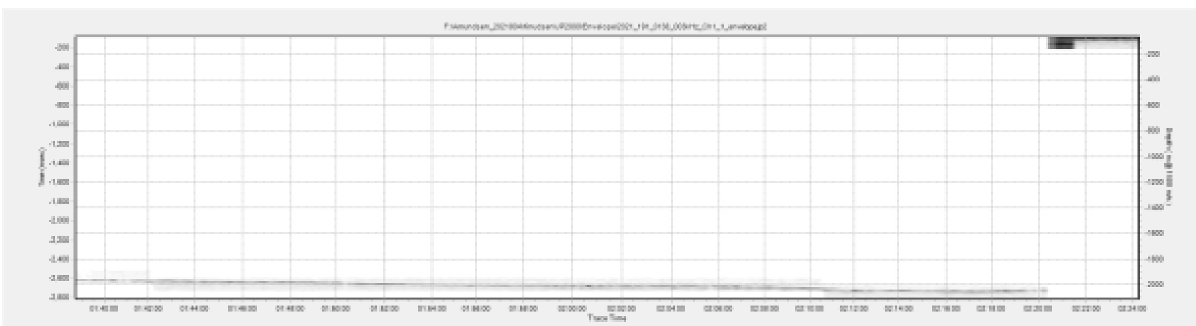

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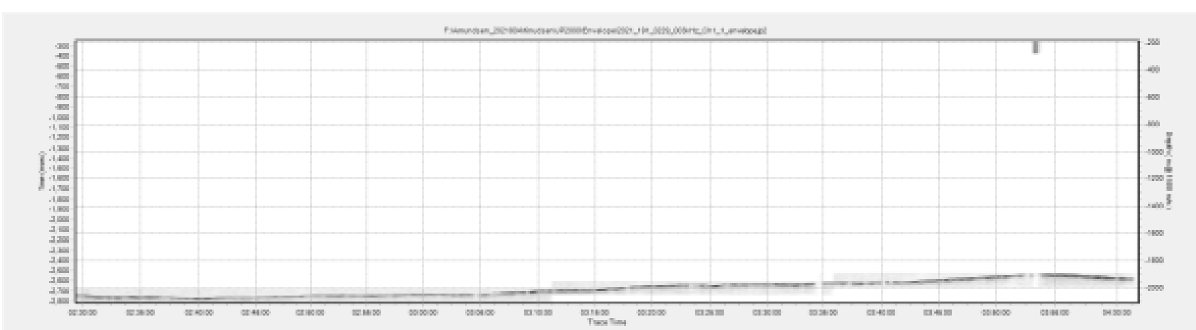

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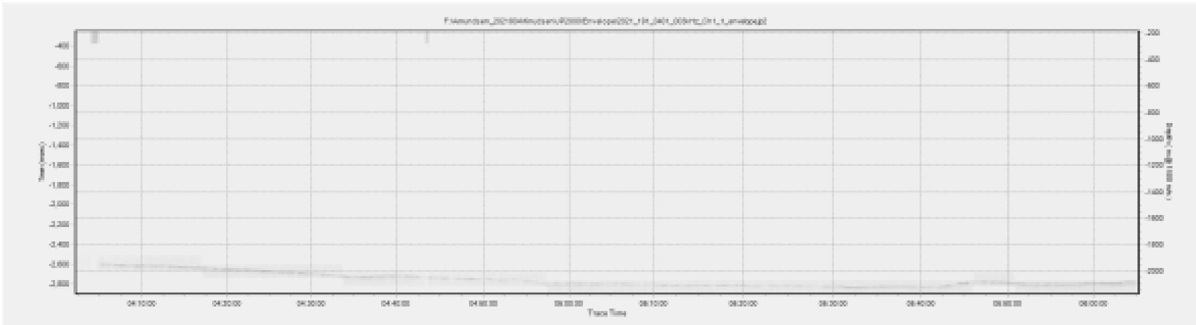

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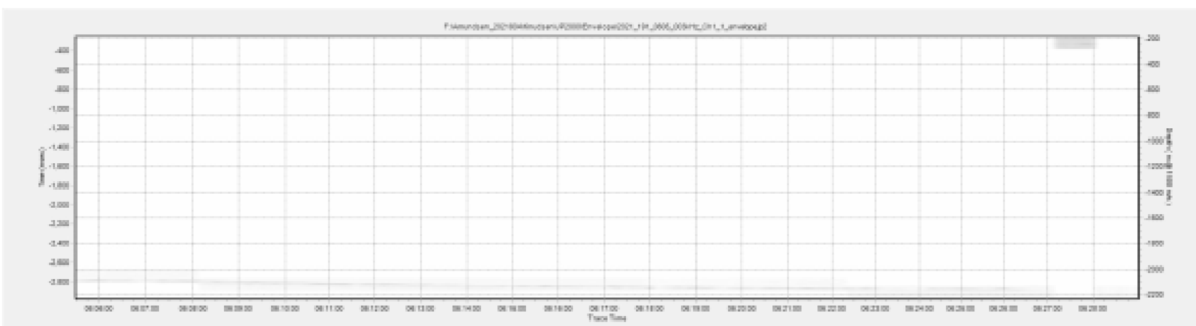

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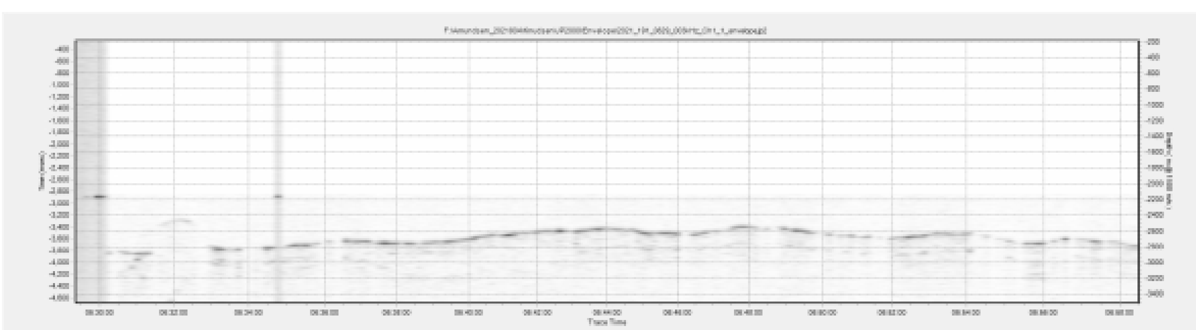

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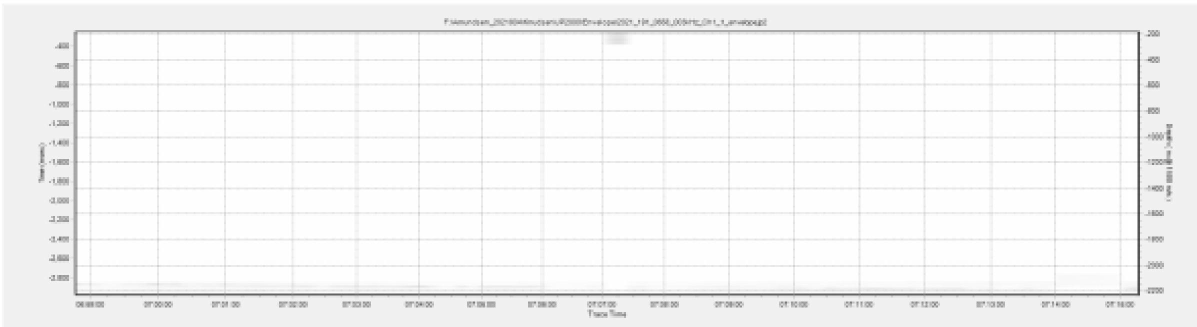

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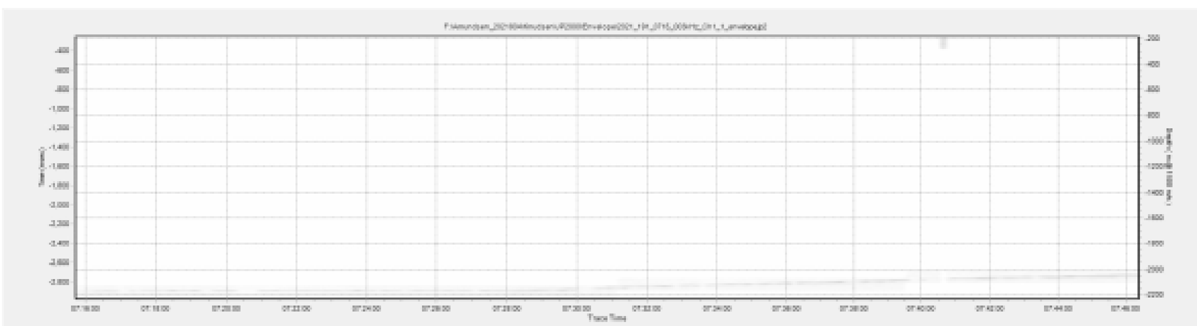

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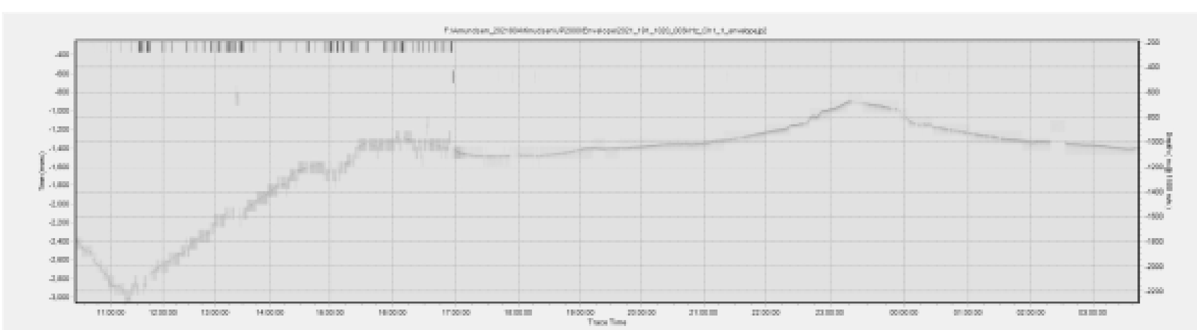

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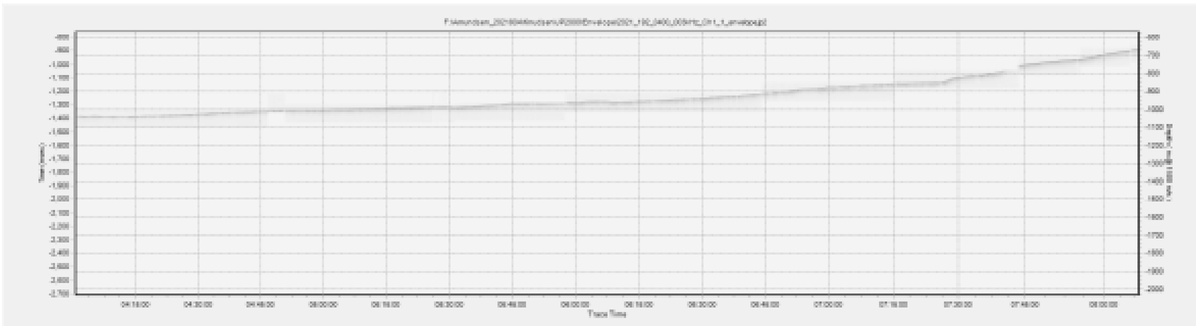

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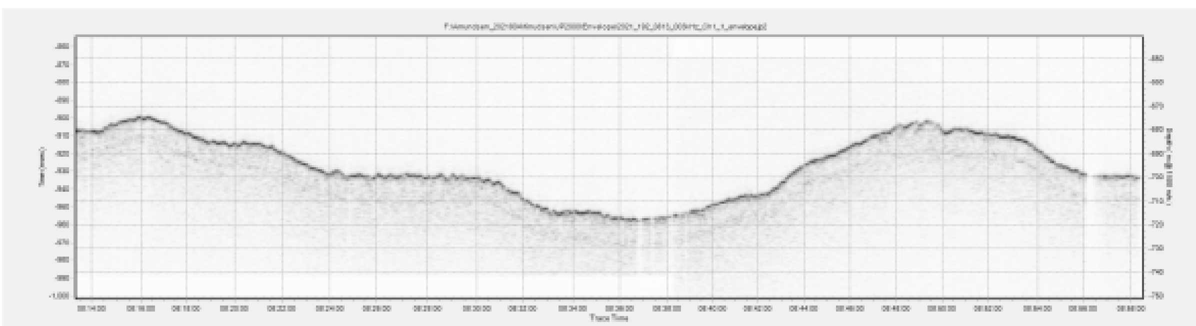

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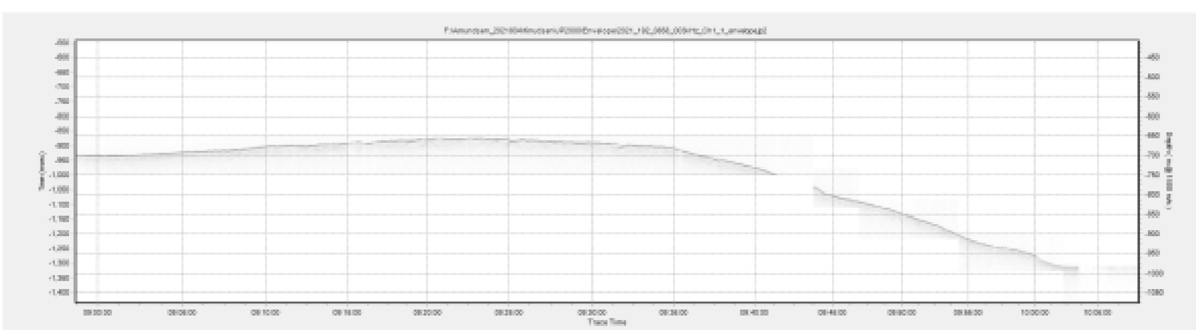

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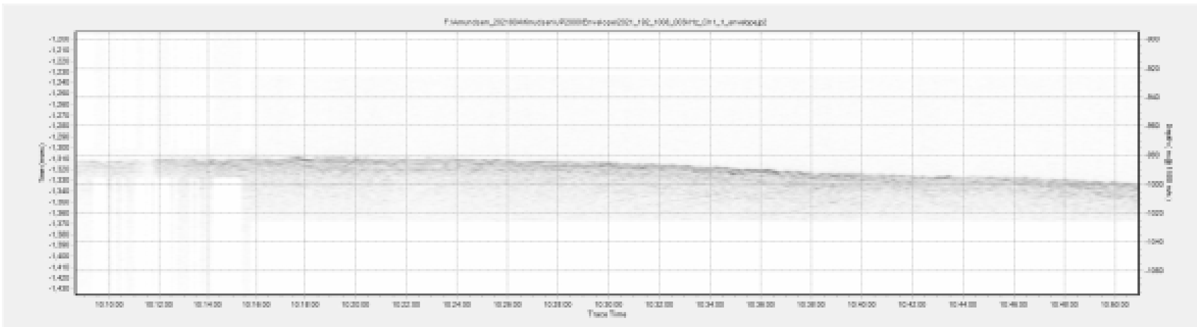

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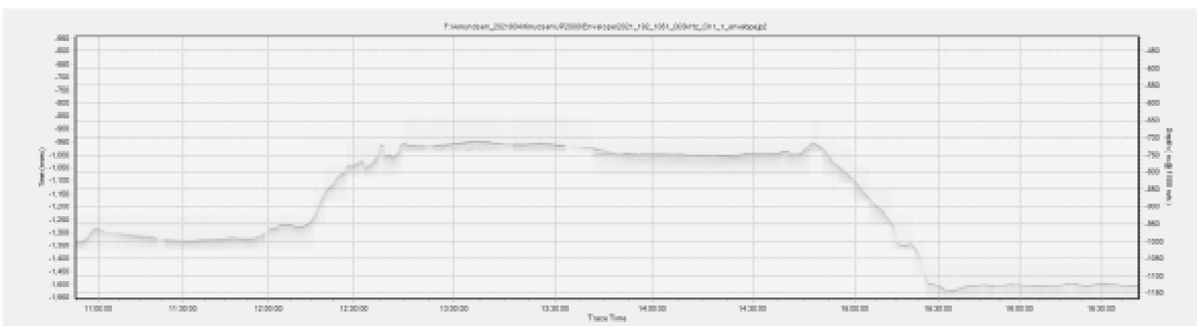

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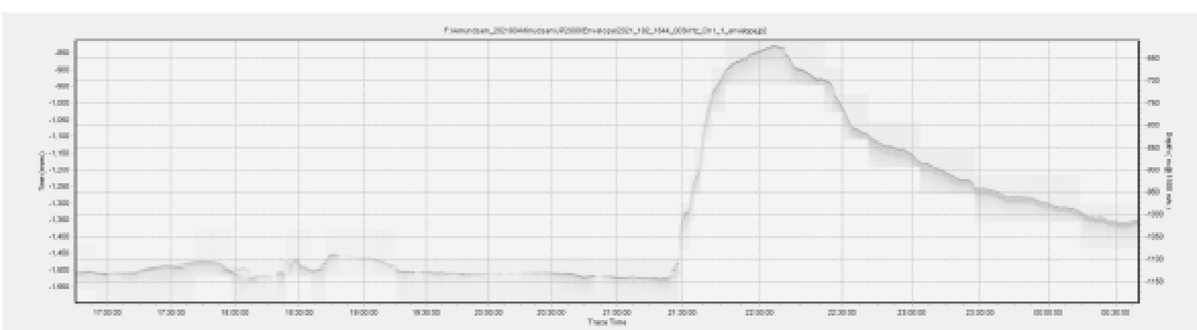

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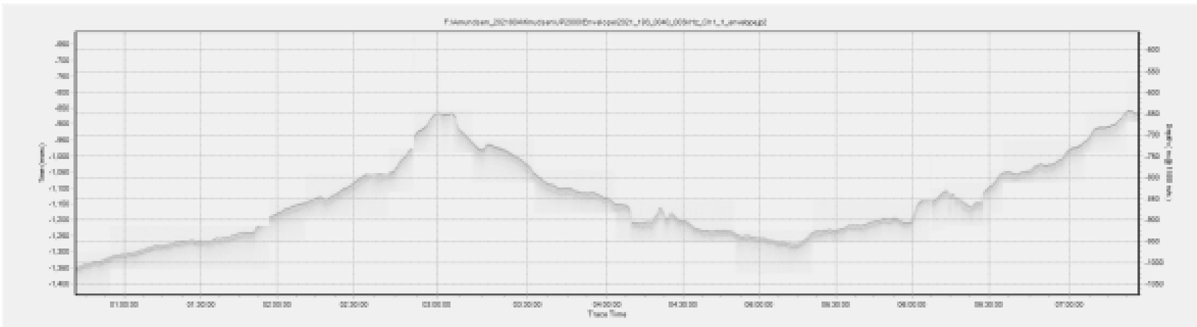

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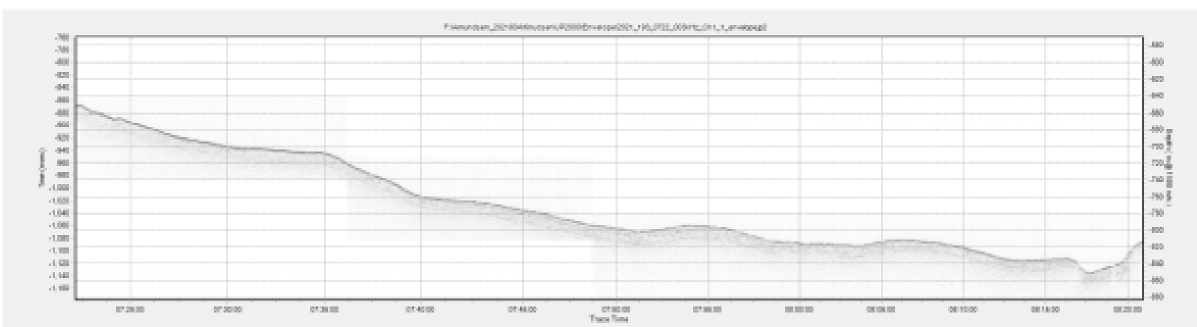

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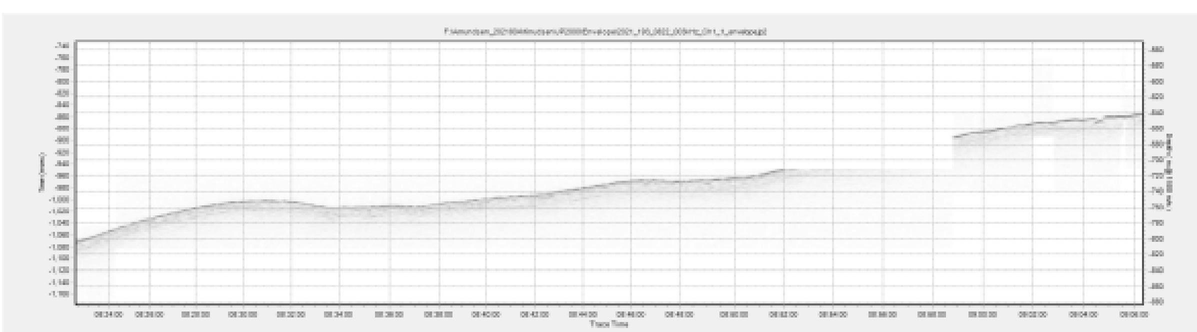

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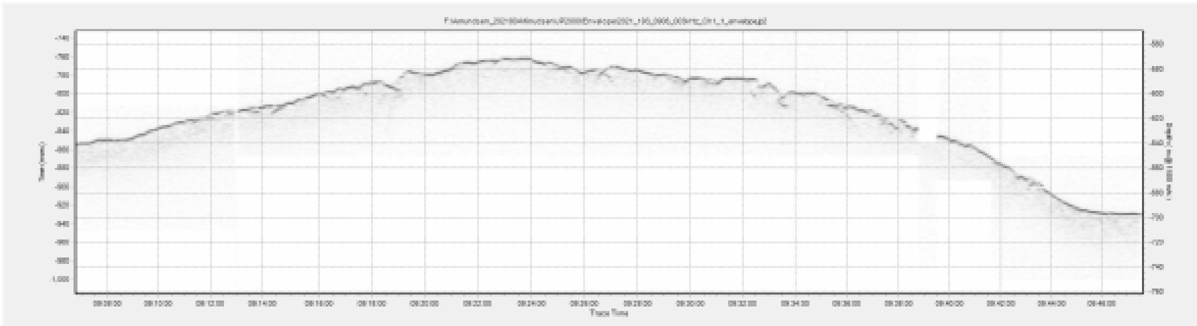

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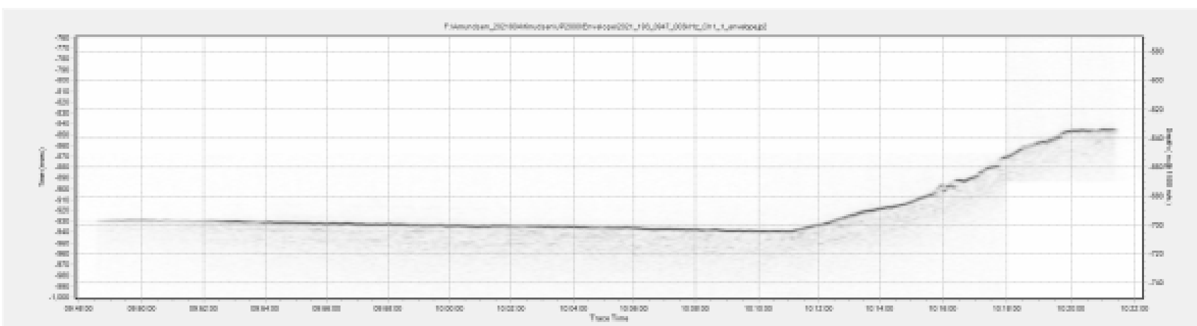

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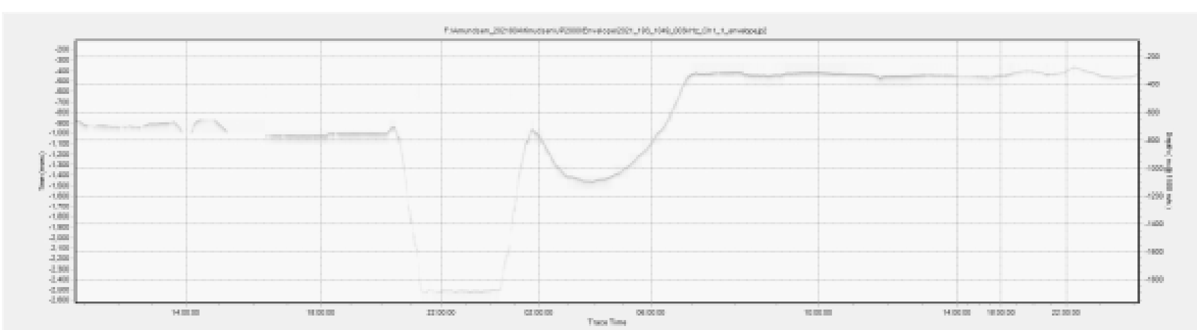

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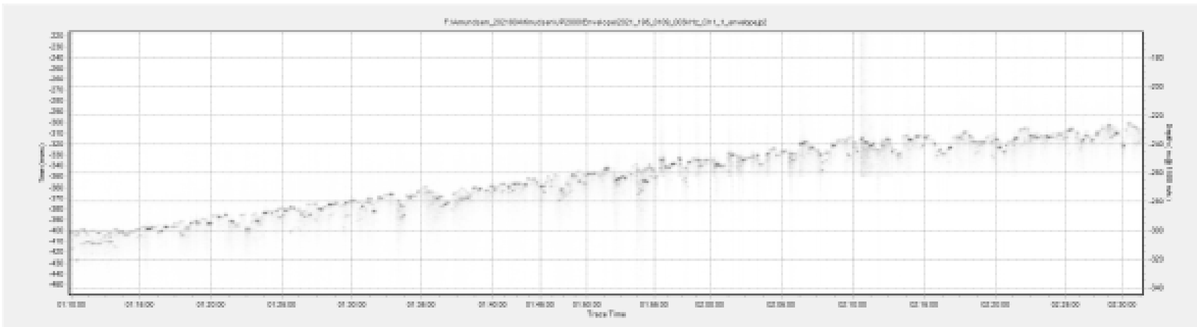

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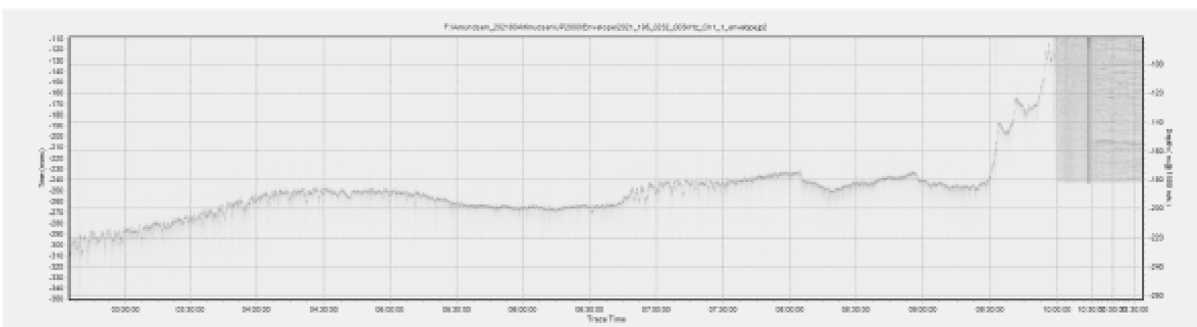

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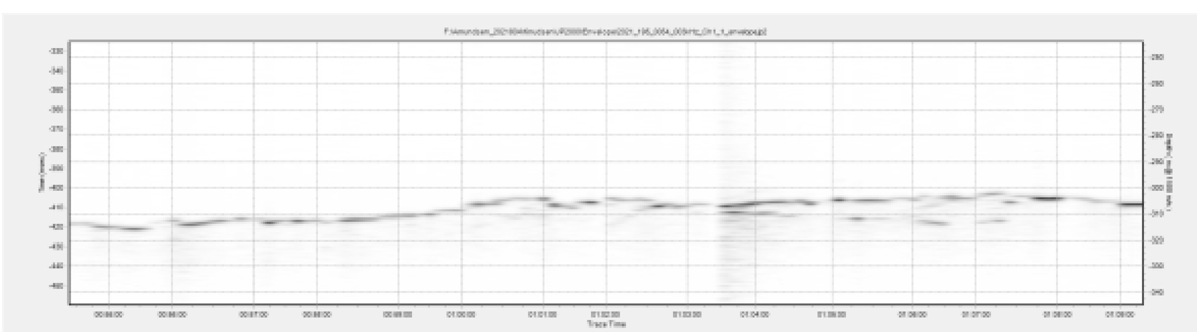

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