Natural Resources Canada | Ressources naturelles Canada

GEOLOGICAL SURVEY OF CANADA
OPEN FILE 8889

Expedition report 21CONDOR: Scotian Slope, August 14–29, 2021

R. Bennett and P.-A. Desiage

2022

Canada

GEOLOGICAL SURVEY OF CANADA
OPEN FILE 8889

Expedition report 21CONDOR: Scotian Slope, August 14–29, 2021

R. Bennett and P.-A. Desiage

2022

Permanent link: https://doi.org/10.4095/329977

This publication is available for free download through GEOSCAN (https://geoscan.nrcan.gc.ca/).

Recommended citation
Bennett, R. and Desiage, P.-A., 2022. Expedition report 21CONDOR: Scotian Slope, August 14–29, 2021; Geological Survey of Canada, Open File 8889, 53 p. https://doi.org/10.4095/329977

Publications in this series have not been edited; they are released as submitted by the author.

Contents

1.0 - Introduction

Since 2015, a joint project between Natural Resources Canada (NRCan), the Nova Scotia Department of Natural Resources and Renewables (NSDNRR), Nova Scotia Offshore Energy Research Association (OERA), the University of Calgary, and Saint Mary's University has been investigating potential offshore hydrocarbon seeps. Multiple expeditions have been undertaken during this project which have accumulated a significant amount of sediment cores, high-resolution seismic reflection, and seafloor bathymetry data. Detailed interpretation of these seismic and seafloor bathymetry data have allowed for high-resolution mapping of pockmarks, seafloor irregularities, and gas washouts with the best examples being selected for further investigation by sediment coring. A number of piston cores, gravity cores, and box cores were collected at the selected sites and subsequently underwent geochemistry and microbial genomic analysis. The results of these analyses imply a working petroleum system in the subsurface. It was determined that the next step in this project would be to directly sample the seafloor features that are indicative of a potential hydrocarbon system.

While collecting sediment samples from a surface vessel (i.e. piston coring, gravity coring, box coring, etc.) is an effective and efficient method to sample marine sediments, it does not allow for precise positioning of the sampling device. The seafloor features that were to be targeted for this expedition could potentially be less than 1 m across and therefore would be incredibly difficult to sample with a piston corer or similar equipment. To obtain the level of precision required to locate and sample these small features, it was determined that a remotely operated underwater vehicle (ROV) would be the best instrument for the next phase of this research.

The sites explored during the expedition are part of the sites selected by NSDNRR and investigated using Autonomous Underwater Vehicle (AUV) during two expeditions, in 2018 and 2020, onboard the CCGS Hudson and the Pacific Constructor respectively. The sites were selected by identifying direct hydrocarbon indicators (DHI's) based on seismic features and attributes. The generalized workflow of site selection began with understanding the regional seismic morphology, faults, and structure to determine hydrocarbon movement to the surface. It then moved on to seismic mapping to identify DHI's, linking DHI's with possible seabed seeps and subsurface hydrocarbon migration pathways, and finally creating maps to show DHI presence and potential source. Potential locations were then ranked based on previous piston coring results (where applicable), size of the DHI, and features present. The 15 highest ranked sites were selected for investigation during this expedition.

The overall goal of the 2021 ROV expedition was to sample up to 15 selected hydrocarbon targets identified through previous research. Each participating research group had their own expected outcomes for the expedition but they can be summarized through these five items:

1. Through the use of an ROV, direct core sampling of hydrocarbon seep sites showing evidence of thermogenic hydrocarbons (i.e. pockmarks, gas vents, bacterial mats, gas hydrates).

2. Preliminary data and analytical results obtained through onboard geochemical and microbiological analysis of collected samples.

3. Preservation of all samples for subsequent onshore scientific analyses by the research team (NSDNRR, University of Calgary, Saint Mary's University) with sample preservation and storage at +4 C°, -20 C° and -80 C°.

4. Validate genomic bioassay strategies through the collection of sediment push cores along transect lines across hydrocarbon seeps.

5. Establishing the feasibility and utility of conducting onboard genetic sequencing as well as testing other new approaches to improve sampling accuracy, speed processing time and generate useful analytical results.

1.1 - Personnel

The following people formed the science team that conducted the research on this expedition (Figure 1).

Robbie Bennett	Natural Resources Canada
Pierre-Arnaud Desiage	Natural Resources Canada
Daniel Gittins	Applied Petroleum Technology
Casey Hubert	University of Calgary
Jackie Zorz	University of Calgary
Anirban Chakraborty	University of Calgary
Todd Ventura	Saint Mary's University
Narges Ahangarian	Saint Mary's University
Ellen Lalk	Massachusetts Institute of Technology

Figure 1: Science team for the 21CONDOR expedition (Courtesy of D. Gittins). [From L to R: Pierre-Arnaud Desiage, Anirban Chakraborty, Narges Ahangarian, Ellen Lalk, Jackie Zorz, Casey Hubert, Robbie Bennett, Daniel Gittins, Todd Ventura]

2.0 - Methods / Equipment

The expedition began on August 14 when the Atlantic Condor departed Dartmouth, NS at approximately 16:00. The research vessel first proceeded to a pre-selected location for the calibration of the ROV's underwater positioning system. After the calibration was complete, the Atlantic Condor proceeded to the first target (site 1-1) and science operations commenced. Over the next 14 days, the expedition conducted ROV dives at 12 sites and returned to Dartmouth, NS on the morning of August 29 (Figure 2). Details of the science operations conducted during the expedition are available in Appendix 1.

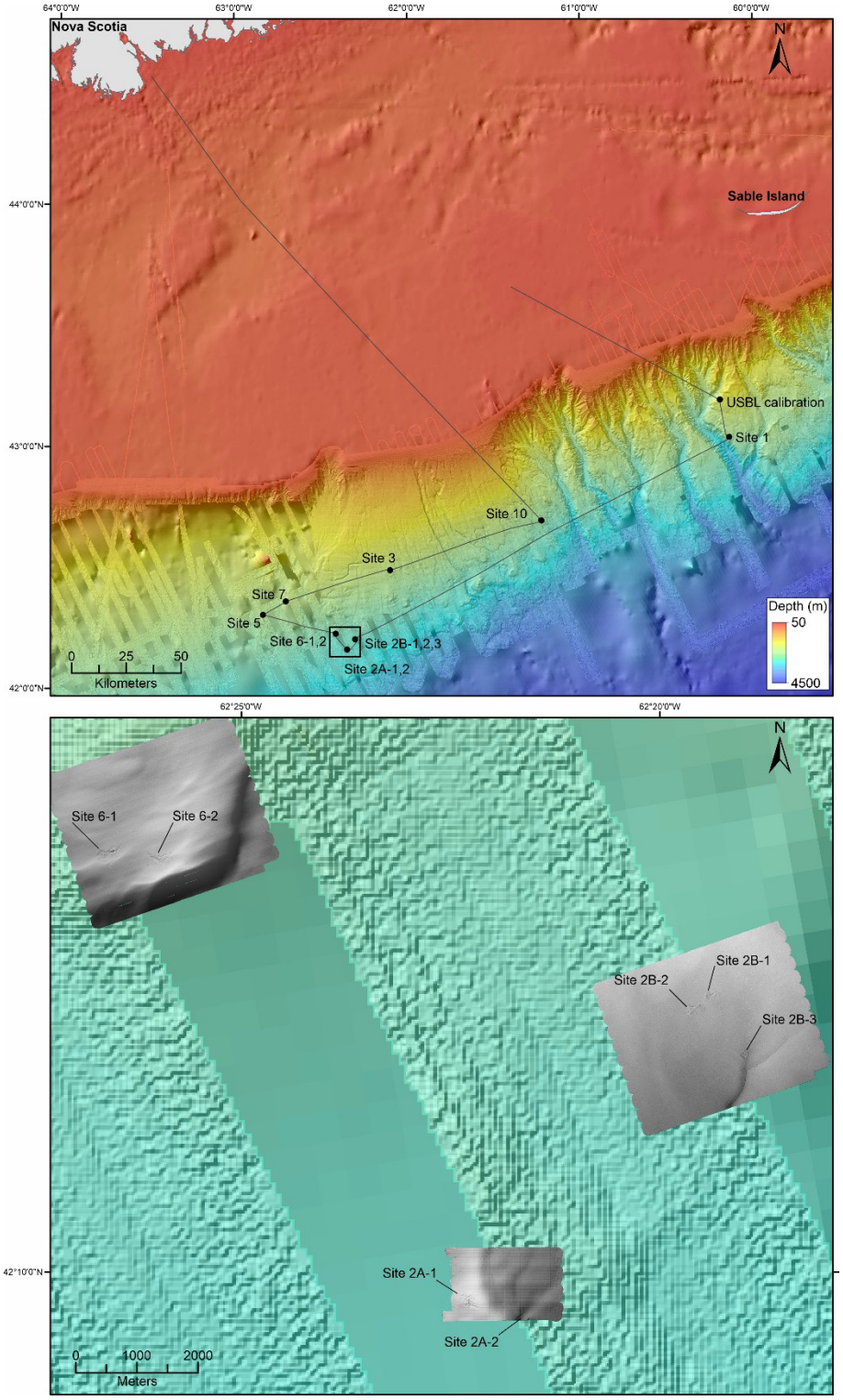

Figure 2. Navigation lines and site locations of 21Condor expedition. The area of sites 2A, 2B and 6 is highlighted with a black square. The bathymetry and the locations investigated for sites 2A, 2B and 6 are also presented.

The weather was impeccable for the majority of the expedition. Most days saw flat seas and very light winds which made the science operations highly productive. Only about 2.5 days of working time were lost due to poor weather.

During the expedition, 12 ROV surveys were conducted leading to the recording of more than 31 h of seabed images (Table 1). In addition, 357 push cores and 1 block of authigenic carbonates were retrieved at 11 sites as well as on two transects. Push cores were processed and sampled onboard, and sediment samples were stored in -20°C and -80°C freezers in order to be analysed after the expedition. Water samples were also collected at four stations using 5, 8 and 12 liters Niskin bottles and gas samples were retrieved at three stations using a gas collection system designed by Todd Ventura of Saint Mary's University. Summary of activities and sample recoveries are detailed in Appendix 2.

Table 1: Summary of ROV activities

Station	Date	JD	Time (ADT)	Latitude	Longitude	Water Depth (m)	Activities
Calibration Point	15/08/2021	227	12:00	43.16483569	-60.25960748	1611	Calibration
Site 1-1	16/08/2021	228	12:40	43.01008881	-60.2119166	2350	Survey and Coring
Site 2B-1	18/08/2021	230	08:00	42.20781179	-62.3238209	2740	Survey, Coring and Gas sampling
Site 2B-2	19/08/2021	231	10:00	42.20546173	-62.32704473	2750	Survey and Coring
Site 2B-3	20/08/2021	232	03:00	42.19873502	-62.31718812	2760	Survey and Coring
Site 2A-1	20/08/2021	232	15:00	42.16269779	-62.3723563	2685	Survey, Coring and Rock, Gas and Water sampling
Site 2A-2	21/08/2021	233	06:30	42.15991979	-62.36026101	2730	Survey, Coring and Water sampling
Site 6-1	22/08/2021	234	04:00	42.22971701	-62.44254835	2560	Survey and Coring
Site 6-2	25/08/2021	237	15:00	42.2283769	-62.43325655	2540	Survey, Coring and Water sampling

Site 5-1	26/08/2021	238	10:00	42.30733111	-62.83802943	2240	Survey, Coring and Water sampling
Site 7-1	27/08/2021	239	08:00	42.36327553	-62.71084085	2080	Survey and Coring
Site 3-1	27/08/2021	239	17:00	42.48901674	-62.1286835	2050	Survey and Coring
Site 10-1	28/08/2021	240	08:00	42.68515622	-61.27714503	2250	Survey

Due to the margin error of the USBL positioning system, the location of sampling sites should be take into consideration with caution. Figure 3 illustrates the variability in the positioning of the ROV, observed especially for the first sites investigated (i.e., Site 1, 2B and 2A), as the locations where the push cores have been retrieved could correspond to a wide cloud of dots.

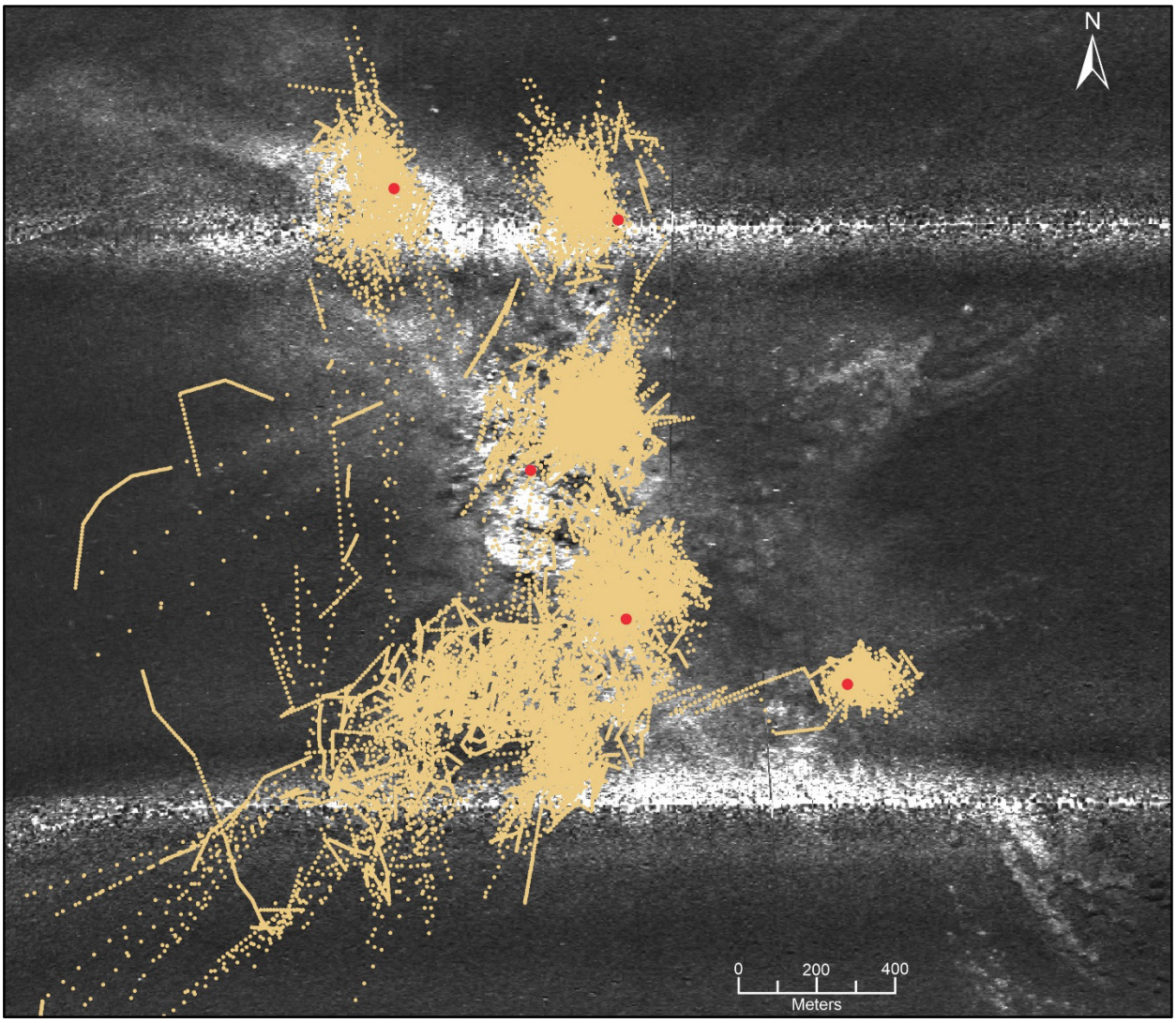

Figure 3. Locations of stations sampled with push corer (red dots) and positioning of the ROV at every second (beige dots) during sampling period at site 2A provided by the survey company (Utec). Spots with high concentration of beige dots illustrate the approximate location of stations sampled.

2.1 - Vessel

The Atlantic Condor was used for science operations during this expedition (Figure 4). To prepare the vessel for science, 1 wet lab container, 2 dry lab containers, and 2 sample storage containers were installed on the aft deck. All sediment cores were processed in the wet lab container and then the samples were either stored in one the sample storage containers (at either 4°C, -20°C, or -80°C) or transferred to one of the dry lab containers for further analyses.

In addition to the lab containers, the ROV, ROV winch, ROV A-frame, work basket winch, and work basket A-frame were installed on the two mezzanine decks above the aft deck (Figure 5). This equipment facilitated the launch and recovery of the ROV and the work basket that was used to

transport the core samples to the surface. An ROV control container and ROV workshop container were also installed on the aft deck to support the ROV operations.

Overall, the vessel performed very well for the science operations completed during the 21CONDOR expedition. The vessel did have some slight difficulties in operating the ROV during rough weather. It was determined during the expedition that wave heights must be less than ~1.5 m for safe operation of the ROV onboard the Atlantic Condor.

The specifications for the Atlantic Condor are as follows.

Year built: 2010

Length: 73 m

Beam: 16 m

Draft: ~5 m

Deadweight: 3129 mt

Figure 4: Atlantic Condor. Photograph by R. Bennett, NRCan photo 2022-193.

Figure 5: Aft deck and mezzanine decks of the Atlantic Condor. Photograph by R. Bennett, NRCan photo 2022-194.

2.1 - Remotely Operated underwater Vehicle (ROV)

The ROV used during this expedition was provided and operated by Helix Robotics Solutions Ltd. from Houston, Texas. The ROV used on the Atlantic Condor was the 200 hp, working-class Triton XLX (ID# 89). It was equipped with 4 cameras, 2 manipulator arms and was rated to work in water depths up to 3000 m. The ROV was controlled from a control room container located on the aft deck. The control room was equipped with 12 display monitors that showed live video from the ROV, ROV system gauges, forward looking sonar display, and a navigation screen (Figure 6). The control room was staffed by 3 ROV personnel (2 pilots and 1 supervisor) and at least one member of the science team.

The ROV preformed well during the expedition. The ROV pilots were very skilled and provided vital advice that contributed to the successful collection of seafloor video and core samples. There were problems with the HD camera that caused the video to be choppy and have a very low framerate. The other cameras (SD color zoom and black and white) were used instead of the HD camera for all ROV operations. The HD video was recorded and used post-dive to extract high quality still images.

Navigation equipment, software, and personnel were provided by Utec Survey from Houston, Texas. Underwater positioning of the ROV was accomplished by an ultra-short baseline (USBL) system that was operated by Utec. The navigation software package, NavView, was used to log and manage all navigational data for the ship's and ROV's position, as well as act as a display for the pre-existing multibeam / sidescan data. Validation of the USBL system onboard the Atlantic Condor determined that

the relative accuracy of the USBL navigation was 0.19% of the water depth. Navigation displays were placed on the bridge of the Atlantic Condor and the ROV control room.

The specifications for the Triton XLX ROV are as follows:

Vehicle number: XLX 89

Propulsion rating: 200 hp

Depth rating: 3000 m

Payload: 250-300 kg

Vehicle dimensions

Length: 3.22 m

Width: 1.80 m

Height: 2.1 m

Weight in air: 4900 kg

Onboard equipment

8 x thrusters in vectored format

Altimeter

12 x lights

1 x Simrad OE 1366 SD color zoom camera

1 x Simrad OE 14-106 manipulator camera

1 x Simrad OE 1358 black and white camera

1 x Imenco SubVIS IP HD 10x zoom camera

Schilling T4 7 function manipulator

RigMaster TA60 5 function grabber

Strobe and locating beacon

Fiberoptic multiplexing

Digi quartz® depth transducer

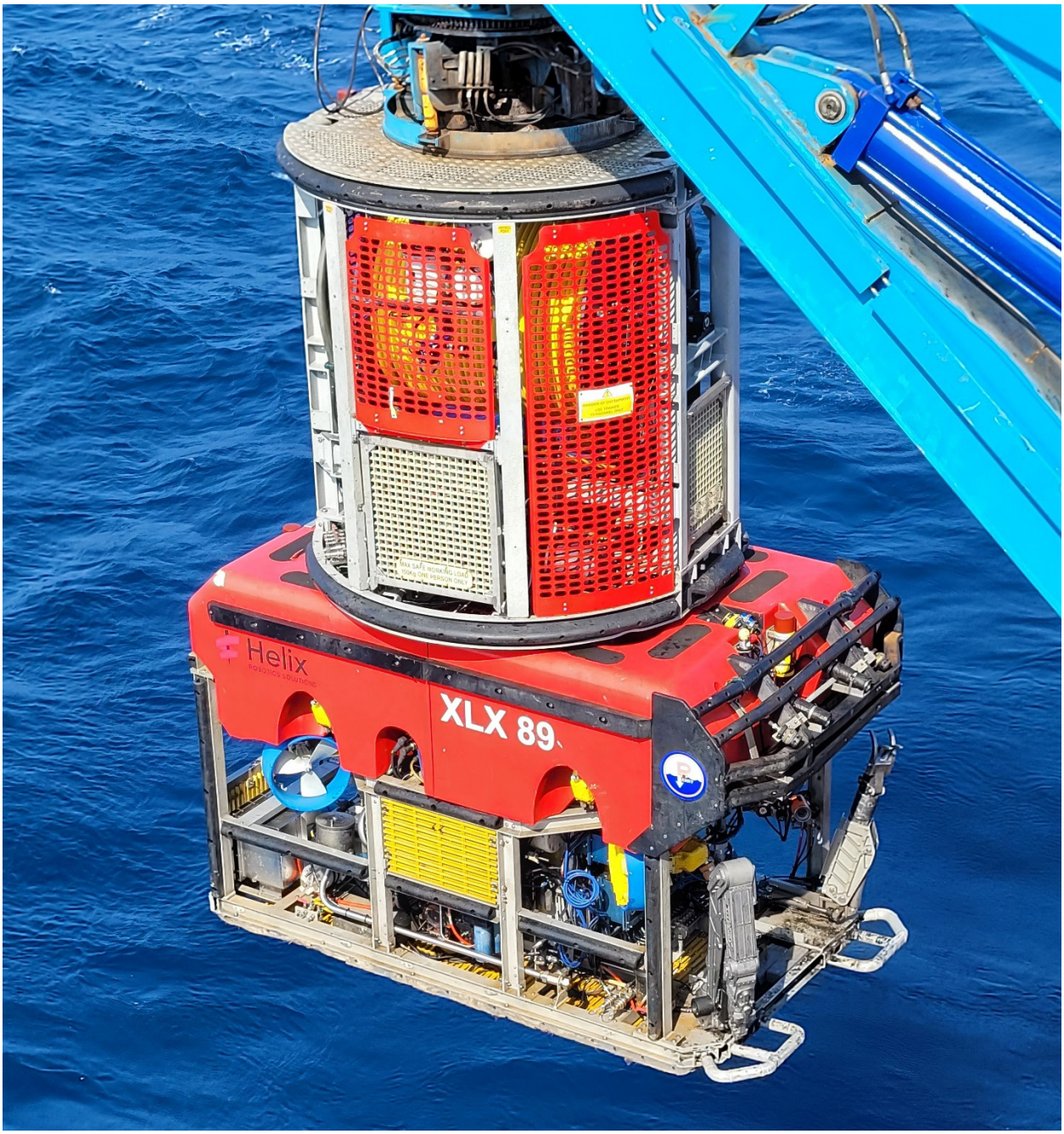

Figure 6: Helix ROV XLX89. Photograph by R. Bennett, NRCan photo 2022-195.

2.3 - Sediment coring system

The push core devices and core transport units (quivers) were designed by Todd Ventura and Jeremey Bentley at Saint Mary's University and built by Velocity Machining and Welding Ltd. in Dartmouth NS. Each push corer was 50 cm long with an internal diameter of 8.89 cm (Figure 7). The push corers (up to 12) were loaded into the quivers and secured with tie wraps to avoid losing them as they were lowered through the water column (Figure 8). Up to 4 quivers were then loaded into the work basket (Figure 9)

and lowered within 10 – 20 m of the seafloor where they could be accessed by the ROV. When coring was to begin, the ROV would fly to the work basket and remove a quiver and position it on the seafloor nearby the selected core site. The push corers would then be inserted into the seafloor by the ROV. The number of cores at each site varied and was determined by the science team based on how much sediment was required at a given location (Figure 10). After all the required push cores were inserted into the seafloor, they were removed by the ROV and placed back into the quiver (Figure 11). At the completion of the dive site or when all the push corers were full, the quivers were placed back into the work basket and it was hoisted to the surface.

Figure 7: ROV push cores on deck following sediment collection. Each clear plastic tube is 50 cm long and has an internal diameter of 8.89 cm (Courtesy of A. Chakraborty).

Figure 8: Quivers loaded with empty push cores inside the work basket ready for deployment (Courtesy of D. Gittins).

Figure 9: Work basket (empty) and work basket A-frame located on the mezzanine deck of the Atlantic Condor (Courtesy of D. Gittins).

Figure 10: Cluster of push cores inserted into the seafloor by the ROV at site 1-1.

Figure 11: Inserting the full push core back into the quiver.

2.4 - Sub-sea Operations

This section will outline the operations that occurred during a typical ROV dive on the 21CONDOR expedition.

All the work sites were selected in advance (see Section 1.0). The coordinates and pre-existing multibeam or sidescan data was provided to the ship's navigator so it could be displayed in the navigation software on the bridge and in the ROV control room. The Chief Scientist would communicate to the Captain which site was to be investigated and the vessel would proceed to that location based on the coordinates in the navigation software.

When arriving at the work site, the Atlantic Condor would first conduct a 30 minute dynamic positioning (DP) check to test the DP thrusters, obtain the optimal heading for the current sea state, and make sure the vessel was holding at the desired coordinates. When the vessel operator was satisfied with the DP's performance, he/she would give the go-ahead to deploy the ROV. At this point, the ROV operators would complete all pre-dive checks and then deploy the ROV. The ROV was lowered to the seafloor at a rate of about 30 m per minute. When the ROV was ~100 m below the surface, the work basket would then be deployed and lowered to within about 20 m of the seafloor at a similar descent rate as the ROV.

Once on the seafloor, the ROV would commence a video survey using the existing multibeam / side scan as a guide. The ROV would fly approximately 3 – 4 m above the seafloor while a member of the science team and the ROV pilots would look for indicators of hydrocarbon escape (i.e. gas bubbles), interesting benthic communities (which may be indicative of the presence of hydrocarbons), as well as any other seafloor anomalies. Any interesting features would be noted by the science team, given a descriptive name (i.e. Clam Hill), and a fix was taken by the navigator so that the feature could be revisited for sediment coring if necessary.

When the survey was completed, the seafloor features that showed the most promise of being hydrocarbon indicators were selected (up to 4 per site) and sediment coring would then proceed as described in section 2.3. At the completion of the coring, the work basket and ROV were recovered to the deck. The sediment samples were then divided amongst the three science groups (NSDNRR, University of Calgary, and Saint Mary's University) and processed according to their individual procedures. No push core sediment samples from this expedition were archived in the NRCan core repository.

The video footage, still images, and navigation data are archived in the NRCan data collections (these data can be accessed in the NRCan Expedition Database at https://ed.gdr.nrcan.gc.ca/index_e.php).

3.0 - Preliminary Results

This section will provide a description of the seafloor and the science operations performed at each site.

3.1 - Site 1-1

The seafloor at 1-1 (Figure 12) shows small pockmarks throughout the entire survey area (Figure 13A). Black pebbles and cobbles interpreted to be glacial dropstones are distributed throughout site 1-1 and are sometimes populated by sponges or corals (Figure 13B). There was a small ridge about 1 – 2 m high

observed at the center of the survey block. There is a cohesive but brittle accumulation of sediment or carbonate material along this ridge with increased biological activity (Figure 13C). The seafloor surrounding the ridge is mostly devoid of life except for a few fish and sponges/corals. No active hydrocarbon venting was observed at 1-1.

Sediment cores were collected at the following locations:

Coring Location 1: This site was selected as a test site for the first deployment of the push cores and quiver system. The seafloor at this location is relatively featureless with a few visible pockmarks nearby (similar to that shown in Figure 13A).

Sponge Bob: near a sponge-like organism attached to a dropstone (as shown in Figure 13B).

Brittle Rock: near brittle sediment or carbonate material with the highest abundance of benthic organisms at this site (Figure 13C).

Bullseye: this site was selected as it is located at the centre of the seafloor feature shown by the pre-existing AUV data. The seafloor at this location is relatively featureless with a few visible pockmarks nearby.

A transect of push cores was also collected to investigate how hydrocarbon indicators in the sediment change with distance from the source. The coring site Bullseye was considered the base of the transect and then cores were collected 10 m to the NW; and 10, 20, 30, and 40 m to the SE of Bullseye (Figure 12).

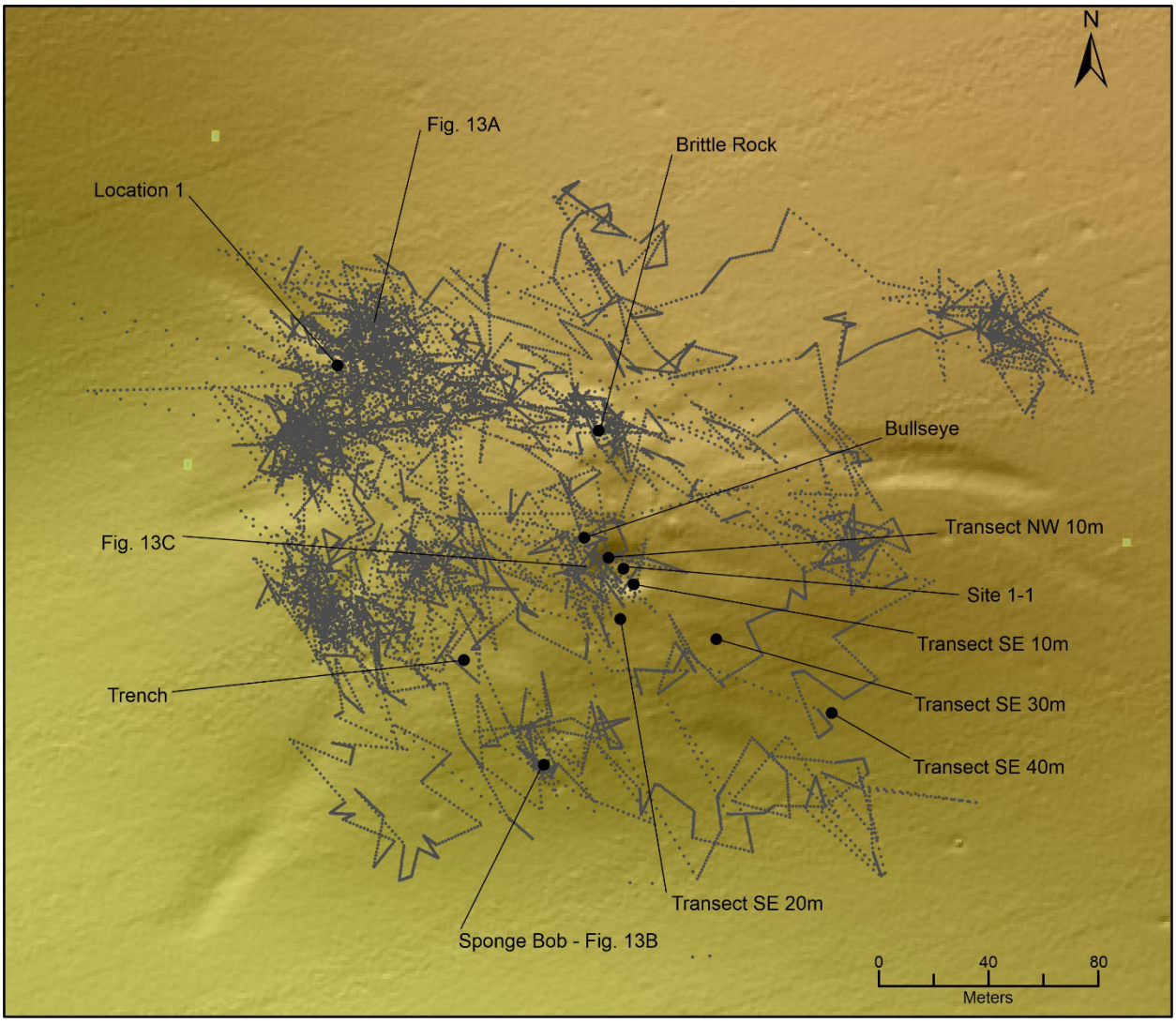

Figure 12: Bathymetric map of site 1-1 showing the positioning of the ROV (grey dots) during the survey and the locations of stations sampled.

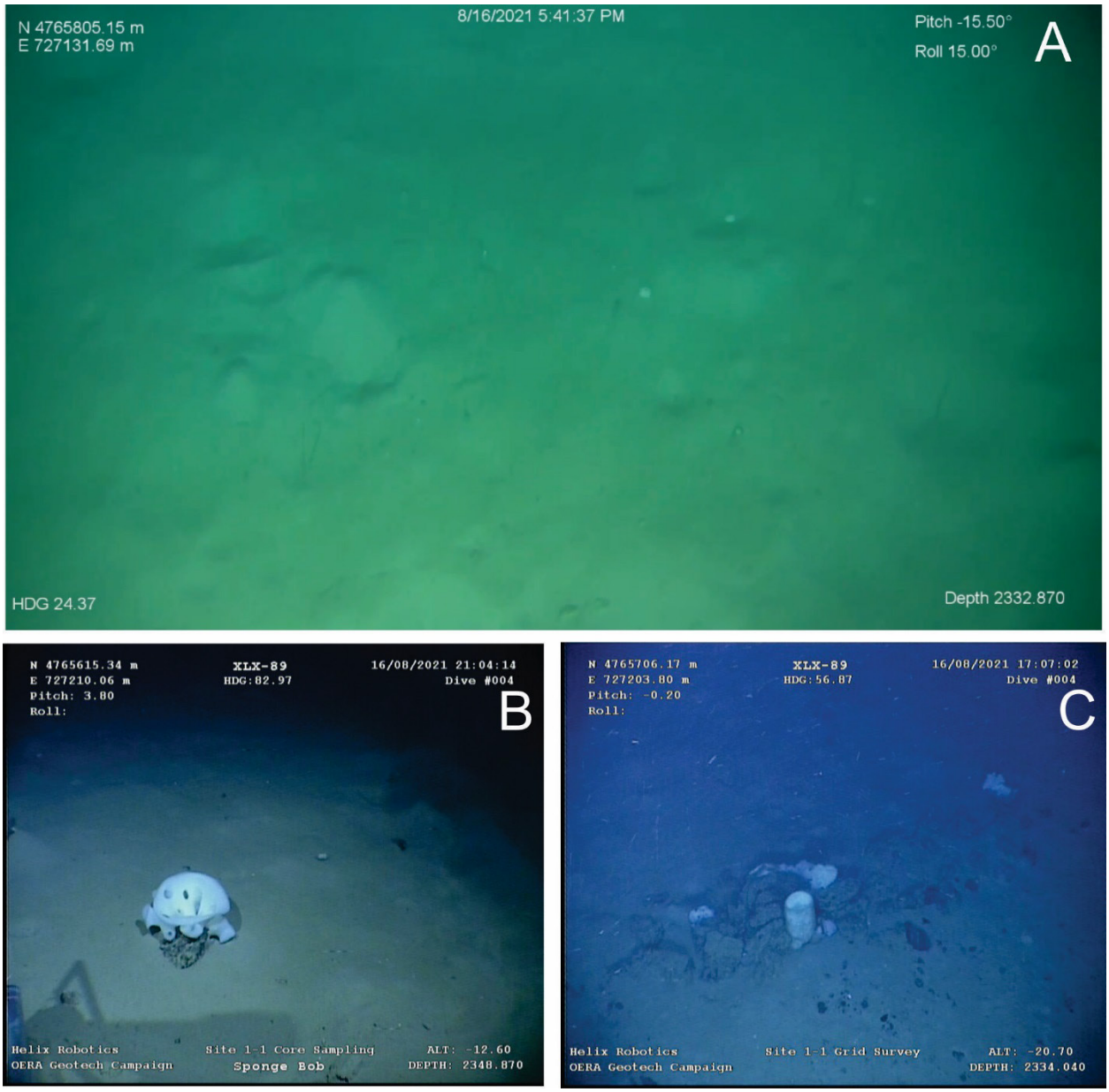

Figure 13: Seafloor images collected at site 1-1. (A) Representative seafloor at 1-1 showing a relatively featureless sediment with several pockmarks. (B) Glacial dropstone inhabited by an unidentified benthic organism. (C) Cohesive sediment or chemosynthetic material with increased biological activity located near the centre of site 1-1.

3.2 - Site 2B-1

The majority of the seafloor at 2B-1 (Figure 14) is flat with extensive bioturbation (i.e. sea urchin tracks, shallow depressions caused by an unknown organism, worm tubes; Figure 15A). White and purple bacterial mats are also observed (Figure 15B). Authigenic carbonate buildups populated by mussels/bivalves and sessile organisms like those at site 2A-1 were also present at this location (Figure 15C). Infrequent gas bubbles were observed slowly emanating from the seabed in one location (sample

site Tiny Bubbles). When the push cores were inserted into the seafloor at some of the coring locations at site 2B-1, gas bubbles were vigorously released from the seafloor (Coral Hill, Clam Shell). Some of the cores also showed bubbling inside the tubes, "cottage cheese" texture, and/or gas cracking when they were examined on the deck of the Atlantic Condor. The warning alarm on the handheld multi-gas detector was also triggered by the cores from this site.

Sediment cores were collected at the following locations:

Tiny Bubbles: grey/white bacterial mat located near outcrops of carbonate material. Some infrequent gas bubbles were observed at this location.

Purple Patch: large purple-colored bacterial mat

Coral Hill: push cores were inserted into a patch of sediment located on the flank of a large carbonate mound or chemoherm. Abundant benthic life at this location.

Clam Shell: push cores were inserted into a patch of sediment located on the flank of a large carbonate mound or chemoherm. Abundant benthic life at this location. Gas collection was also conducted at this site by SMU.

A transect of push cores was also collected to investigate how hydrocarbon indicators in the sediment change with distance from the source. The coring site Tiny Bubbles was considered the base of the transect and then cores were collected 75, 40 and 25 m to the NW; and 75, 40, and 25 m to the SE of Tiny Bubbles (Figure 14).

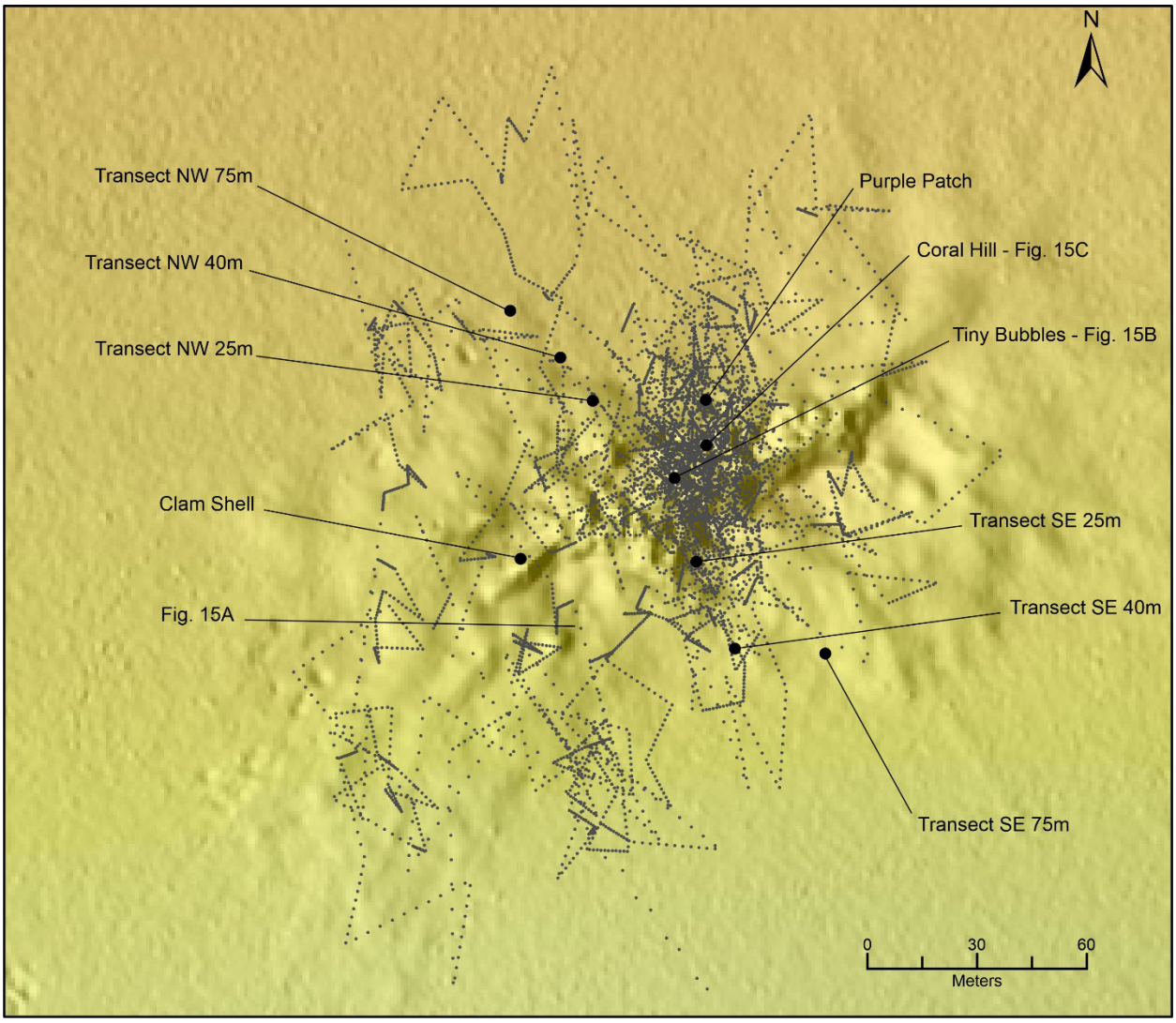

Figure 14: Bathymetric map of site 2B-1 showing the positioning of the ROV (grey dots) during the survey and the locations of stations sampled.

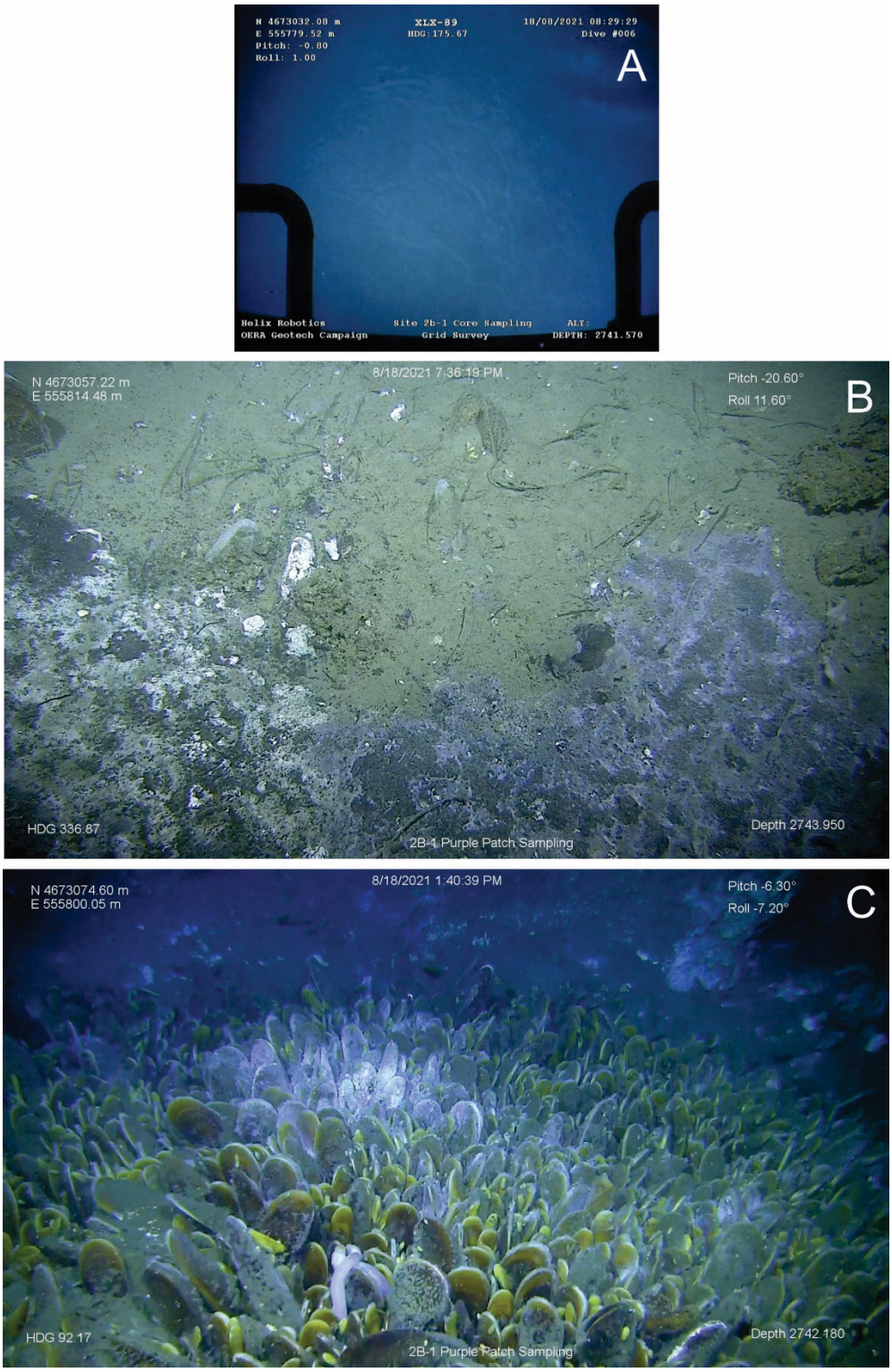

Figure 15: Seafloor images collected at site 2B-1. (A) Representative seafloor at 2B-1 showing some bioturbation in the form of sea urchin tracks. (B) White, grey, and purple bacterial mats at coring location Tiny Bubbles. (C) Authigenic carbonate buildups populated by mussels/bivalves and sessile organisms at coring location Coral Hill.

3.3 - Site 2B-2

The seafloor at 2b-2 (Figure 16) shows small mounds covered by pockmarks that do not appear to be active (Figure 17A). Benthic organisms are frequent but not to the extent of some of the more active site such as 2A-1 and 2B-1. Several purple, white, and gray bacterial mats were observed (Figure 17B) as well as some broken mollusc shells and what appears to be some form of vegetation (Figure 17C). Similar to 2B-1, when the push cores were inserted into the sediment at some of the coring locations at site 2B-2, gas bubbles were vigorously released from the seafloor.

Sediment cores were collected at the following locations:

Big Purple Patch: very large purple-colored bacterial mat.

Dark Seabed: the color of the seafloor sediments at this location is darker than the surrounding sediments. Broken mollusc shells are also observed at this location.

Scaly Seabed: broken mollusc shells and what appears to be some form of vegetation on the seafloor.

Pockmark Mound: small mound covered by small, well-defined pockmarks.

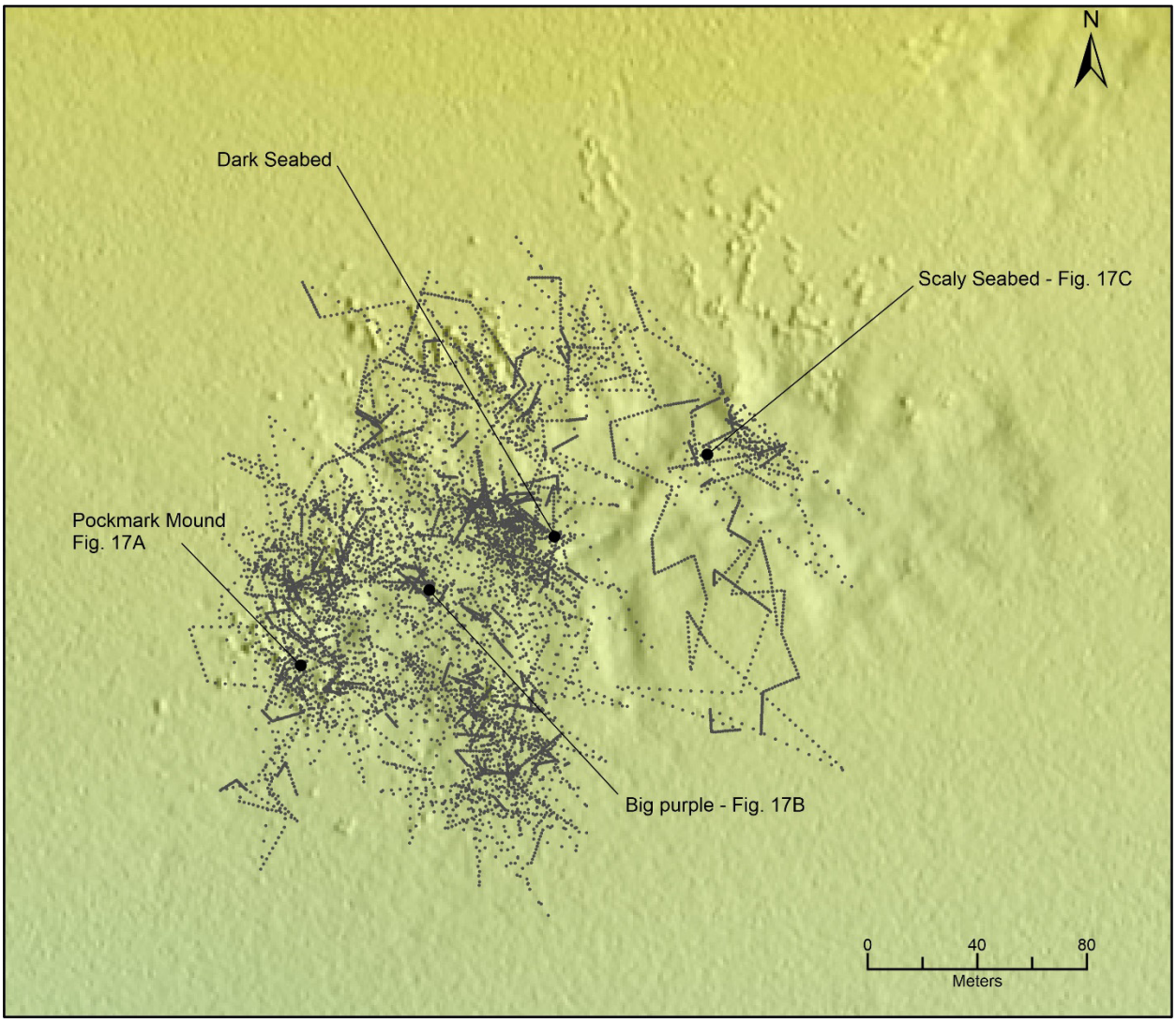

Figure 16: Bathymetric map of site 2B-2 showing the positioning of the ROV (grey dots) during the survey and the locations of stations sampled.

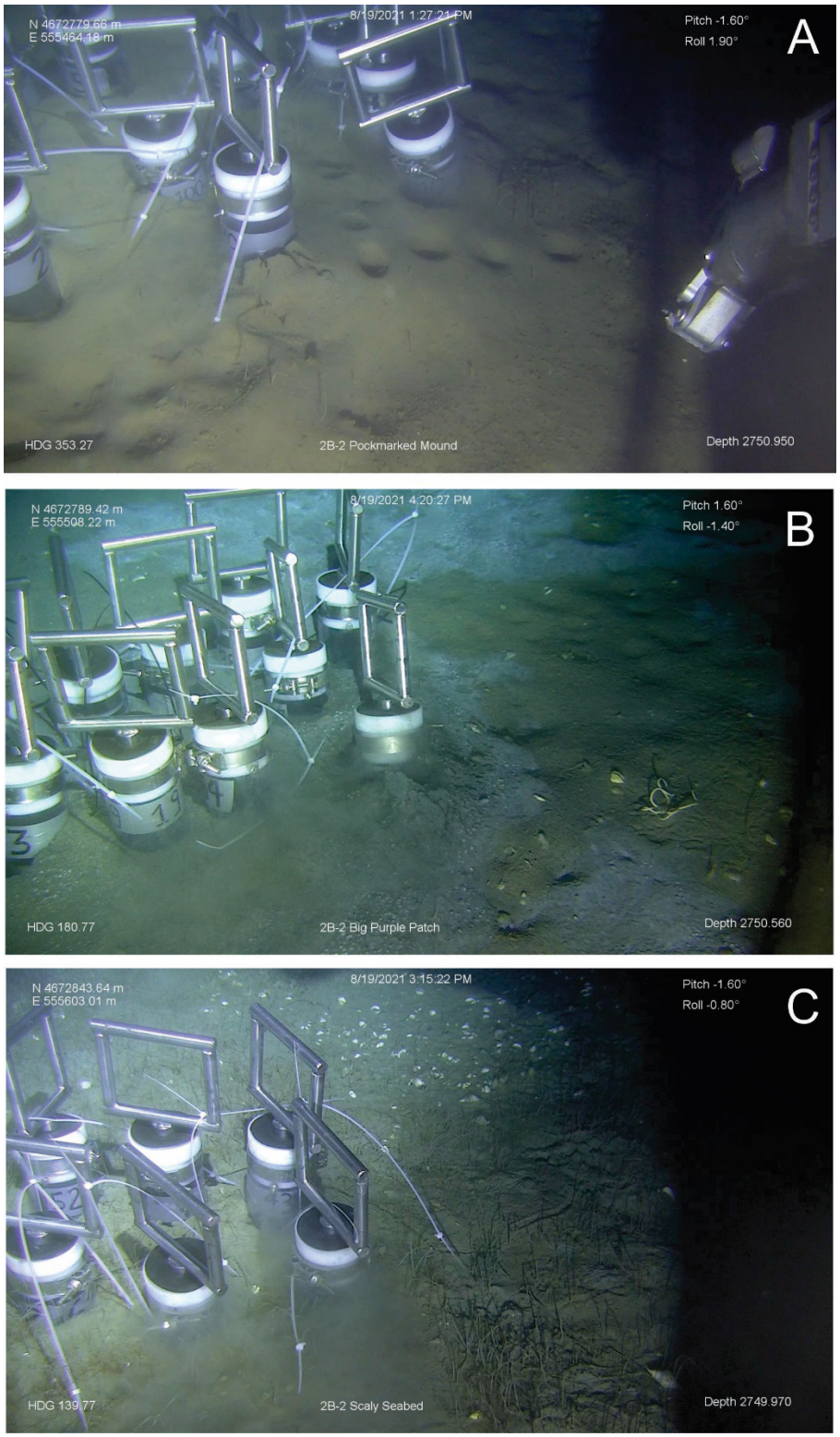

Figure 17: Seafloor images collected at site 2B-2. (A) Small mound covered by pockmarks at coring location Pockmark Mound. (B) White, grey, and purple bacterial mats at coring location Big Purple Patch. (C) Broken mollusc shells and what appears to be some form of vegetation at coring location Scaly Seabed.

3.4 - Site 2B-3

According to the AUV data recorded in 2020, the seep at site 2B-3 consists of an almost triangular shape within radiating structure (Fig. 18). A large part of the seafloor in the seep area is composed of soft sediment sporadically covered by small spots or isolate empty shells and shell remains (Dead Shells; Figure 19A). Furthermore, patches of bivalve shells and shell fragments were noticed in the central part of the seep (Shell Colony; Figure 19B). Theses patches seem mostly made of empty shells and shell remains as shown by the pictures obtained during the sampling at the station Shell Colony (Figure 19C). Areas of reworked seafloor, expressed as elongate scars and hummocky seabed, were also observed in the central part of the seep, including at the station Grey Scar and Blackish Pillow (Figures 19D and 19E, respectively).

At the site 2B-3, four stations (Shell Colony, Blackish Pillow, Dead Shells and Grey Scar) were sampled with a push corer. The samples of Blackish Pillow have been retrieved near the feature illustrated in Figure 19E but no camera records are available for this sampling period.

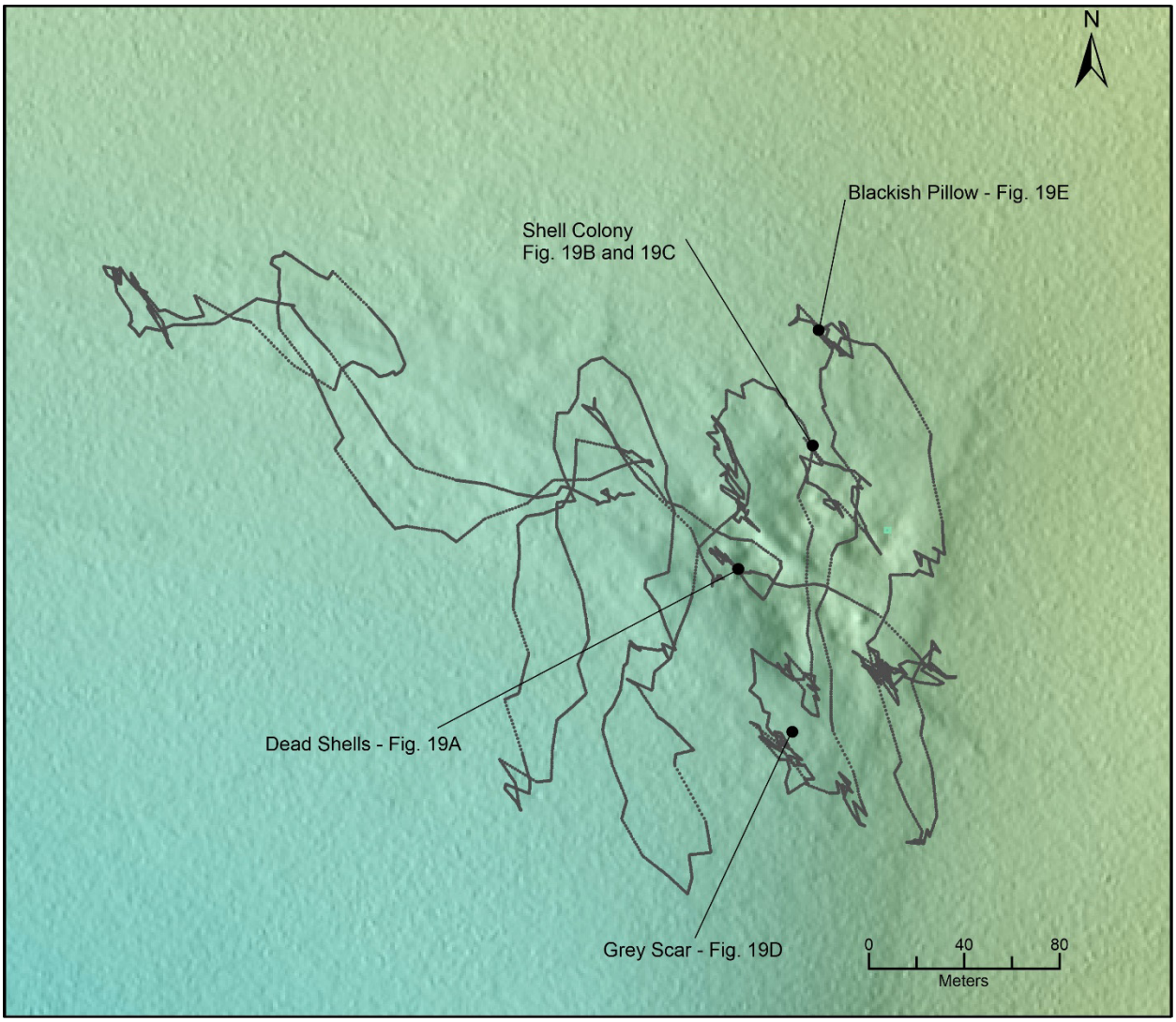

Figure 18: Bathymetric map of site 2B-3 showing the positioning of the ROV (grey dots) during the survey and the locations of stations sampled.

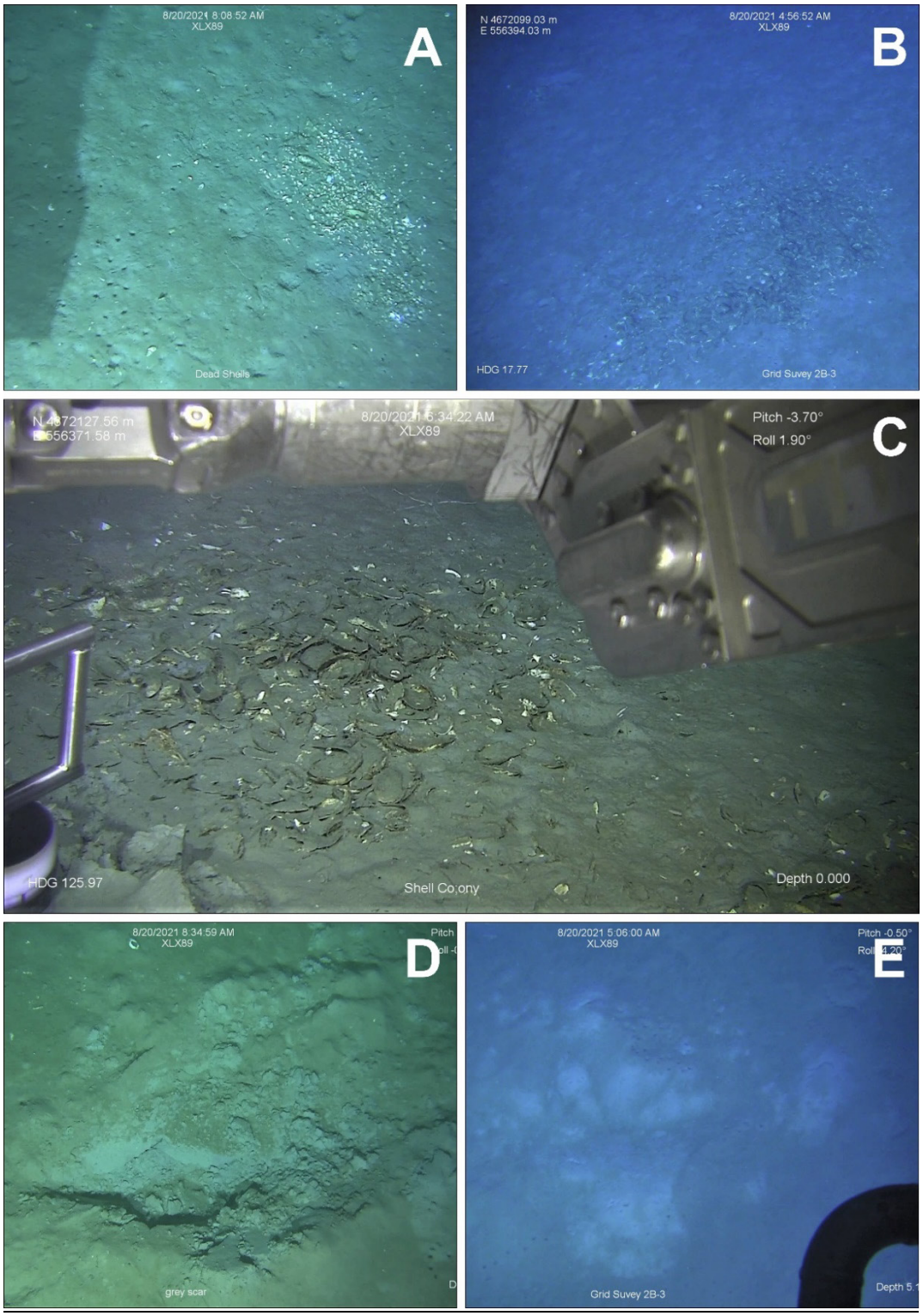

Figure 19: Seafloor photography at site 2B-3 showing characteristic features. (A) Spot of shells at station Dead Shells. (B) Patches of bivalve shells and shell remains at station Shell Colony. (C) Empty shells and fragments observed during the sampling at station Shell Colony. (D) Reworked seafloor at station Grey Scar. (E) Hummocky seabed and elongate scar at station Blackish Pillow.

3.5 - Site 2A-1

The ROV survey was initiated ~200 m south of the seep identified in the 2018 AUV data due to potential positioning errors in these data (Figure 20). After several minutes of survey without seeing any evidence of structure related to seepage, it was decided to move up north to finally reach the seep area ~150m north of the diving position. According to the AUV data recorded in 2018, the seep is characterized by an elongate shape oriented NW-SE within radiating structure. Images recorded in the central part of the seep by the ROV shows authigenic carbonates buildup populated by mussels/bivalves and sessile organisms (Figure 21A). Authigenic carbonates are also the substrate of small patches of white, dark-grey and light-purple bacterial mats but most of the larger mats (i.e., pluri-decimetric spots) are located at the edge of the seep overlying soft sediment as identified at the stations Deep Purple and Crusty White Clams (Figure 21B). At the sampling station named The Hole, authigenic carbonates form a depression where a constant release of gas bubble have been observed (Figure 21A). Some bubbles seemed to be trapped as gas hydrates under a block of authigenic carbonates (Figure 21C). In the vicinity of the seep, the seabed is mostly covered by soft structureless sediment with sporadic crater-like structure (Holy Ground; Figure 21D), blocky carbonates, shells as well as dense patches of mussels/bivalves (Clam Hill and Crusty White Clams; Figure 21E).

At the site 2A-1, five stations (Clam Hill, Deep Purple, Holy Ground, Crusty White Clams and The Hole) were sampled with a push corer. Gas, water and a block of authigenic carbonate were also retrieved at the station The Hole.

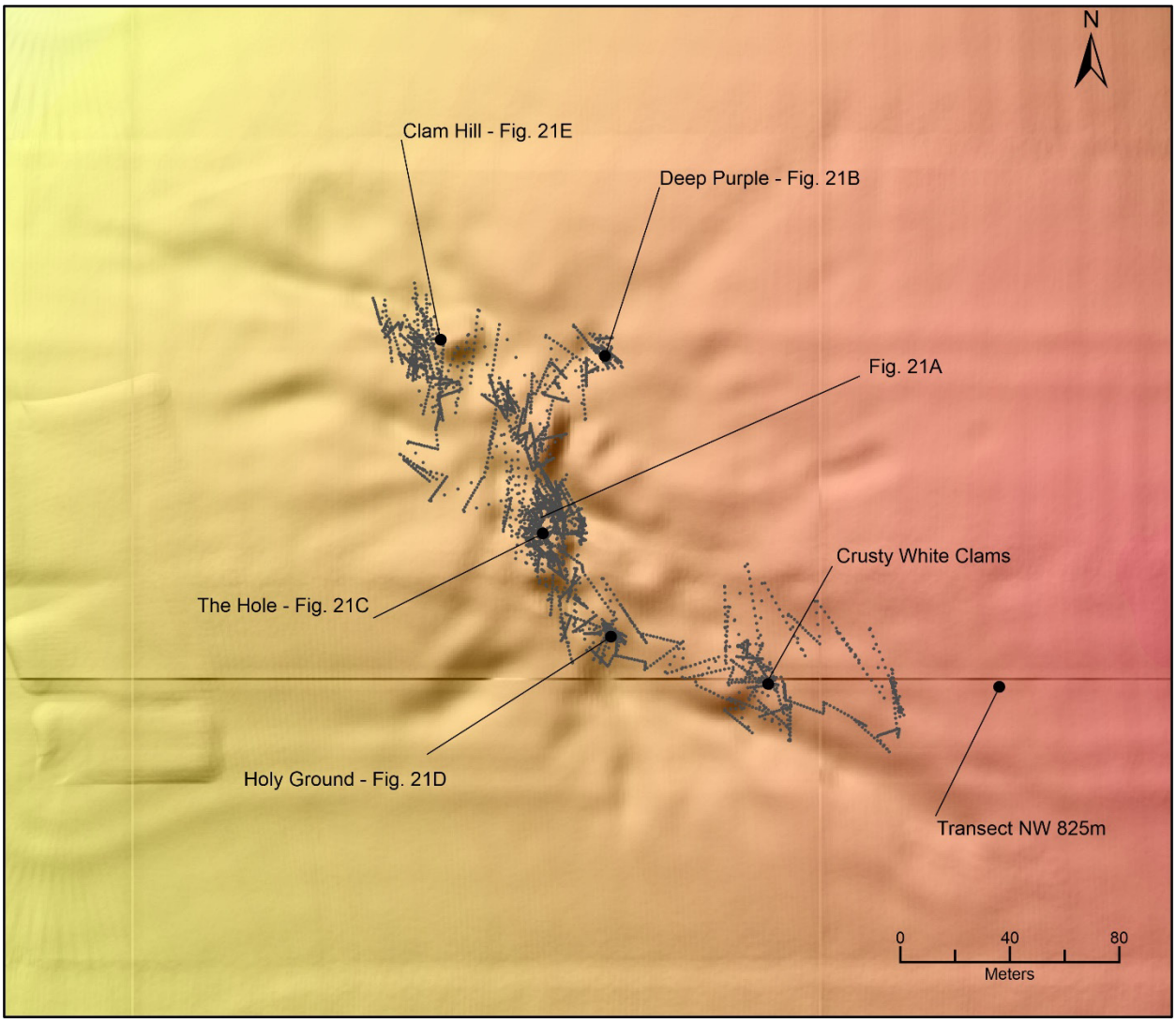

Figure 20: Bathymetric map of site 2A-1 showing the positioning of the ROV (grey dots) during the survey and the locations of stations sampled.

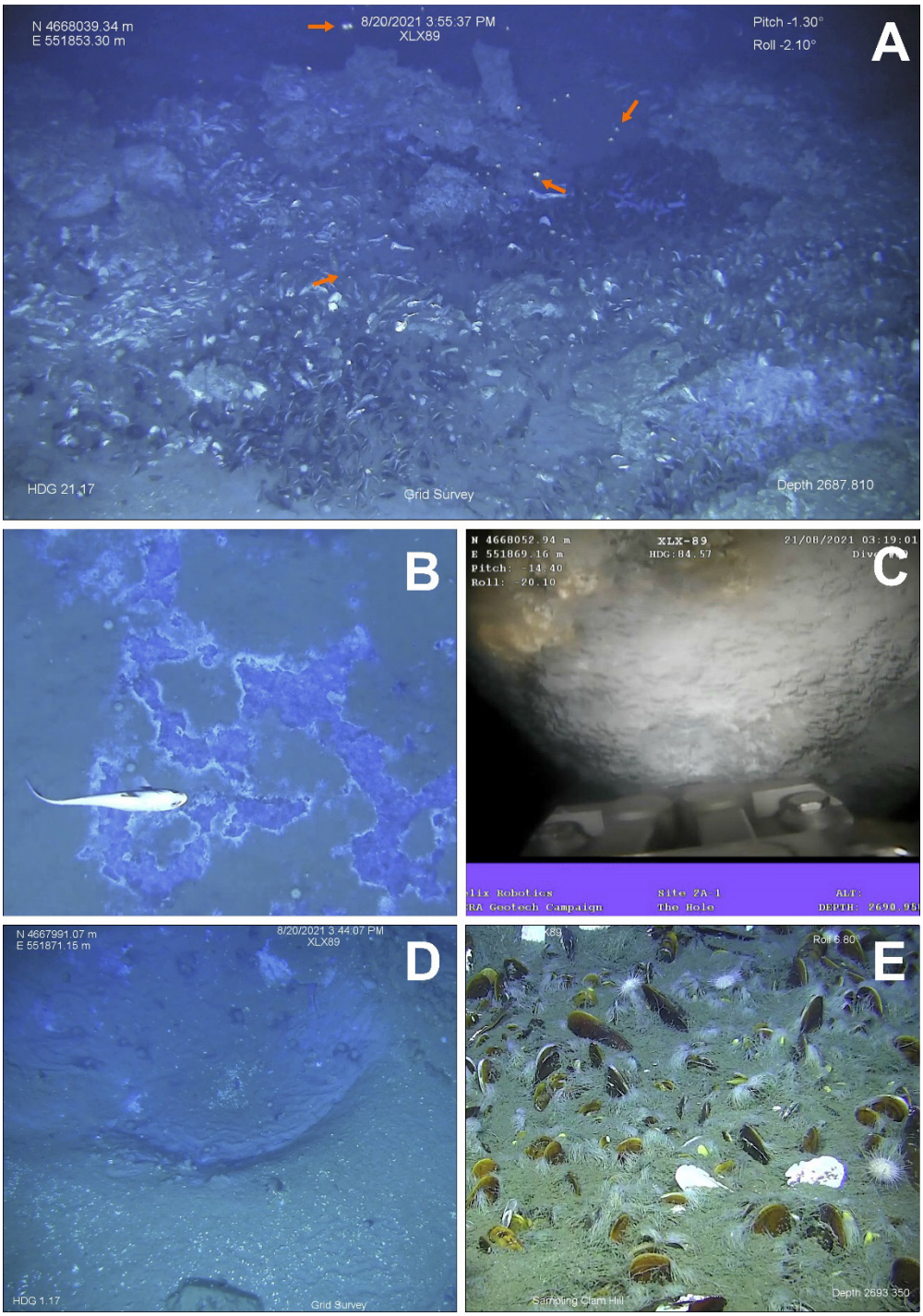

Figure 21: Seafloor photography at site 2A-1 showing characteristic features. (A) Photography over The Hole with authigenic carbonates buildup, faunas and ascending bubbles identified with orange arrows. (B) White and light-purple mats at station Deep Purple. (C) Gas hydrates and bubbles trapped under a chemoherm block at station The Hole. (D) Crater-like structure with bivalves, shells and blocky carbonates at station Holy Ground. (E) Patch of mussels/bivalves with urchins at station Clam Hill.

3.6 - Site 2A-2

Located ~1000 m southeast of the site 2A-1, site 2A-2 (Figure 22) presents similar characteristics to the previous site but at a smaller scale. The authigenic carbonates buildup with patches of mussels/bivalves seemed gathered in a crater-like feature of about 40 m in diameter (Figure 23A). White, dark-grey and light-purple bacterial mats, shells and living bivalves surround the carbonates at the station Purple Haze (Figure 23B). Near this station, a gas bubble stream was observed emanating from a spot with soft sediment and patches of potential bacterial mats (Figure 23C). On the edge of the seep, the soft sediments are disturbed by benthic activities and some smaller mats can be observed with blocky carbonates and shells (Purple Hill; Figure 23D).

At site 2A-2, two stations (Purple Hill and Purple Haze) were sampled with a push corer. A transect between site 2A-2 and 2A-1 has been done after the completion of these stations (Figure 24). Push cores have been retrieved on the transect at 175 m, 350 m, 525 m, 700 m and 875 m from the site 2A-2. Water samples were also collected at 525 m from the site 2A-2.

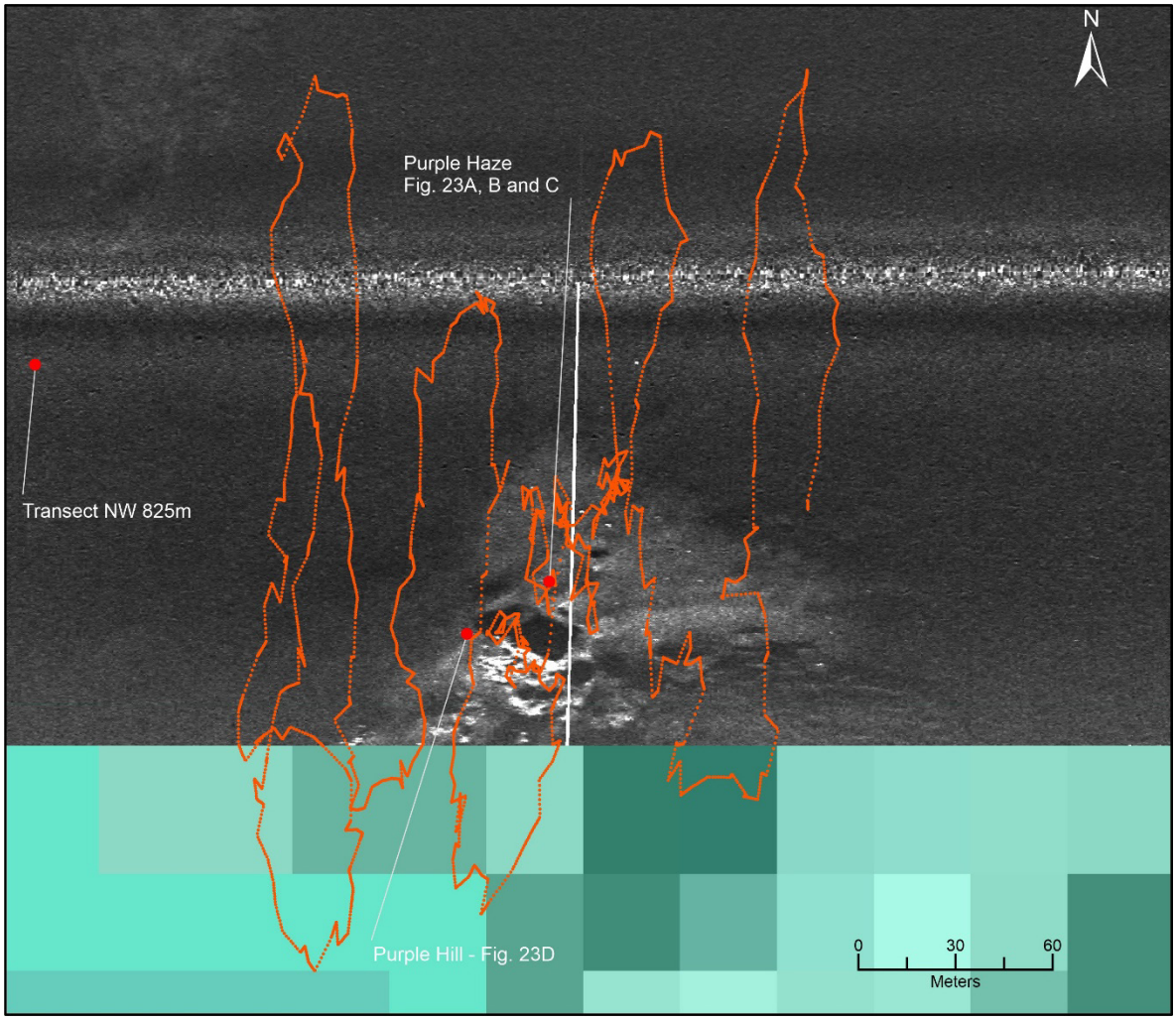

Figure 22: Sidescan sonar image of site 2A-2 showing the positioning of the ROV (orange dots) during the survey and the locations of stations sampled.

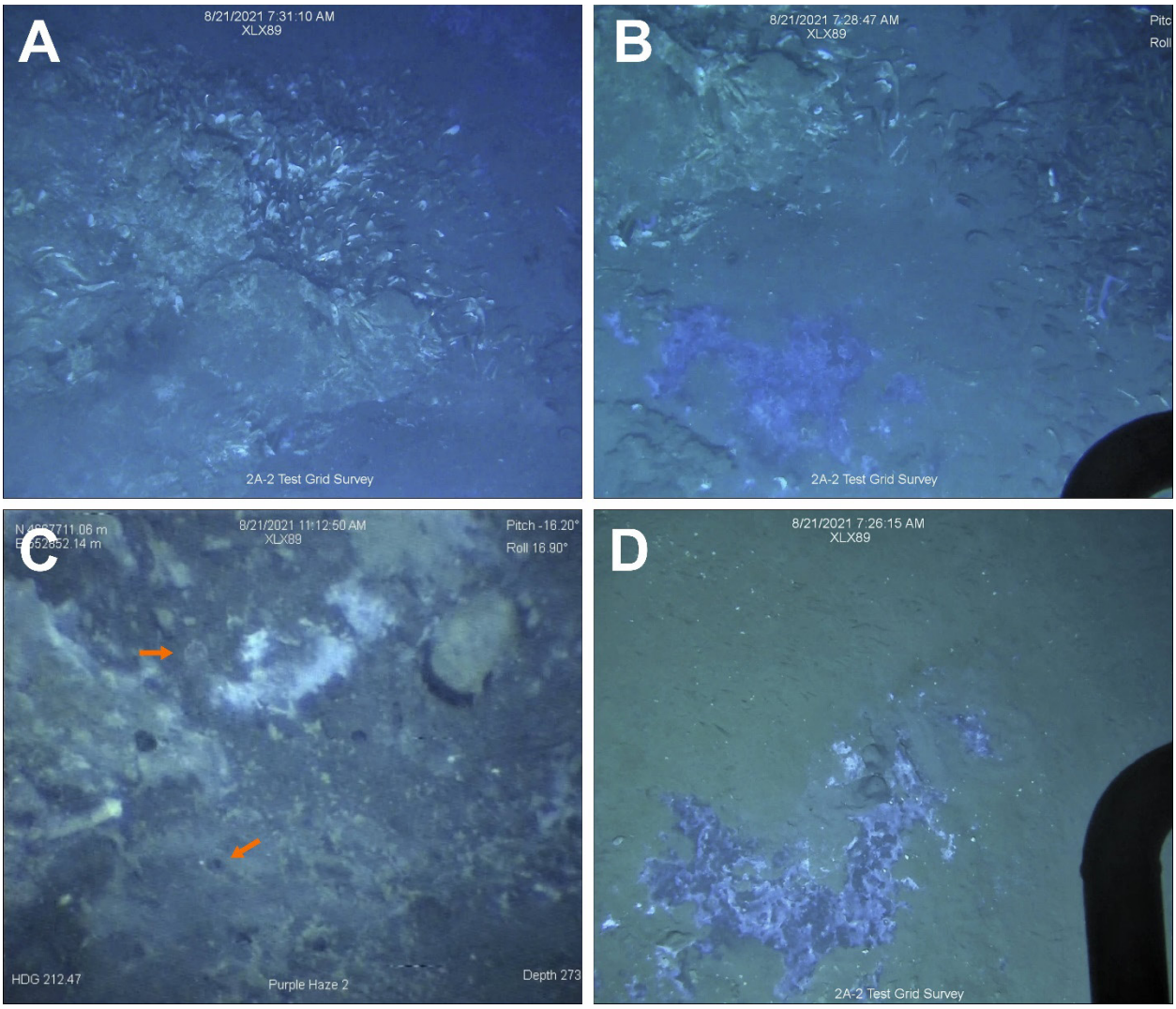

Figure 23: Seafloor photography at site 2A-2 showing characteristic features. (A) Authigenic carbonates buildup and faunas in the central part of the seep. (B) Dark-grey and light-purple mats with authigenic carbonates and patches of mussels/bivalves at station Purple Haze. (C) Bubbles (orange arrows) emanating from soft sediment. (D) White, dark-grey and light-purple mats, shells and living bivalves at station Purple Hill.

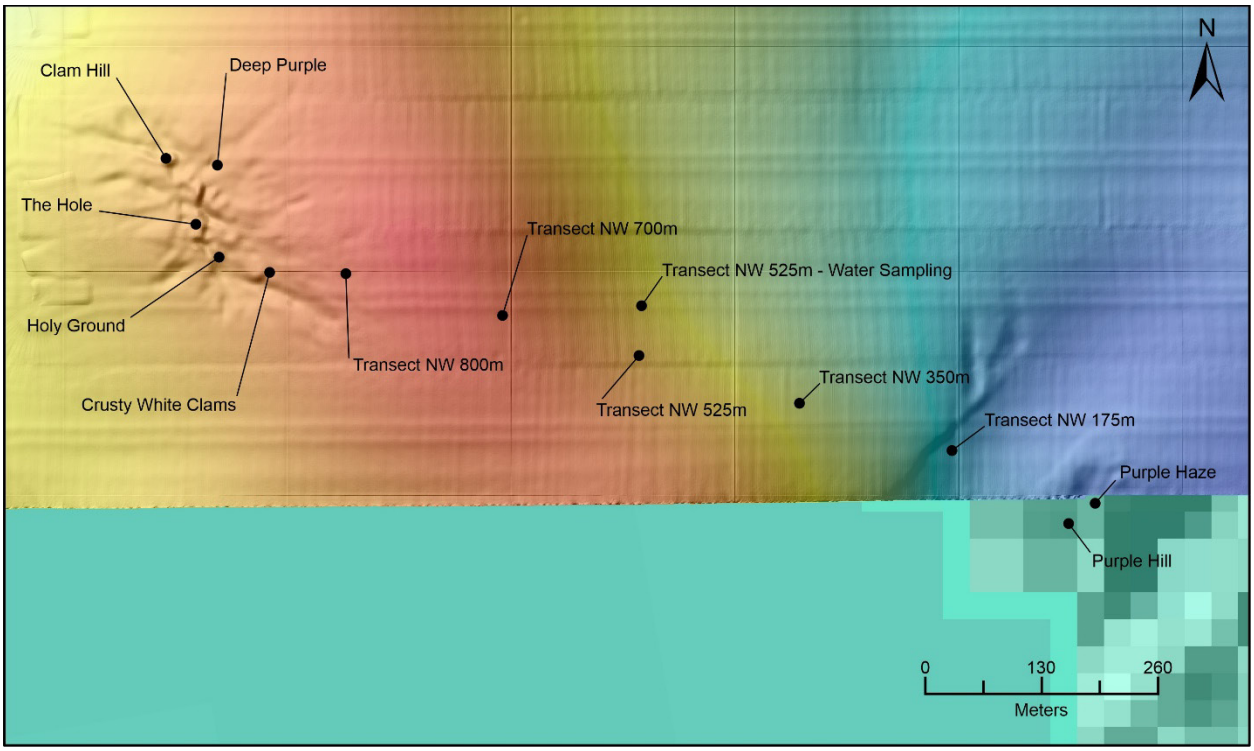

Figure 24: Bathymetric map of sites 2A-1 and 2A-2 showing the locations of stations sampled (black dots) in the area.

3.7 - Site 6-1

According to the AUV data recorded in 2020, the seep identified at site 6-1 is characterized by an elongate shape oriented W-E within radiating structure (Figure 25). The eastern part of the seep presents the most chaotic seabed with pluri-metric crater-like depressions. Patches of white, dark-grey and light-purple bacterial mats, blocky and reworked carbonates as well as spots of sediments disturbed by benthic activities sporadically compose the rims and the walls of the craters (Figure 26A). These features are also present at the center of the craters with smaller mats and less abundant blocky carbonates (Figure 26B). Furthermore, the area is characterized by spots of a large number of empty shells and shell remains littering the surface of soft sediment as identified at station Smithers (Figure 26C). High-concentrations of shells are occasionally associated with bacterial mats or can also form pluri-metric linear features as well as, in the western part of the seep, pluri-centimetric to metric circle surrounding soft sediment with abundant traces left by benthic activities (Figure 26D).

At the site 6-1, one station (Smithers) was sampled with a push corer. After station Smithers, the sampling was interrupted and the ROV was brought back to the surface due to poor weather. Later it was decided to end investigations at site 6-1 and to move to site 6-2.

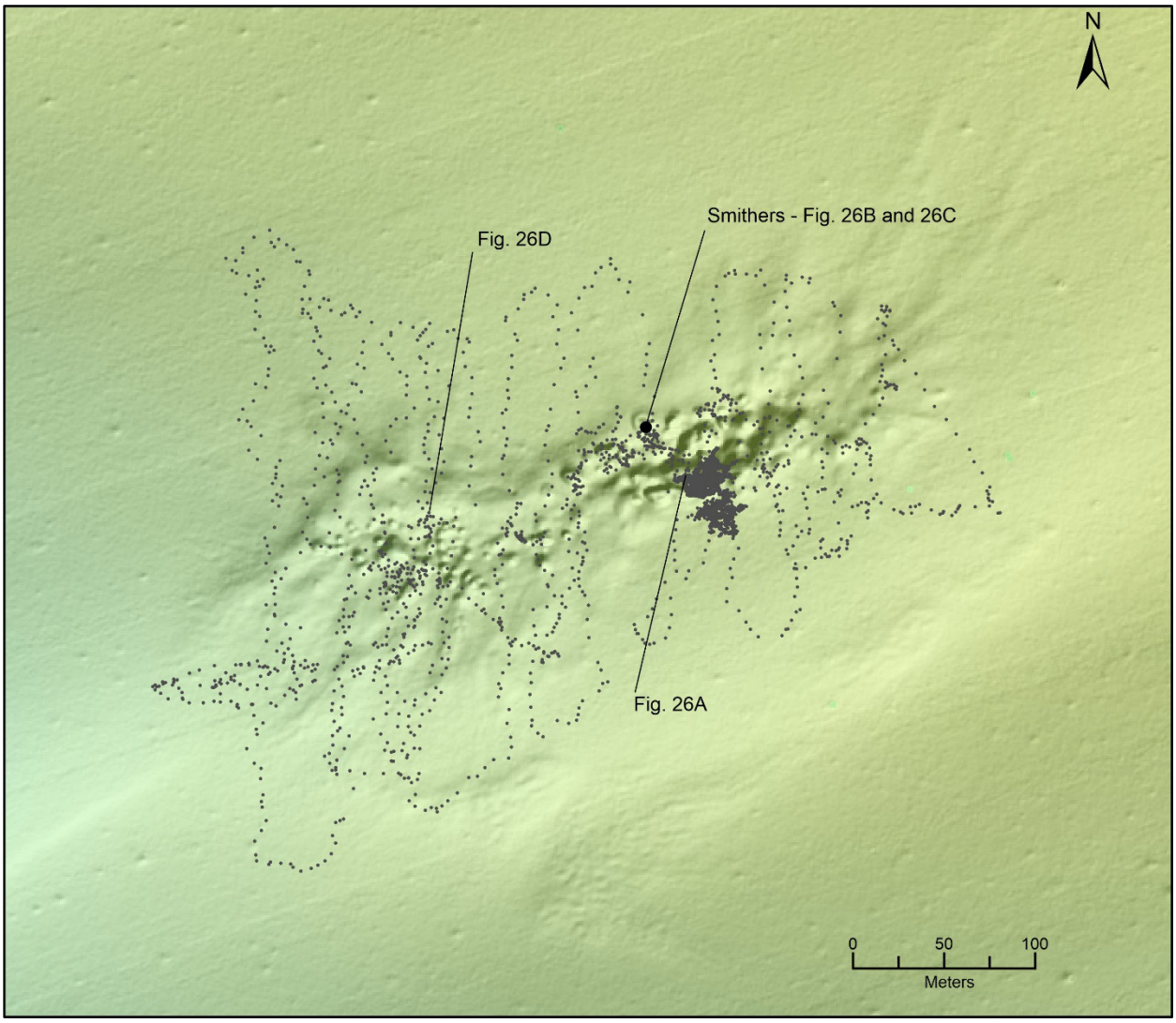

Figure 25: Bathymetric map of site 6-1 showing the positioning of the ROV (grey dots) during the survey and the locations of station sampled.

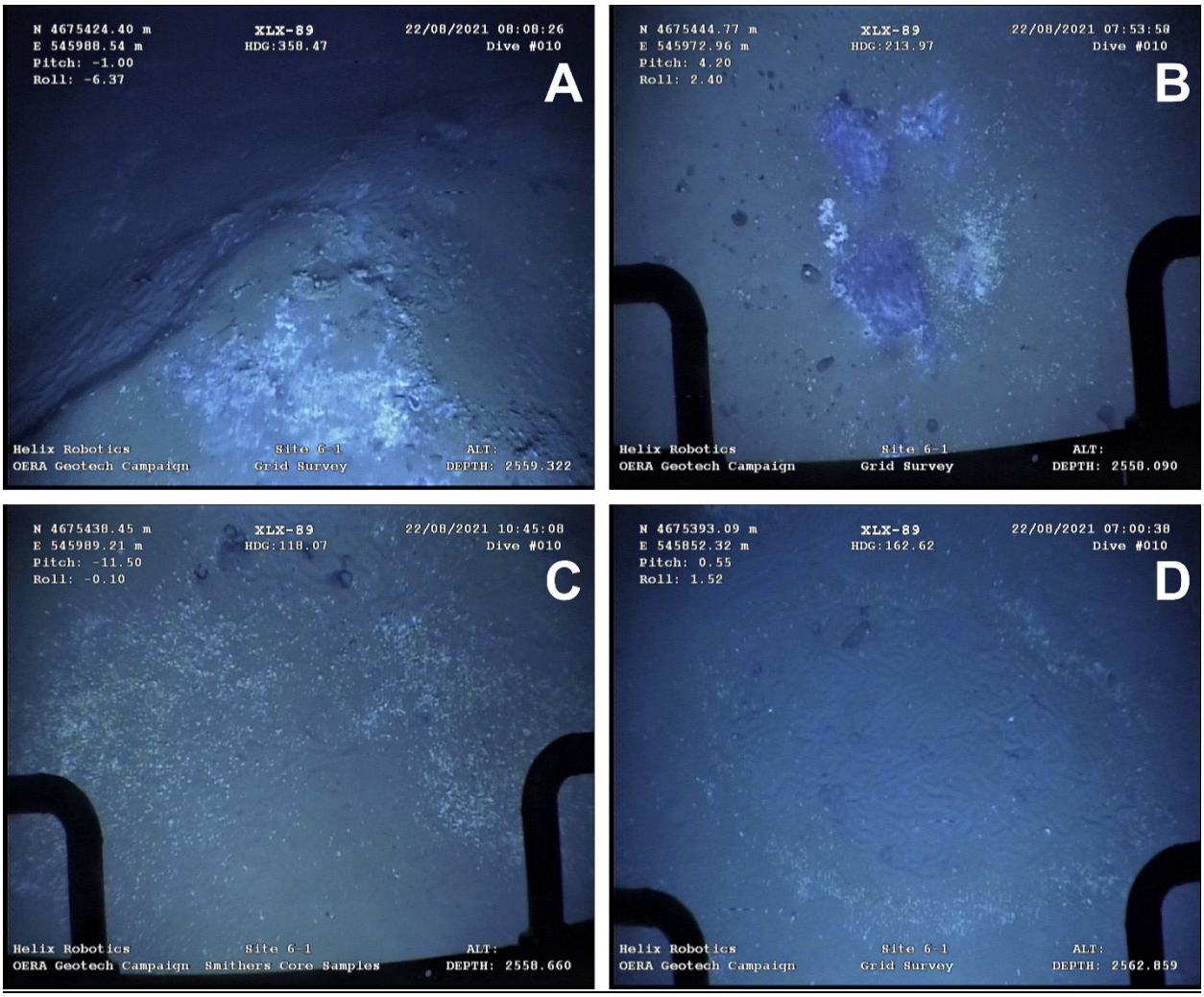

Figure 26: Seafloor photography at site 6-1 showing characteristic features. (A) Rim and walls of the depressions covered by blocky and reworked carbonates as well as patches of white and light-purple mats. (B) Dark-grey and light-purple mats with empty shells. (C) Patches of shells with living bivalves at station Smithers. (D) Shell remains forming a circle with bivalves and soft sediment disturbed by benthic activities.

3.8 - Site 6-2

Located ~800 m east of the site 6-1, the site 6-2 shows a curved shape with a topography less pronounced than its neighbor site (Figure 27). During the survey, no evidence of crater-like features has been identified but numerous pluri-centimetric conic depressions were present on the seafloor. The central part of the seep reveals some patches of empty shells and shell remains covering the surface of soft sediment (Arm and Hammer and Club Sandwich; Figure 28A and 28B, respectively). However, the density of shells is significantly inferior to what was observed on site 6-1. On the edge of the seep, the seafloor is composed of soft structureless sediment with sporadically black cobbles and boulders.

At the site 6-2, two stations (Arm and Hammer and Club Sandwich) were sampled with a push corer. Water samples were also retrieved at the station Club Sandwich. A transect between sites 6-1 and 5 has been

done after the completion of these stations (Figure 29). Push cores have been retrieved on the transect at 15 km from the site 5.

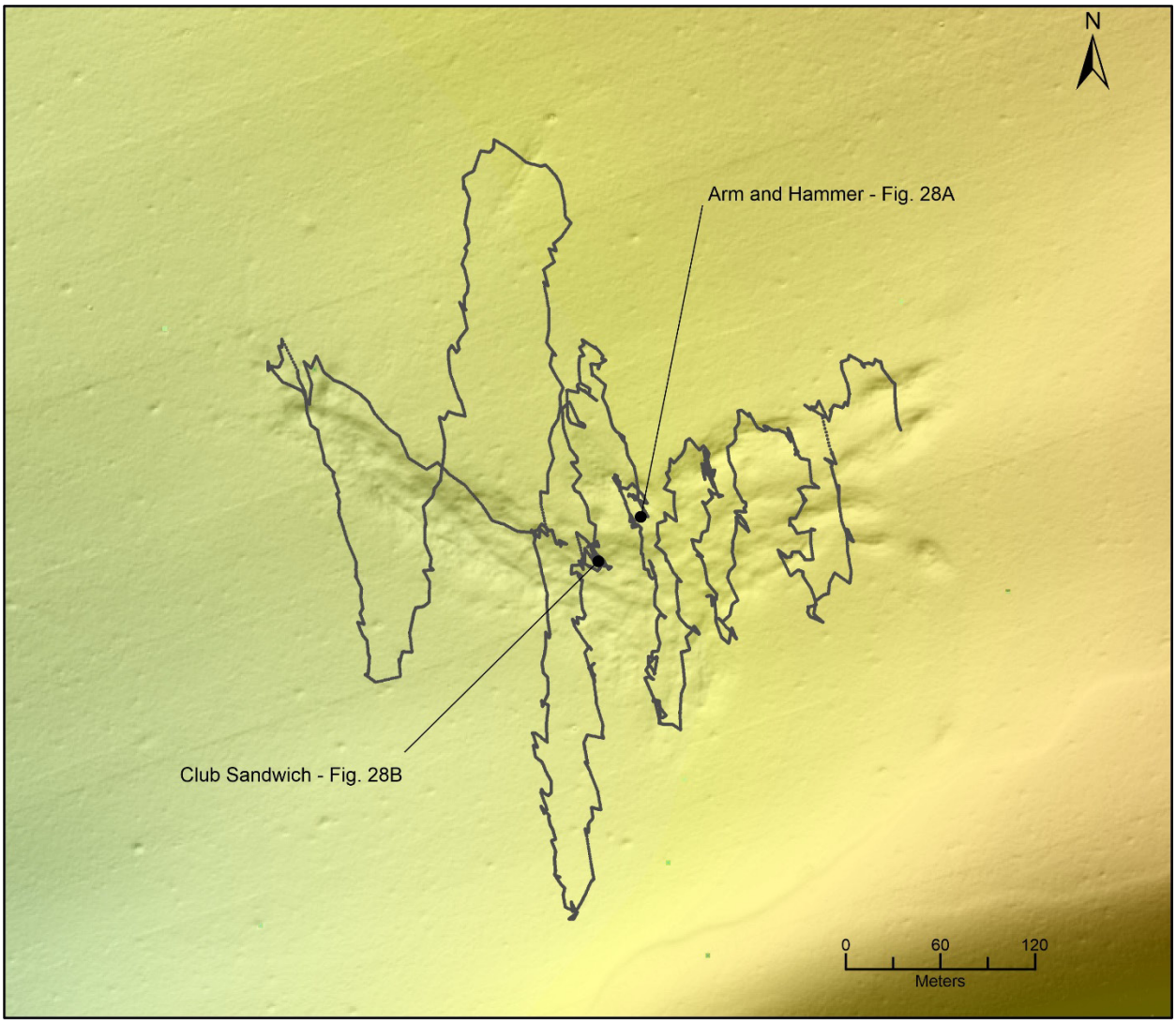

Figure 27: Bathymetric map of site 6-2 showing the positioning of the ROV (grey dots) during the survey and the locations of stations sampled.

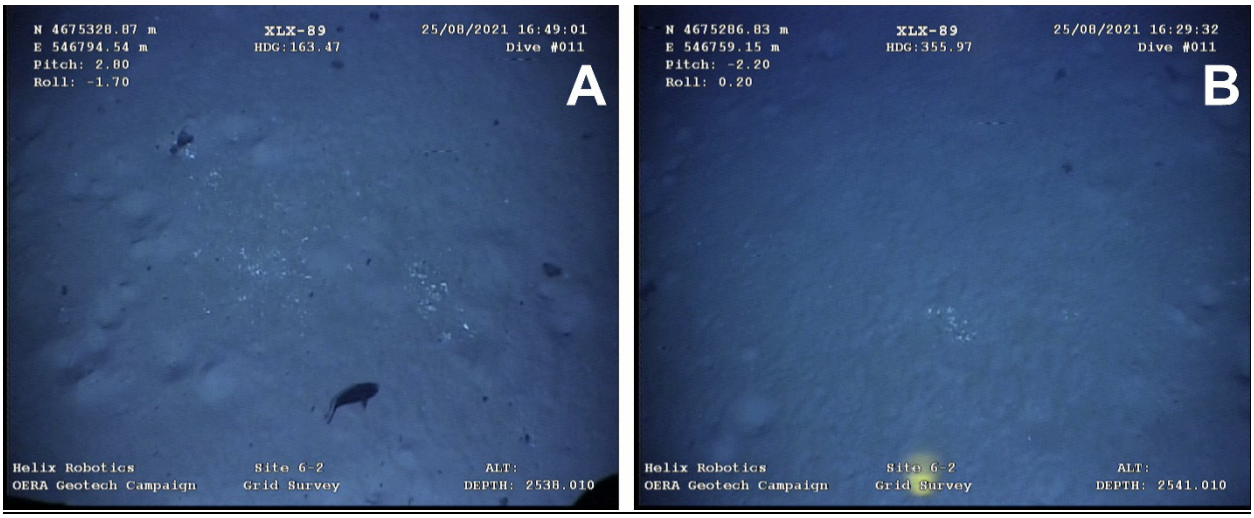

Figure 28: Seafloor photography at site 6-2 showing characteristic features. (A) Patches of shells and conic depressions at station Arm and Hammer. (B) Small spot of shell remains at station Club Sandwich.

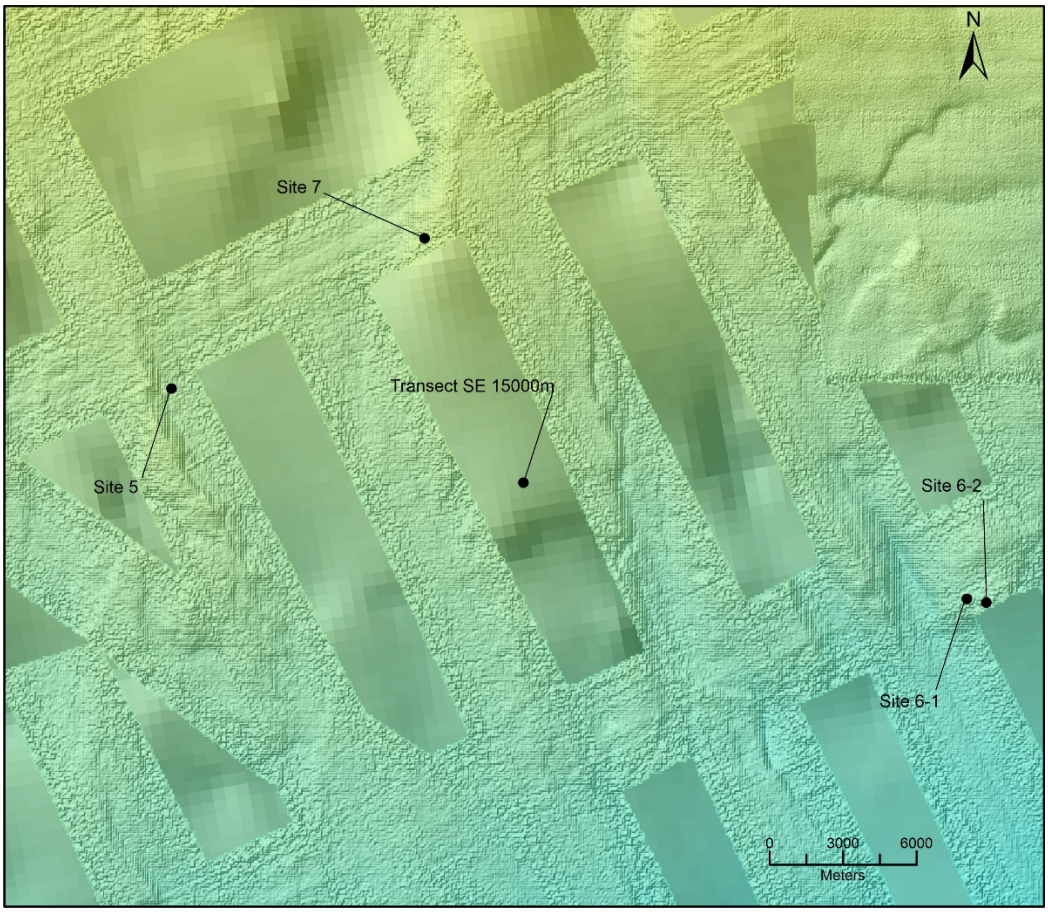

Figure 29: Bathymetric map of the area between sites 6 and 5 showing the location of station sampled during transect to site 5-1.

3.9 - Site 5-1

The area investigated during the survey of Site 5-1 is characterized by two distinct morphologies, with a slightly irregular seafloor to the north and an elongate seep-like feature to the south (Figure 30). Images recorded by the ROV on the site 5-1 show some large filamentous green mats covering soft structureless sediment (Delta; Figure 31A). As observed at stations Kilo and Juliette (Figures 31B and 31C, respectively), the filamentous mats are occasionally associated with smaller patches of white, dark-grey and light-purple bacterial mats as well as with urchins, shells and fragments of carbonates (Juliette; Figure 31D). In the central part of the site, the top of a ridge presents an outcrop of consolidated material (Foxtrot; Figure 31E). The outcrop seems partially composed of carbonate buildup and fragments (Figure 31F).

At site 5-1, four stations (Kilo, Juliette, Foxtrot and Delta) were sampled with a push corer. Water samples were also retrieved at the location of the ship when arriving on site 5-1. The samples of Foxtrot have been retrieved near the feature illustrated in Figure 31E, at the base of the ridge.

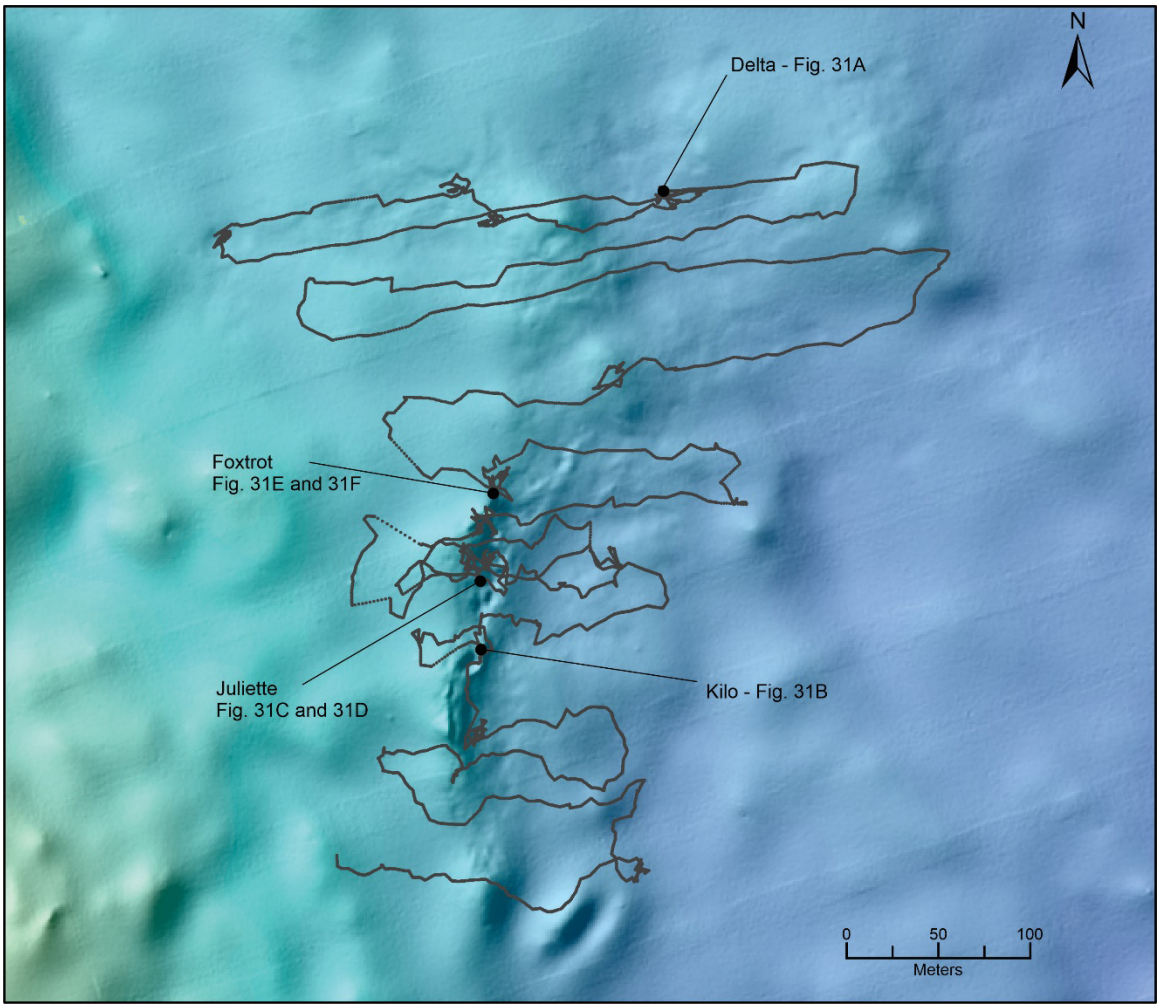

Figure 30: Bathymetric map of site 5-1 showing the positioning of the ROV (grey dots) during the survey and the locations of stations sampled.

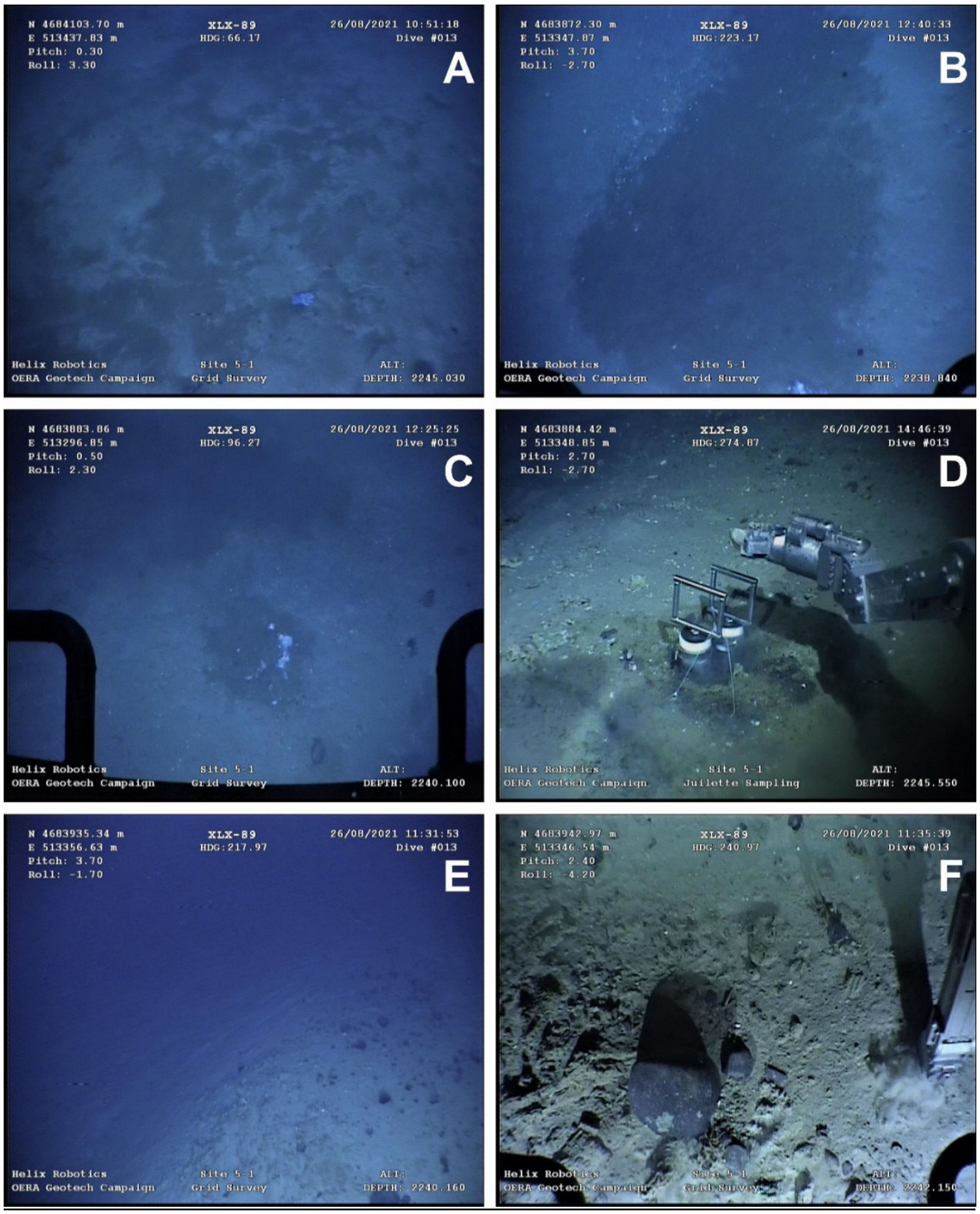

Figure 31: Seafloor photography at site 5-1 showing characteristic features. (A) Filamentous green mats and a rubber glove at station Delta. (B) Filamentous mats with shells and a spot of white and light-purple mats (bottom of the picture) in a depression at station Kilo. (C) Patch of white, dark-grey and light-purple mats associated with filamentous mats and carbonates fragments at station Juliette. (D) Carbonate fragments and shells littering the seabed at station Juliette which was revealed during the sampling of a bacterial mat with push cores. (E) Outcrop of consolidated material at the top of a ridge at station Foxtrot. (F) Close-up of the outcrop illustrating potential carbonate buildup partially covered with soft sediment.

3.10 - Site 7-1

The ROV investigations took place in two different areas of site 7-1 (Figure 32). A first survey located further south revealed spots of coarse sediment with pebbles occasionally coupled with pluri-centimetric to pluri-metric boulders identified as potential glacial dropstones (Figure 33A). The seafloor in the area is mostly composed by soft structureless sediment. The western part of this first survey shows an extensive block of cohesive coarse sediment with pebbles and cobbles (Figure 33B). The edges of this feature are the substrate of deep sea sponges and/or soft corals. The first survey was interrupted after ~ 1 h and the ROV was brought back to the surface due to technical issues with the umbilical and the Tether management system.

The second survey of site 7-1 was conducted slightly north, in a linear depression widening westward. The area is characterized by decametric patches covered by coarser sediment, pebbles, cobbles and boulders mostly concentrated in the deeper part of the depression (Figure 33C), but not exclusively as some smaller spots can be observed on the walls and the banks of the structure. Cobbles and boulders are also populated by some deep sea sponges and/or soft corals. Push cores have been retrieved in the vicinity of an almost perfect pluri-centimetric circle of soft sediment surrounded by coarser material (Moon; Figure 33D).

At the site 7-1, one station (Moon) was sampled with a push corer.

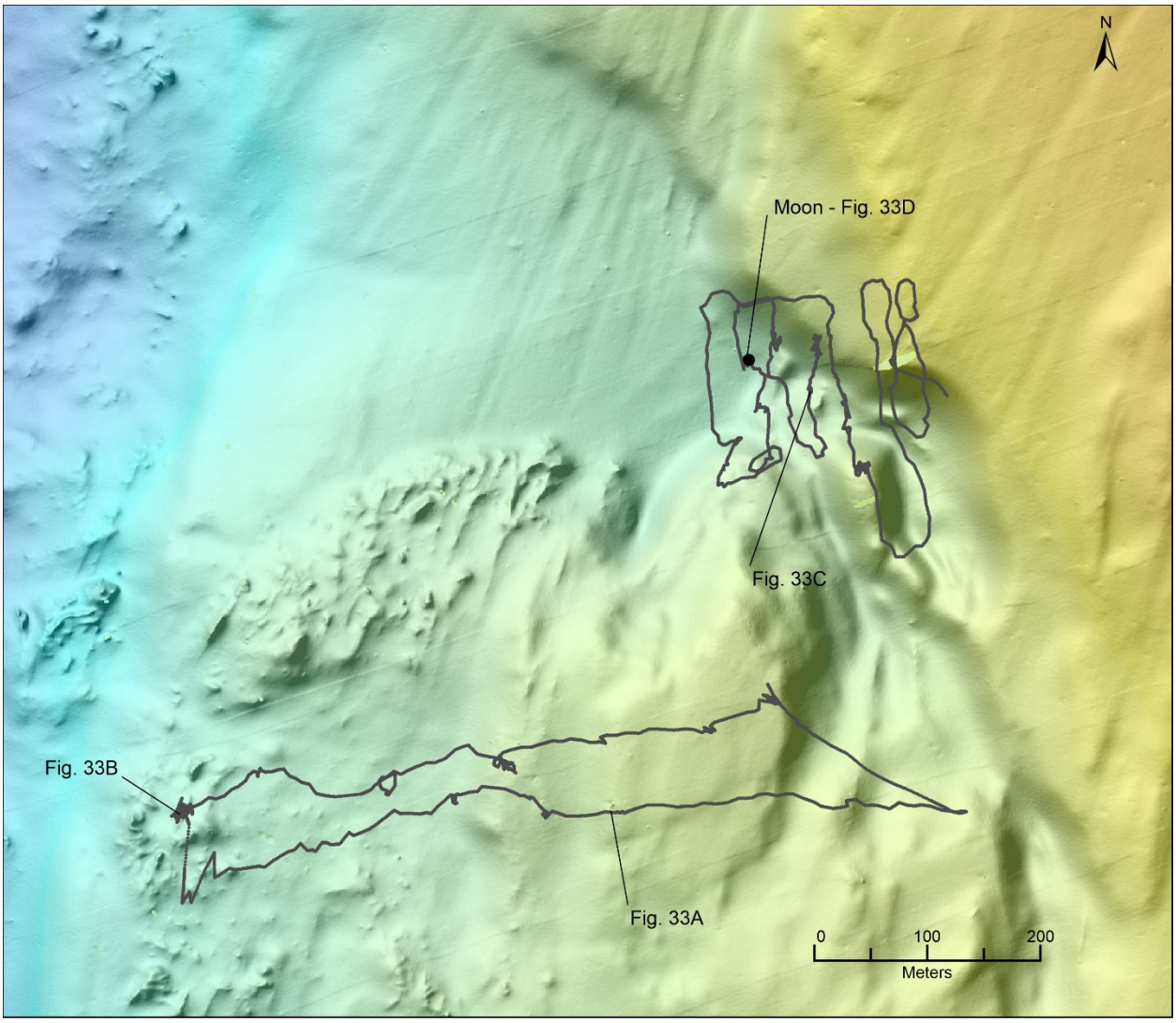

Figure 32: Bathymetric map of site 7-1 showing the positioning of the ROV (grey dots) during the survey and the location of station sampled.

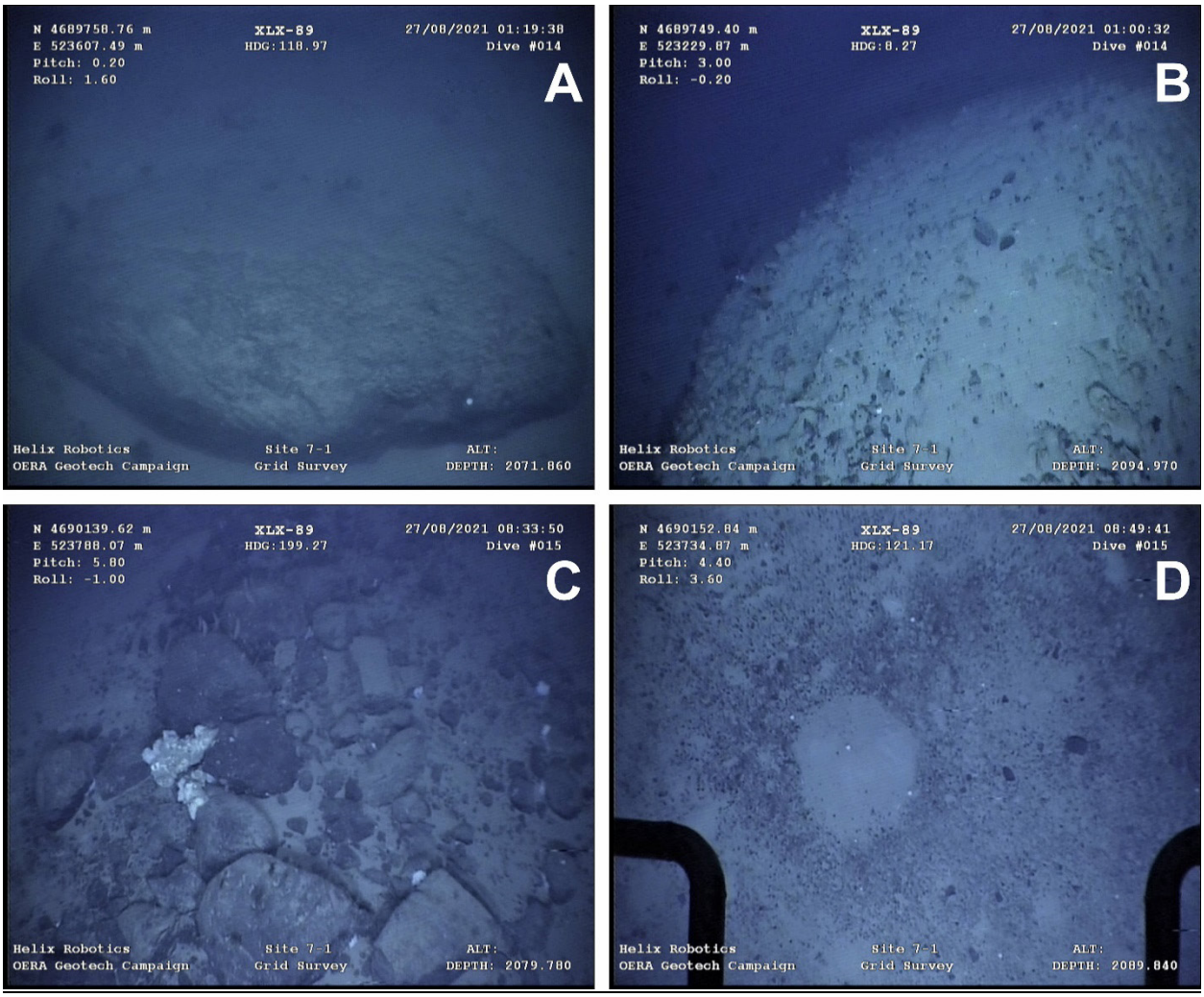

Figure 33: Seafloor photography at site 7-1 showing characteristic features. (A) Pluri-metric boulder observed during the first survey of site 7-1. (B) Block of cohesive coarse sediment with pebbles and cobbles. (C) Coarse sediment, pebbles, cobbles and boulders with deep sea sponges and/or soft corals. (D) Soft sediment feature surrounded by coarser material at station Moon.

3.11 - Site 3-1

The seafloor at site 3-1 (Figure 34) is similar to that of 1-1. Small pockmarks and dropstones are observed on the seabed but are less frequent than at site 1-1. There was no evidence of hydrocarbon seepage at 3-1 and the occurrence of benthic life was low. Visibility at this location was low and it effected the ability of the ROV to conduct a survey and to collect push cores.

Sediment push cores were collected at the following location:

LaHave: a small depression on the seabed with serval benthic organisms inside (Figure 35).

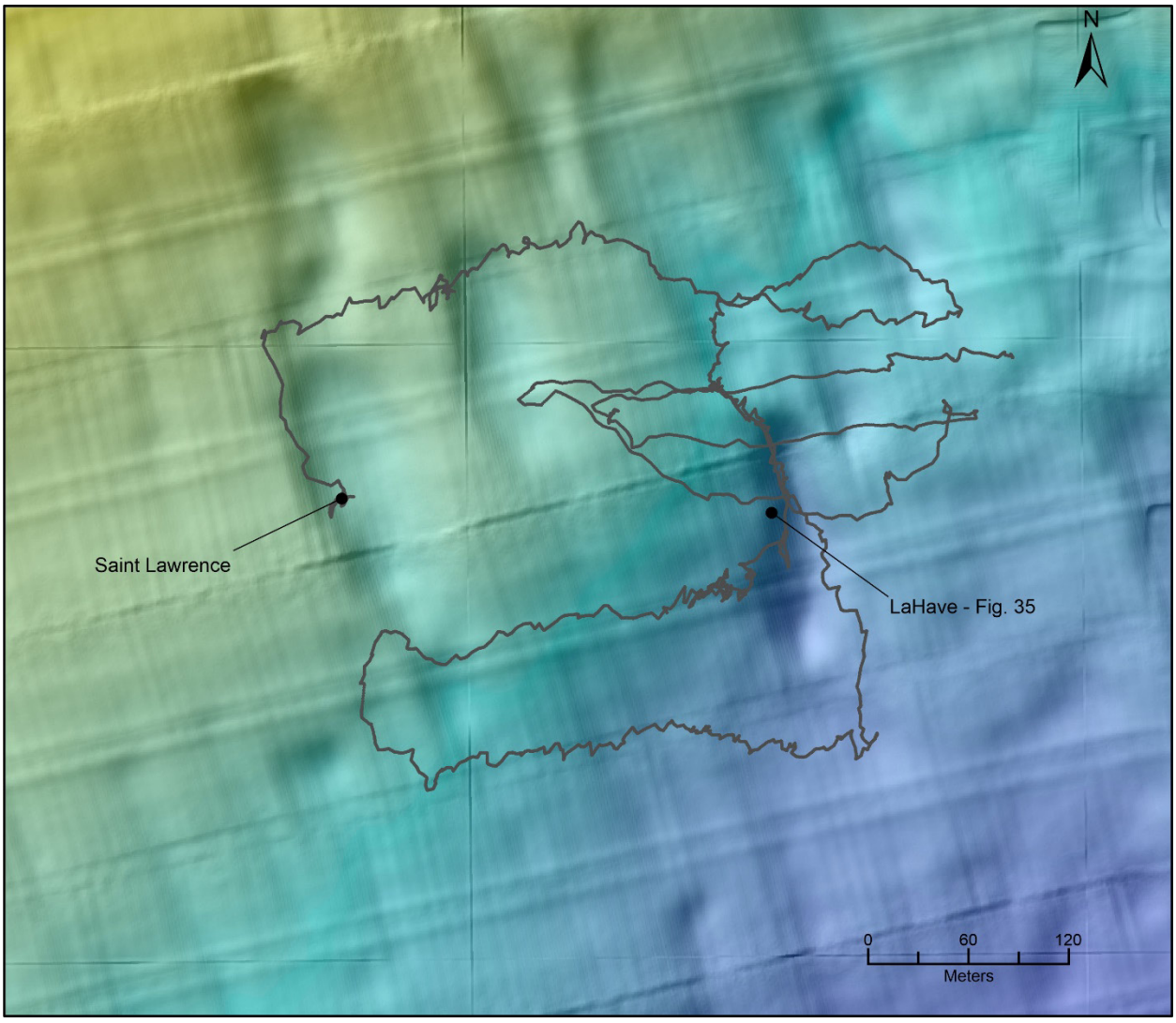

Figure 34: Bathymetric map of site 3 showing the positioning of the ROV (grey dots) during the survey and the locations of stations sampled.

Figure 35: Push cores collected at 3-1 sampling site LaHave.

3.12 - Site 10-1

Site 10-1 occurs near what appears to be a mass transport deposit on the seafloor. ROV imagery of the seafloor at 10-1 (Figure 36) shows it is almost completely featureless. Black rocks interpreted to be glacial dropstones are rare and benthic organisms are almost non-existent. One benthic organism was observed attached to one of these dropstones (Figure 37). No features that would be indicative of hydrocarbons were observed.

During the reconnaissance survey of 10-1, the weather became too dangerous to safely deploy the work basket or operate the ROV. Due to these weather constraints, no push cores were collected at site 10-1.

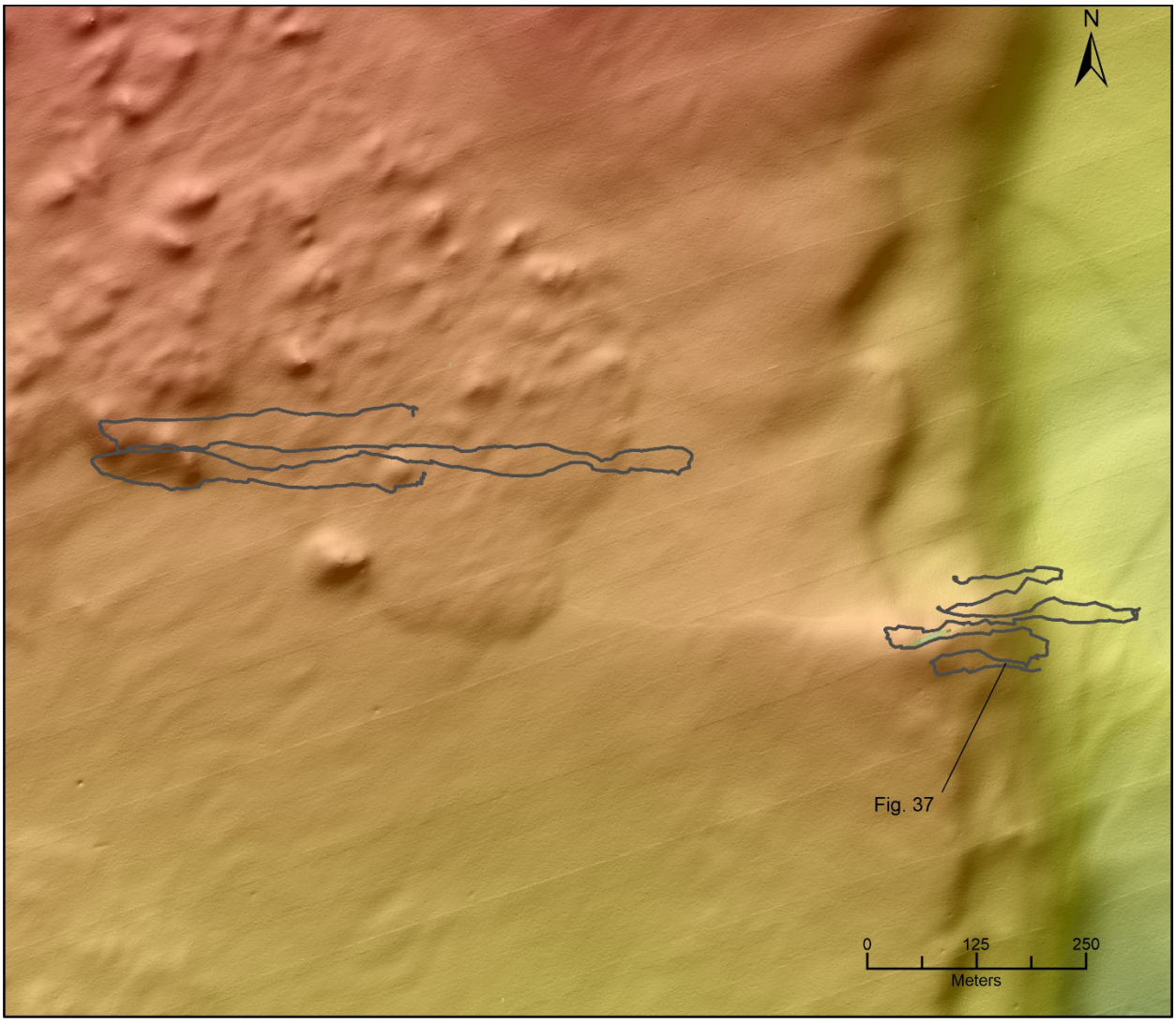

Figure 36: Bathymetric map of site 10-1 showing the positioning of the ROV (grey dots) during the survey.

Figure 37: Benthic organism attached to a rock on the seafloor of site 10-1.

4.0 - Conclusions and Recommendations

The images recorded during the expedition show several instances of venting hydrocarbons in the form of gas bubble streams as well as microbial activity and other benthic fauna on the sites investigated. This expedition has shown for the first time the detailed presence of deep-sea, oasis-type ecosystems related to seeps on the Scotian margin. Further analyses of the samples will continue in the months and years following the 21CONDOR expedition. At the time of this report, NSDNRR has completed geochemical analysis including Leco total organic carbon (TOC), stable isotopes, gas composition, and gas chromatography mass spectrometry (GC-MS).

From an operational standpoint, the expedition was very successful with only a few minor equipment problems. Recommendations to improve similar expeditions on the Atlantic Condor in the future include:

- Have spare, non-standard ROV equipment onboard (specifically a spare HD camera and spare scaling lasers).
- Modify the quivers so that they provide more grip on the seabed as to not slide away from the ROV while on an uneven seafloor.

Appendix 1 – 21CONDOR Daily Narrative

Friday, August 13

This was the planned departure date but the Atlantic Condor remains at the Woodside dock. A few delays that have caused the departure date to slip to tomorrow. These include: a) the umbilical for the ROV was damaged and has to be re-terminated, should be completed by tomorrow; b) the HD camera on the ROV is not functional, should be fixed tonight; c) an inspection of the Dominion Diving a-frame revealed that more welding is required to secure it to the mezzanine deck. This will be done tomorrow morning.

Saturday, August 14

Today we did a test deployment of the work basket and a quiver at the ATL dock. Everything performed well.

We departed Woodside at 4pm and we are in transit to the "calibration" site to calibrate the underwater positioning system and do a test of the ROV. Once that is complete we will move on to site 1-1.

Sunday, August 15

We arrived at the calibration point this morning but the location was covered with fishing equipment (long lines for swordfish) drifting at about 1.5 knots. Desiage selected another calibration site based of off a multibeam dataset he has onboard and we transited to that site. Unfortunately this site was also covered in fishing equipment. Both of these locations were located near the shelf break so we speculated that this area must be a fishing hotspot so it was decided to move to deeper water. Desiage selected another site on about 1650 m water depth and when we arrived at about 11 am it was found to be free of fishing gear so we began the calibration and ROV tests.

The ROV was put in the water for tests but initially there were some issues with the USBL system picking up the beacons on the ROV. These issues were eventually fixed and then the ROV was used to position a large beacon on the seafloor to be used for the USBL system calibration. Due to the deeper water at this calibration point, the calibration will take most of the night so the current ETA for site 1-1 is 7am Monday morning.

Monday, August 16

We arrived at site 1-1 this morning and began to deploy the ROV and work basket. Everything was in position and ROV surveying commenced by noon.

The seafloor in this area shows what we think are small pockmarks throughout the entire survey area. No active gas venting was observed however. There was a small ridge or fissure observed at the center

of the survey block. There is a cohesive but brittle accumulation of sediment along this ridge with increased biological activity. Unfortunately, no active venting was observed here either but it was the most anomalous feature observed at the site.

We did unfortunately lose the SMU gas sampler during the first work basket deployment. It was too light and broke free from the tie wraps that were securing it inside the basket. The chief engineer has made a new one which we will try again in the future.

We will continue working at this station through the night.

Tuesday, August 17

Unfortunately, there was some poor core performance through the night at the best location at site 1-1. Since this site was the highest priority, we tried to get 8 push cores at 1-1 again and we got some fantastic cores. They were mostly filled to the top, and some showed gas cracking. We have completed site 1-1 and are in transit to 2b-1, due to arrive sometime early tomorrow morning.

Wednesday, August 18

2b-1 has turned out to be a great site. We have done 3 cluster sites so far and 2 of them showed vigorous gas expulsion from the seafloor when the push cores were inserted. When the cores arrived at the surface they showed bubbling inside the tubes, "cottage cheese" texture, and/or gas cracking. Some of the cores did trigger the handheld H2S detector when they got on deck... the cores were retested every 10 minutes until they were under the alarm level of the detector (1ppm).

After the 4th and final cluster site is completed shortly, University of Calgary and SMU researchers will be doing a transect and maybe some water sampling if time allows. The plan is to complete this site at 8 am and move on to 2b-2.

Thursday, August 19

We had a successful dive today but site 2b-2 was not quite as exciting as 2b-1. The seafloor was fairly barren of life or hydrocarbon indicators. We still got some good cores and some of them showed bubbling when they were taken the corer was inserted into the seafloor.

Friday, August 20

Working at site 2b-3. Completed site 2b-3 and then transited to 2a-1. Conduct ROV survey of 2a-1 to select coring sites. An active gas vent was located that is surrounded by a very active benthic community. 2a-1 is a very good site with lots of interesting features. Lots of good video, cores, and other data collected. We will continue to work at this location until the early morning hours of August 21.

Saturday, August 21

Completed work on 2a-1 and then transit to 2a-2. Worked at 2a-2 today but it was challenging as underwater visibility was very poor. The ROV pilots said it was due to the lack of current so when the ROV disturbed any sediment it took a long time to clear.

Despite the poor visibility, we were able to locate another gas vent. This one was spread over a larger area and was emanating from a patch of soft sediment. There was a large clam bed and some carbonate material nearby. We are currently working on a transect between 2a-1 and 2a-2. This should be completed tonight or tomorrow morning and then we will move on to 6-1. We are expecting bad weather sometime tomorrow so we will do as much as we can until then.

Sunday, August 22

We were able to complete a survey of 6-1 and collect one cluster of cores in a large pockmark before the weather deteriorated. The seafloor at 6-1 looks very much like the AUV data with large pockmarks clustered in an elongated area. There was no evidence of gas escape however, and there is a bit of life present but not as much as 2A or 2B.

Although we only collected cores at one location at 6-1, I feel that we captured the best this site has to offer and I don't think we would gain that much by returning there when the weather improves.

The captain thinks the weather should improve enough for us to get the ROV back in the water by Wednesday and the forecast of Thursday, Friday and Saturday looks very good.

Monday, August 23

Still on standby due to poor weather. The weather forecast looks like we will be back working tomorrow night or Wednesday.

Tuesday, August 24

The winds have come down but we are still dealing with 2 - 3 m swells. The forecast looks good for tomorrow and we think we should have the ROV in the water sometime tomorrow morning. We'll be starting at site 6-2.

Wednesday, August 25

We have completed the survey of 6-2 but it was mostly featureless. There was an increased abundance of small pockmarks in the area of the feature imaged in the AUV data but not much else. We did identify a couple of sites for coring so we will do that this evening. When completed, we will move on to site 5-1, stopping halfway in between 6-2 and 5-1 to collect some cores for a long transect that Hubert has

proposed. It will provide a good background for the rest of the samples collected on this expedition. We should be at 5-1 in the early hours of tomorrow.

Thursday, August 26

We have completed site 5-1 and will be on our way to 7-1. We will be picking up the pace to make every effort to get sites 7, 3, and 10 completed by the end of the expedition.

Friday, August 27

Today we completed site 5-1. It did not show any obvious signs of hydrocarbons. Desiage suspects that 5-1 might be the sight of a mass failure. There were boulders and cobbles throughout the area. We collected cores at one location before we got cut short by another ROV malfunction. Instead of waiting for the ROV to be repaired and then redeployed at 5-1 we instead moved on to 3-1. We are currently surveying 3-1 and will move on to 10-1 sometime through the night or early tomorrow morning to hopefully do a dive there.

Saturday, August 28

We completed site 3-1 through the night and arrived at site 10-1 this morning. We were able to launch the ROV and began a survey but the weather quickly turned and we were not able to deploy the work basket safely. We did an ROV survey until the weather got bad enough that we had to retrieve the ROV. Unfortunately we were not able to collect any cores at 10-1 due to the poor weather. The only consolation maybe is that the site did not look promising for hydrocarbon indicators. It was probably the most featureless seafloor we have observed the whole expedition.

We just began our return trip to Dartmouth. We are due to tie up at the ATL Woodside dock around 9am tomorrow.

Sunday, August 29

Arrived in Dartmouth at ATL Woodside dock. Begin demobilization.

Appendix 2: Data collection summary

	Latitude	Longitude	JD	Time (ADT)	Push core		Gas sampling	Water sampling	Rock sample
					Quantity	Basket			
Site 1-1									
Location 1	43.01079492	-60.21315862	228	18:04	8	A			
Sponge Bob	43.00946251	-60.21228989	228	21:02	8	B			
Brittle Rock	43.01054079	-60.21202191	228	23:38	8	C			
Bullseye	43.01020812	-60.21206683	229	03:18	8	E			
Transect NW 10m	43.01012923	-60.21197432	229	04:28	4	C			
Transect SE 10m	43.01004189	-60.21187103	229	05:00	4	E			
Transect SE 20m	43.00991976	-60.21197882	229		3	A			
Transect SE 30m	43.00985225	-60.21149788	229	12:52	3	A			
Transect SE 40m	43.00959616	-60.21099286	229	13:17	4	A			
Site 1-1	43.0101	-60.211906	229	14:20	12	A and D			
Trench	43.00981399	-60.21262732	229	16:25	2	D			
Site 2B-1									
Purple Patch	42.20805927	-62.32374909	230	11:33	10	A			
Coral Hill	42.20794019	-62.3237691	230	14:40	11	E			
Clam Shell	42.20765418	-62.32440912	230	15:58	10	B	x		
Tiny Bubbles	42.20785355	-62.32388621	230	19:38	11	c	x		
Transect NW 75m	42.20826513	-62.3244242	230	21:47	4	D			
Transect NW 40m	42.20815154	-62.32426769	230	22:42	4	D			
Transect NW 25m	42.20804497	-62.32417094	230	23:29	4	D			
Transect SE 25m	42.20763941	-62.32381874	231	05:17	4	A			
Transect SE 40m	42.20742953	-62.32369027	231	05:45	4	A			
Transect SE 75m	42.207407	-62.323383	231	06:25	4	A			
Site 2B-2									

Pockmark Mound	42.20520207	-62.32809274	231	13:13	10	E			
Dark Seabed	42.2055023	-62.32703162	231	14:19	6	B			
Scaly Seabed	42.20576674	-62.32635458	231	15:07	6	B			
Big purple	42.205319	-62.327586	231	15:54	10	C			
Site 2B-3									
Shell Colony	42.19927567	-62.31714001	232	06:26	6	D			
Blackish Pillow	42.19968641	-62.31710823	232		6	D			
Dead Shells	42.19875377	-62.31749611	232	08:12	6	E			
Grey Scar	42.19820084	-62.31724552	232	08:38	6	E			
Site 2A-1									
Clam Hill	42.16334987	-62.37277168	232	17:32	8	E			
Deep Purple	42.16327492	-62.37207714	232	18:26	10	D			
Holy Ground	42.16235325	-62.37206222	232	19:49	10	A			
Crusty White Clams	42.16219753	-62.37137755	233	00:25	7	E			
The Hole	42.16269779	-62.3723563	233	01:23	10	C	x	x	x
Site 2A-2									
Purple Hill	42.15961604	-62.36060369	233	12:12	6	B			
Purple Haze	42.15981701	-62.3602432	233	13:50	10	D			
Transect 2A-2 to 2A-1									
2A Transect NW 175m	42.16035672	-62.36217473	233	15:24	5	E			
2A Transect NW 350m	42.16084539	-62.36423398	233	16:47	5	E			
2A Transect NW 525m	42.16133439	-62.36639438	233	19:52	10	C		x	
2A Transect NW 700m	42.16174577	-62.36823756	233	21:45	6	B			
2A transect NW 875m	42.16217985	-62.37035106	233	22h46	6	B			
Site 6-1									
Smithers	42.2297976	-62.44289492	234	09:30	10	A			
Site 6-2									
Arm and Hammer	42.22863217	-62.43291052	237	18:35	10	A			

Club Sandwich	42.22838391	-62.43324089	237	19:30	10	B	x
Transect 6-1 to 5-1							
5-1 Transect SE 15000m	42.27331505	-62.66221991	238	02:21	10	D	
Site 5-1							
Water Sampling 5-1	42.307344	-62.838002	238	08:00			x
Kilo	42.3068338	-62.83817817	238	13:59	10	E	
Juliette	42.30709551	-62.8381183	238	14:45	8	C	
Foxtrot	42.30753516	-62.83808845	238	15:26	8	B	
Delta	42.30908996	-62.83692365	238	17:52	10	A	
Site 7-1							
Moon	42.3633195	-62.71176758	239	10:18	10	E	
Site 3-1							
Saint Lawrence	42.488801	-62.131888	239	21:42	5	D	
LaHave	42.488627	-62.128882	239	23:02	8	B	