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2021004PGC cruise report: mapping Salish Sea marine geohazards, British Columbia

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2022

Canada

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2021004PGC cruise report: mapping Salish Sea marine geohazards, British Columbia

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2022

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

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Abstract:

The Geological Survey of Canada (GSC) undertook marine fieldwork onboard the Canadian Coast Guard Ship (CCGS) *Vector* to locate and map potential geohazards and geological features in the Salish Sea in the interest of public safety from August 11-18, 2021. This work was conducted under the Natural Resources Canada Marine Geoscience for Marine Spatial Planning (MGMSP) and the Public Safety Geoscience Programs. The GSC had observed multiple potential faults in existing data near Central Haro Strait, Stuart Channel, South of Hornby Island and near Cape Lazo through existing CHIRP and multibeam bathymetry data but required further data to quantify their activity and potential seismic risk (Barrie et al, 2021). In addition to fault activity, the GSC had detected numerous large underwater landslide deposits in Howe Sound and Saanich Inlet. The GSC required further data to constrain volumes and timing of slide activity. In English Bay the origin and evolution of a field of pockmarks was poorly understood. In Burrard Inlet, the survey required a better understanding of frequency of landslides as well as depth of sediment in order to understand natural sediment depositional rates. The research expedition included deep-tow system (DTS) sub-bottom surveys and multibeam water column and bathymetric surveys in each of these areas to better understand these marine geohazards and processes. Hydrographic surveys were completed by the Canadian Hydrographic Service (CHS) at night in Pylades Channel and near Point Grey to maximize use of ship time. Weather was good, seas were calm, and good quality data were collected. The data collected will be made publicly available and have the potential to contribute to building codes and to help communities in their decision-making and understanding of risks.

Introduction:

Previous CHIRP 3.5 kHz sub-bottom data, multibeam bathymetry, older seismic data and morphological features, led us to investigate potential crustal faults in: Stuart Channel, the Strait of Georgia off Cape Lazo, and in Central Haro Strait (Figure 1). Prior to this expedition, we were lacking sub-bottom data in the mid-range resolution for determining activity and potential seismic risk. Landslides had previously been mapped in Howe Sound, Saanich Inlet and Burrard Inlet but deep tow system data were lacking to see through the deposits. Burrard Inlet has historically had very little deeper sub-bottom data and CHIRP data alone didn't allow calculations for depositional rates and unit thicknesses. This expedition aimed to collect the data needed to improve our understanding of these issues and improve our ability to assess the related geohazards.

The expedition started in Saanich Inlet, followed by Stuart Channel, Cape Lazo, Howe Sound, Burrard Inlet, Central Haro Strait, and finished in Sansum Narrows. Evening surveys were conducted by the Canadian Hydrographic Service covering the Point Grey Spoil Grounds for Environment and Climate Change Canada and Pylades Channel for Natural Resources Canada. A Geoforce Deep-tow system was used in parallel with an EM710 multibeam bathymetry collecting both bathymetric data and water column data. Locations and tracklines are shown in Figure 1.

Saanich Inlet surveys included a parallel study in partnership with the Malahat Nation using hydrophones from the Malahat vessel in a vertical array to determine sound exposure levels from our surveys in the Inlet. This will later be used to assess the acoustic impact the deep-tow system makes at our actual survey levels in a coastal fjord.

Individual reports exist for marine mammal observation, DTS data collection, and CHS bathymetric data collection and are available as annexes to this document.

Figure 1. Location of the study areas by date and tracklines covered within the Salish Sea. Basemap from Pacific Coast Digital Elevation model (Kung et al, 2021) and Canadian Hydrographic Chart 3001 (for illustrative purposes only, not to be used for navigation).

Field Party (Figure. 2)**:**

Natural Resources Canada (Geological Survey of Canada, Pacific):

Karen Douglas (Chief Scientist)

J. Vaughn Barrie (Co-chief Scientist)

Tom Fralic (Contracted Geoforce DTS Technician)

Nicole Koshure (Contracted Marine Mammal Observer)

Fisheries and Oceans Canada (CHS, Pacific):

Tony Dill (Hydrographer in Charge)

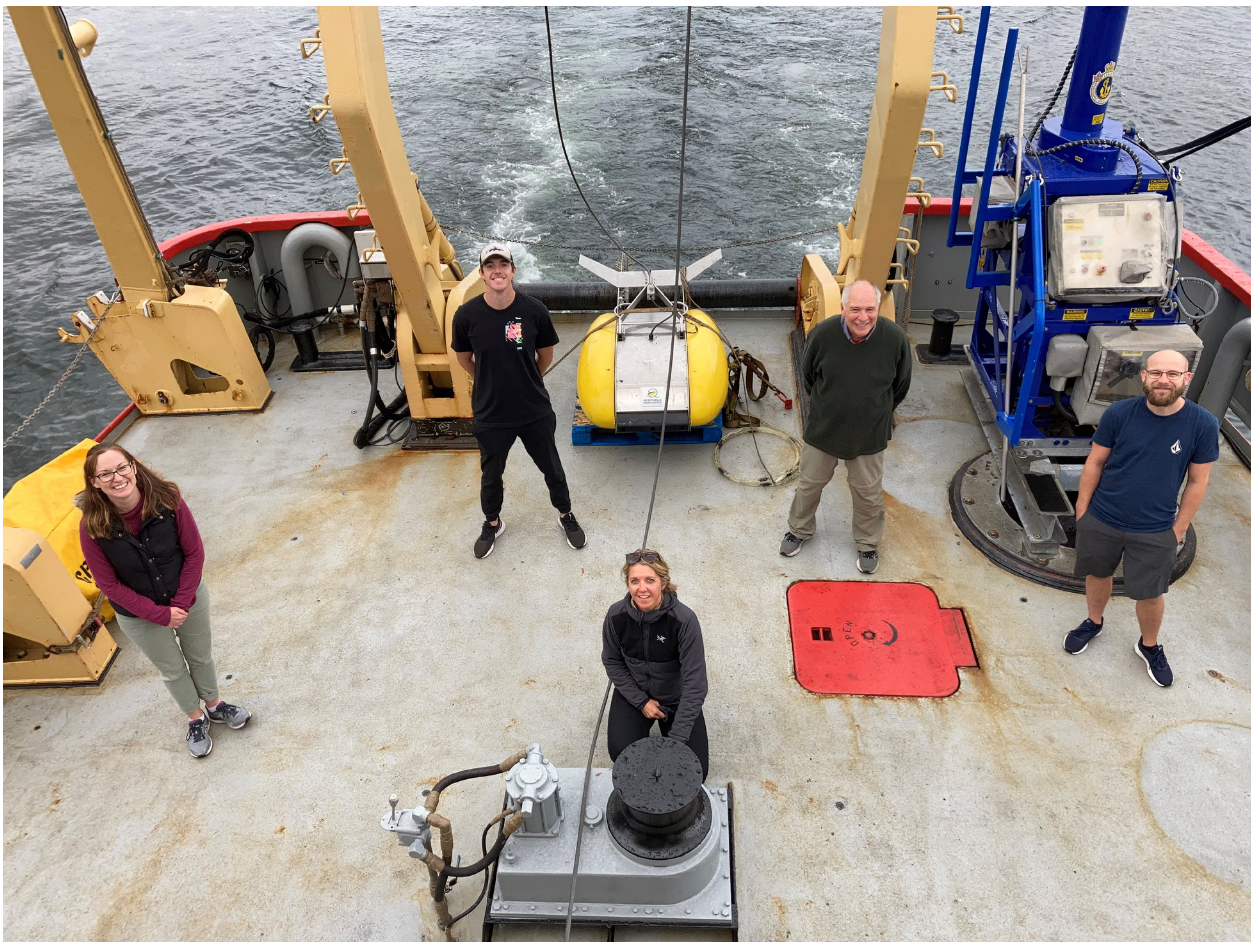

Figure 2. 2021004PGC CCGS Vector Field party. From Left to Right: Karen Douglas, Tony Dill, Nicole Koshure, Vaughn Barrie, Tom Fralic. Photograph by Canadian Coast Guard Vector's Crew for NRCan. NRCan photo 2021-674.

Survey Equipment

- Geoforce Deep Tow System (Serial #3004) (Figure 3)
- Kongsberg EM710 Multibeam Echosounder (water column and bathymetry)
- Jasco sound trap hydrophones (From Juanes Lab, University of Victoria) (Figure 4)

Contingency equipment: camera, shipek grab sampler and CHIRP echosounder were not used.

Figure 3. Photograph of the Geoforce Deep-tow System on the aft deck of the Vector, below the A-frame. *Photograph by K. Douglas. NRCan photo 2021-664.*

Figure 4. Photographs of the three Jasco sound trap hydrophones (Juanes Lab, UVic) used in the Saanich Inlet sound exposure level experiment. Depths deployed were A) 5 m = 1 band of black electrical tape, B)10 m = 2 bands of black electrical tape, C) 15 m = Juanes lab label. Photographs in this figure used with permission, courtesy of Desiree Bulger, Malahat Nation.

Narrative of Events:

August 11 - Day 223

- Mobilization of Scientific Equipment in afternoon at IOS
- Safety familiarization meeting
- All equipment on board by 1900 PDT
- Pylades Channel hydrographic survey (CHS)

August 12 – Day 224

- Saanich Inlet Marine mammal visual survey
- Saanich Inlet DTS Sparker and multibeam water column survey
- Saanich Inlet Hydrophone experiment with Malahat Nation
- Pylades Channel hydrographic survey (CHS)

August 13 – Day 225

- Stuart Channel marine mammal visual survey
- Stuart Channel DTS Boomer/Sparker and multibeam water column survey
- Point Grey Spoil Grounds hydrographic survey (CHS)

August 14 – Day 226

- Cape Lazo marine mammal visual survey
- Cape Lazo DTS Sparker and multibeam water column survey
- Point Grey Spoil Grounds hydrographic survey (CHS)

August 15 – Day 227

- Howe Sound marine mammal visual survey
- Howe Sound DTS Boomer/Sparker and multibeam water column survey
- Point Grey Spoil Grounds hydrographic survey (CHS)

August 16 – Day 228

- Burrard Inlet marine mammal visual survey
- Burrard Inlet DTS Boomer and multibeam water column survey
- Point Grey Spoil Grounds hydrographic survey (CHS)

August 17 – Day 229

- Central Haro Strait marine mammal visual survey
- Central Haro Strait DTS sparker and multibeam water column survey
- Sansum Narrows DTS sparker and multibeam water column survey
- Saanich Inlet multibeam echosounder patch test (CHS)

August 18 – Day 230

- Demobilization of scientific equipment in morning at IOS

Data Collection:

Water column data are available from the Kongsberg EM710 bathymetric sonar as .wcd files upon request from the author. File sizes are large and a repository for these data has yet to be identified.

Hydrophone data are available from the Jasco Soundtrap Hydrophones upon request from the author. File sizes are also large and a repository for these data has yet to be identified.

Navigation data are publicly available through the Geological Survey of Canada's Expedition Database: https://ed.gdr.nrcan.gc.ca/index_e.php

Bathymetry data collected at Point Grey and Pylades Channel can be obtained from the Canadian Hydrographic Service. Surveys are known as 2021PointGrey_DAS_9001476 and 2021PyladesChannel_9001474. Preview images are provided below (Figure 5).

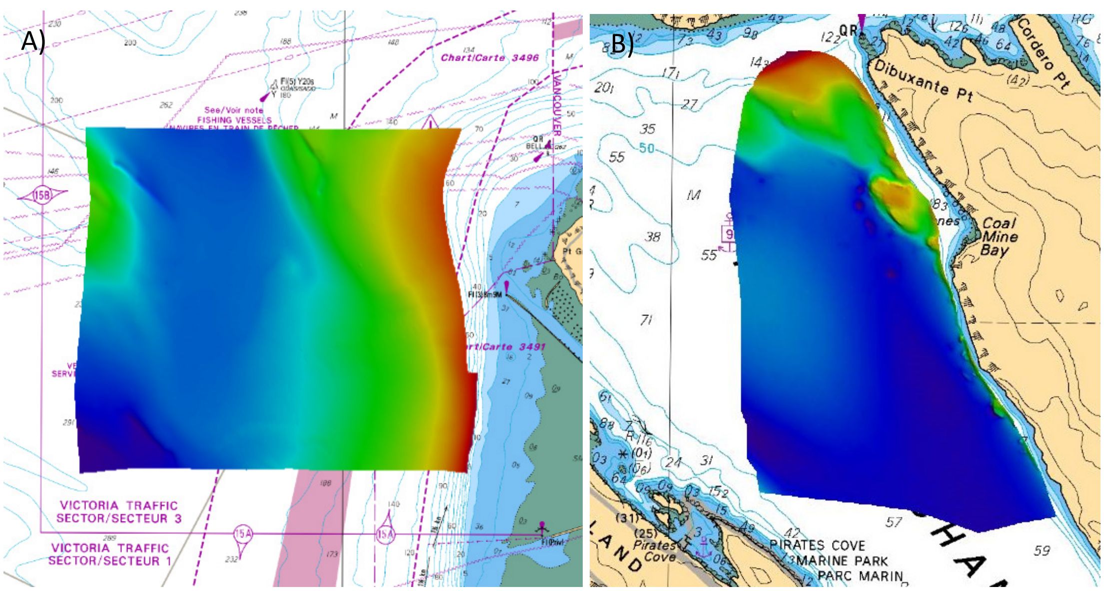

Figure 5. Canadian Hydrographic Service preliminary bathymetry, collected at A) Point Grey, and B) Pylades Channel Anchorage Trincomali #8.

DTS data files are publicly available through the Canadian National Marine Seismic Data Repository at https://open.canada.ca/data/en/dataset/e1fa0090-4b06-e476-5c71-e2326666a4d0. Images are provided below.

Geophysical DTS surveys and multibeam water column data were collected along the following lines:

SAANICH INLET

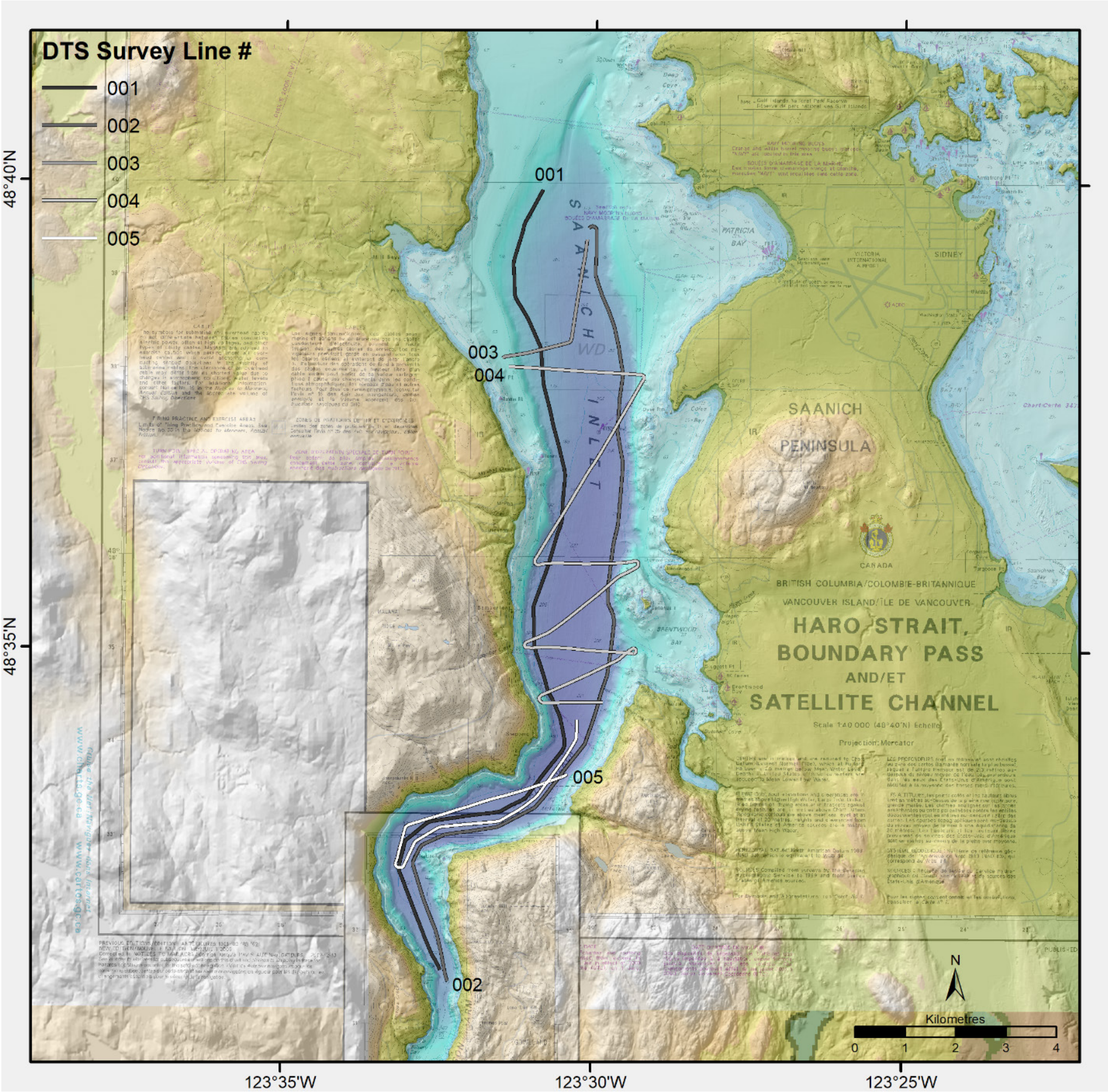

Figure 6. Saanich Inlet deep-tow surveys (lines 001-005). Basemap from Pacific Coast Digital Elevation model (Kung et al, 2021) and Canadian Hydrographic Chart 3441 (for illustrative purposes only, not to be used for navigation).

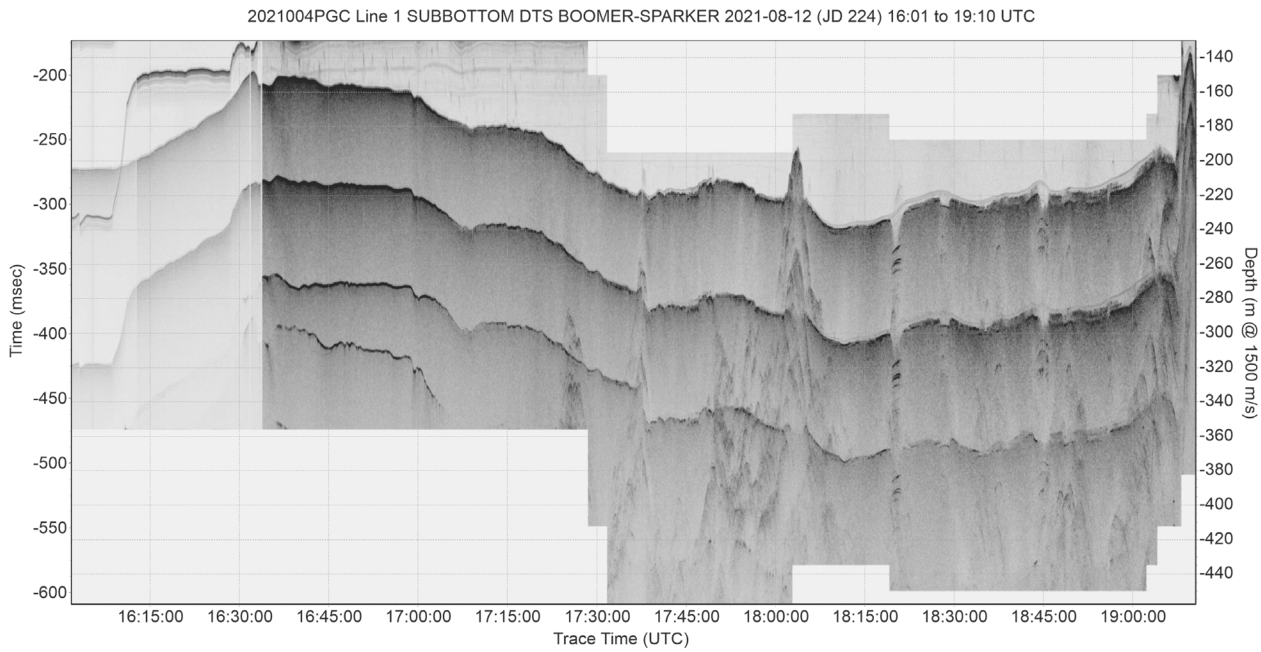

Figure 7. Deep-tow System Line 001 subbottom boomer and sparker data collected in Saanich Inlet from North to South on 2021-08-12 from 16:01 to 19:10 UTC.

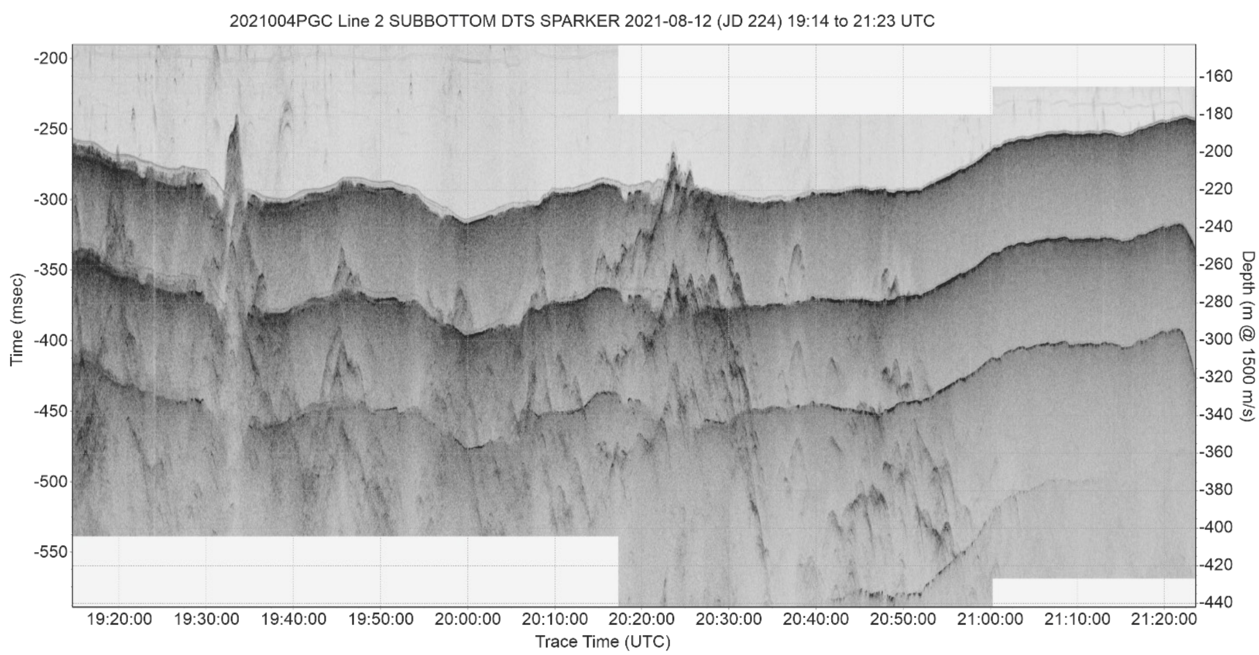

Figure 8. Deep-tow System Line 002 subbottom sparker data collected in Saanich Inlet from South to North on 2021-08-12 from 19:14 to 21:23 UTC.

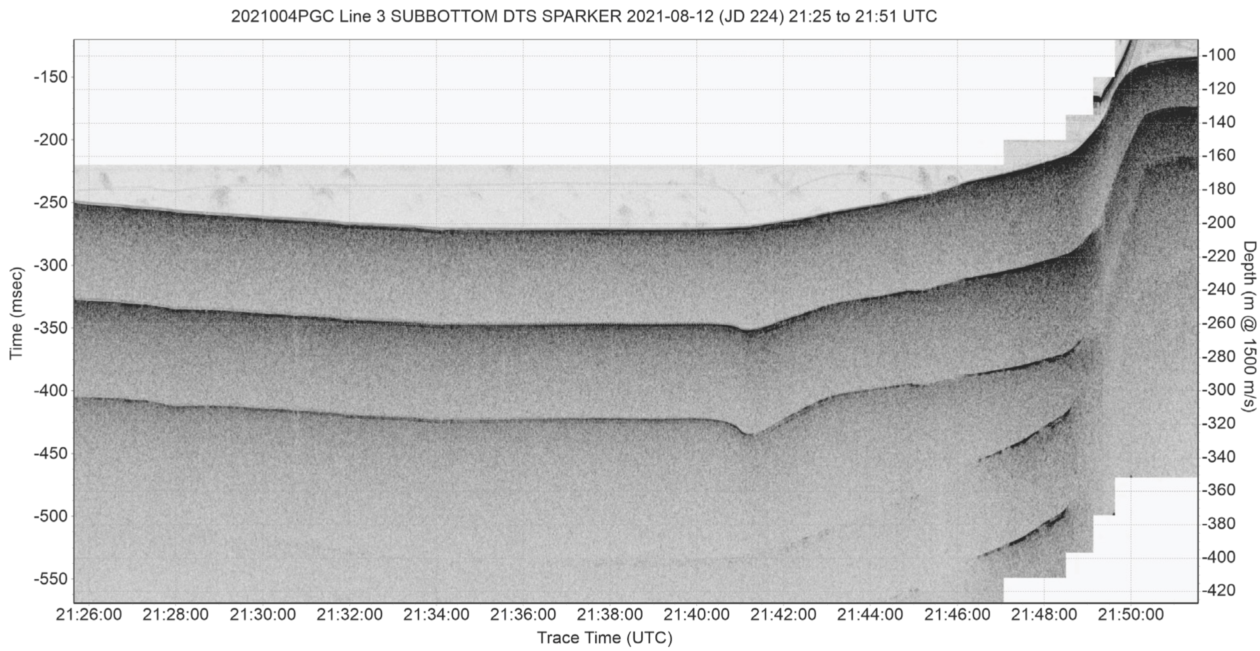

Figure 9. Deep-tow System Line 003 subbottom sparker data collected in Saanich Inlet from North to South on 2021-08-12 from 21:25 to 21:51 UTC.

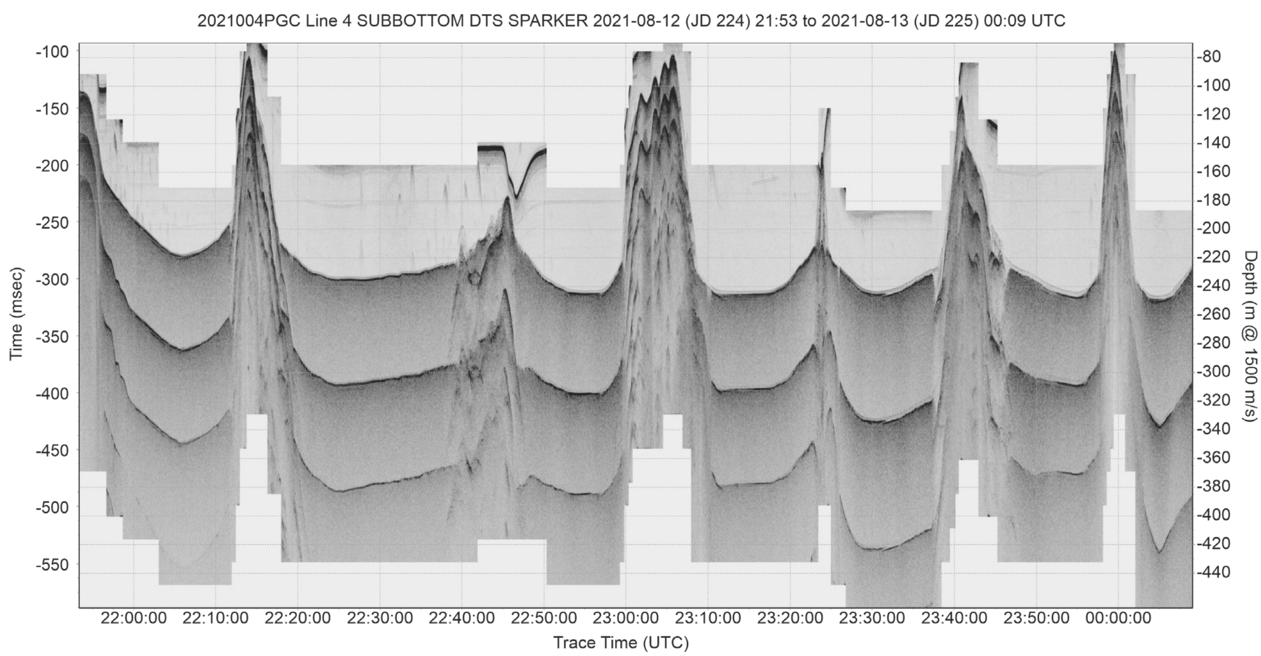

Figure 10. Deep-tow System Line 004 subbottom sparker data collected in Saanich Inlet from North to South on 2021-08-12 from 21:53 to 2021-08-13 00:09 UTC.

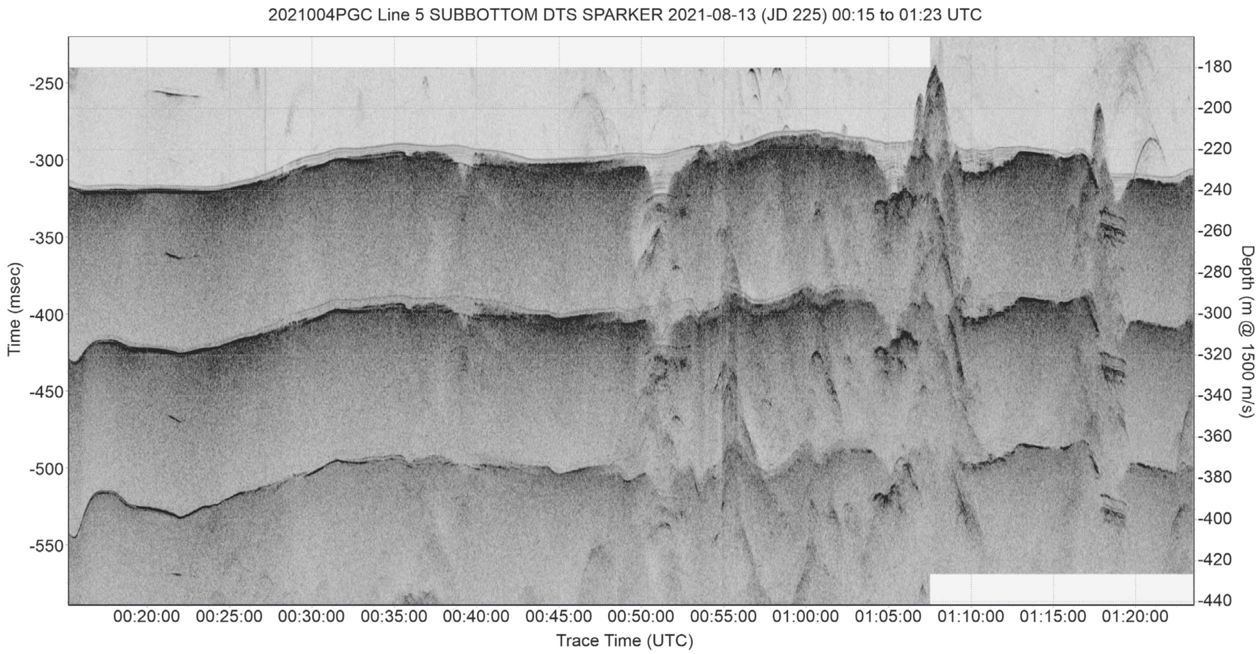

Figure 11. Deep-tow System Line 005 subbottom sparker data collected in Saanich Inlet from North to South to North on 2021-08-13 from 00:15 to 01:23 UTC.

STUART CHANNEL

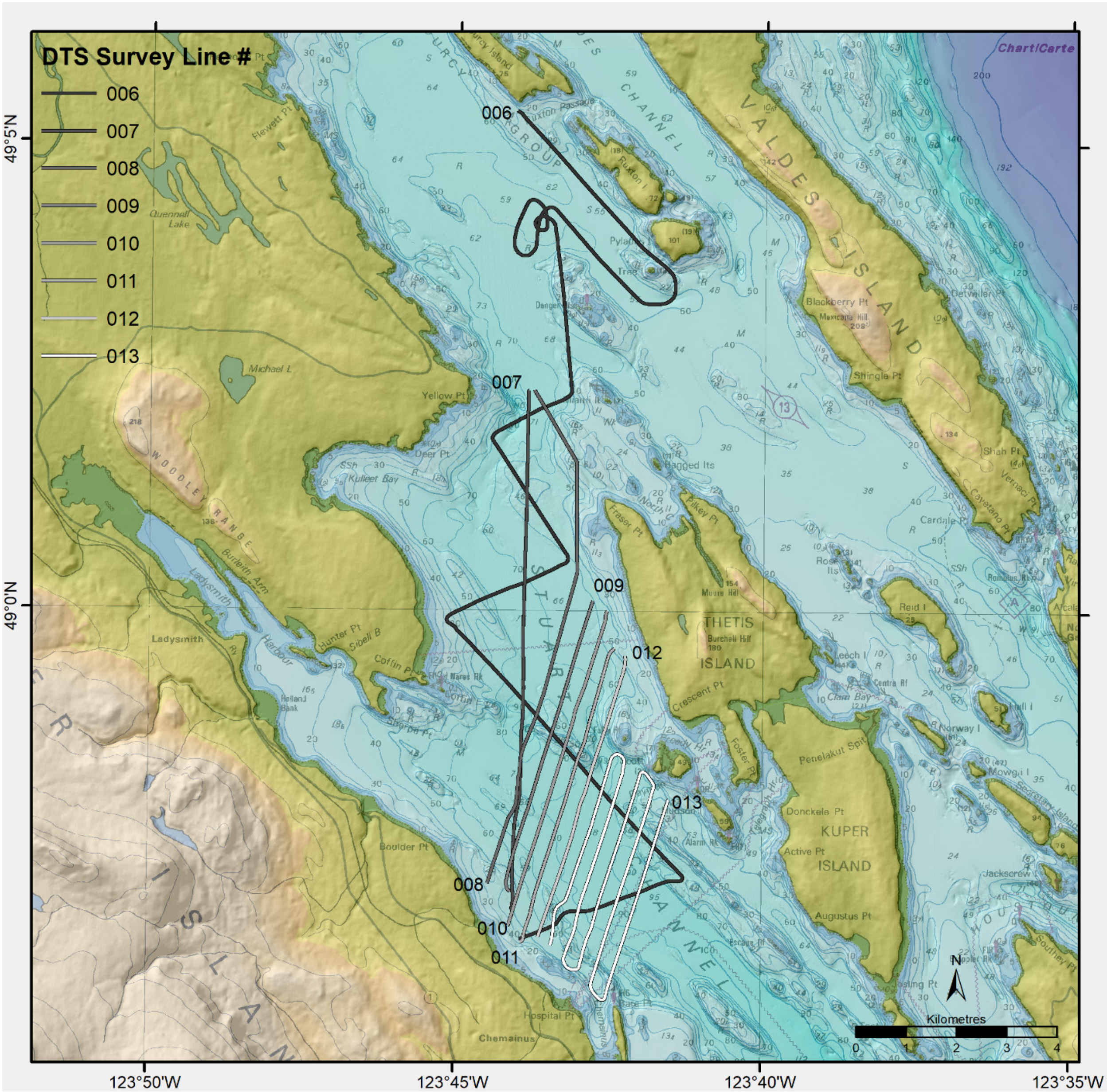

Figure 12. Stuart Channel (lines 006-013). Basemap from Pacific Coast Digital Elevation model (Kung et al, 2021) and Canadian Hydrographic Chart 3463 (for illustrative purposes only, not to be used for navigation).

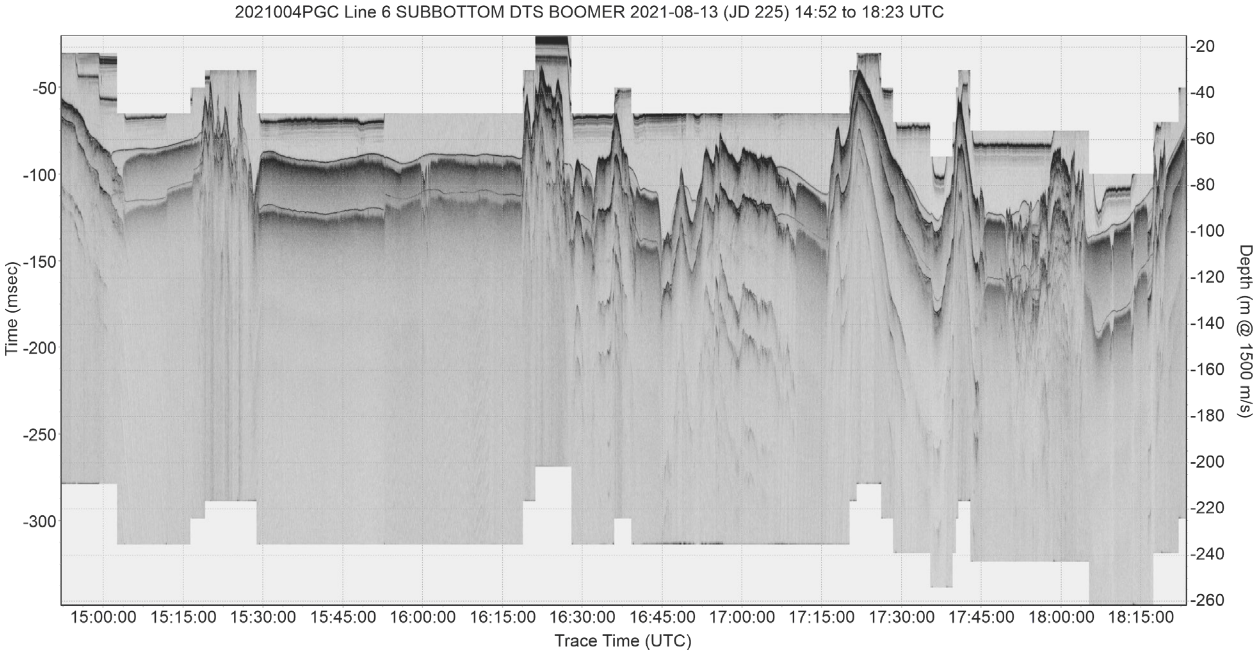

Figure 13. Deep-tow System Line 006 subbottom boomer data collected near Ruxton Passage on 2021-08-13 from 14:52 to 18:23 UTC.

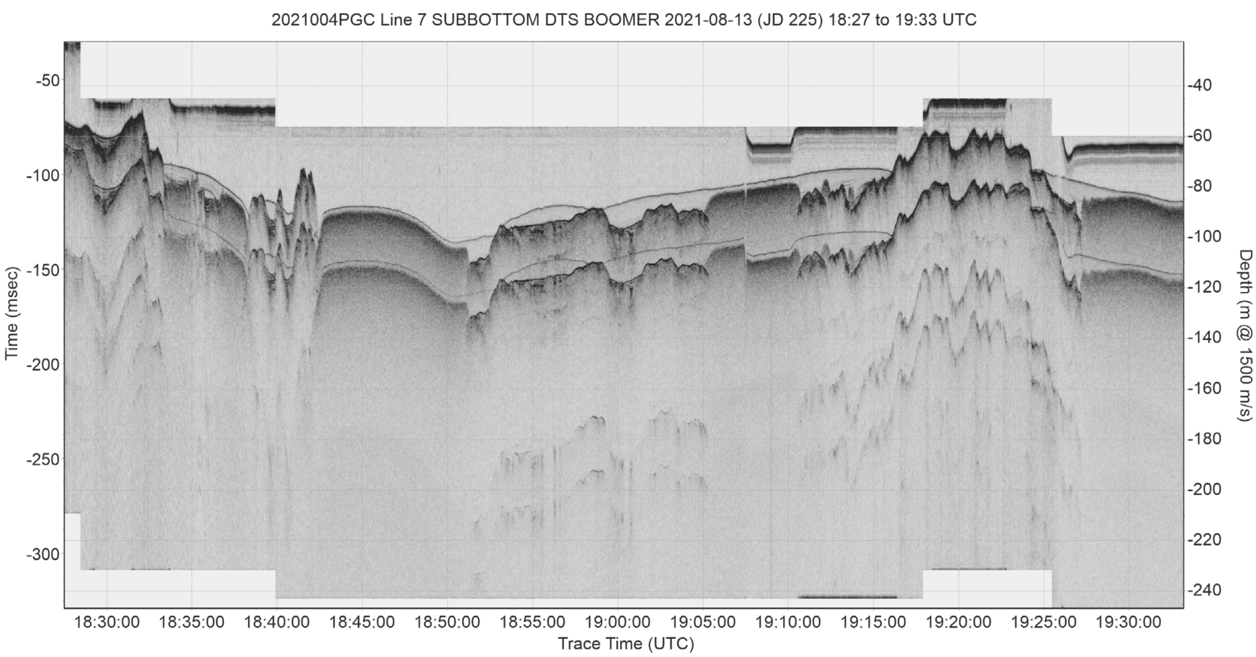

Figure 14. Deep-tow System Line 007 subbottom boomer data collected in Stuart Channel from North to South on 2021-08-13 from 18:27 to 19:33 UTC.

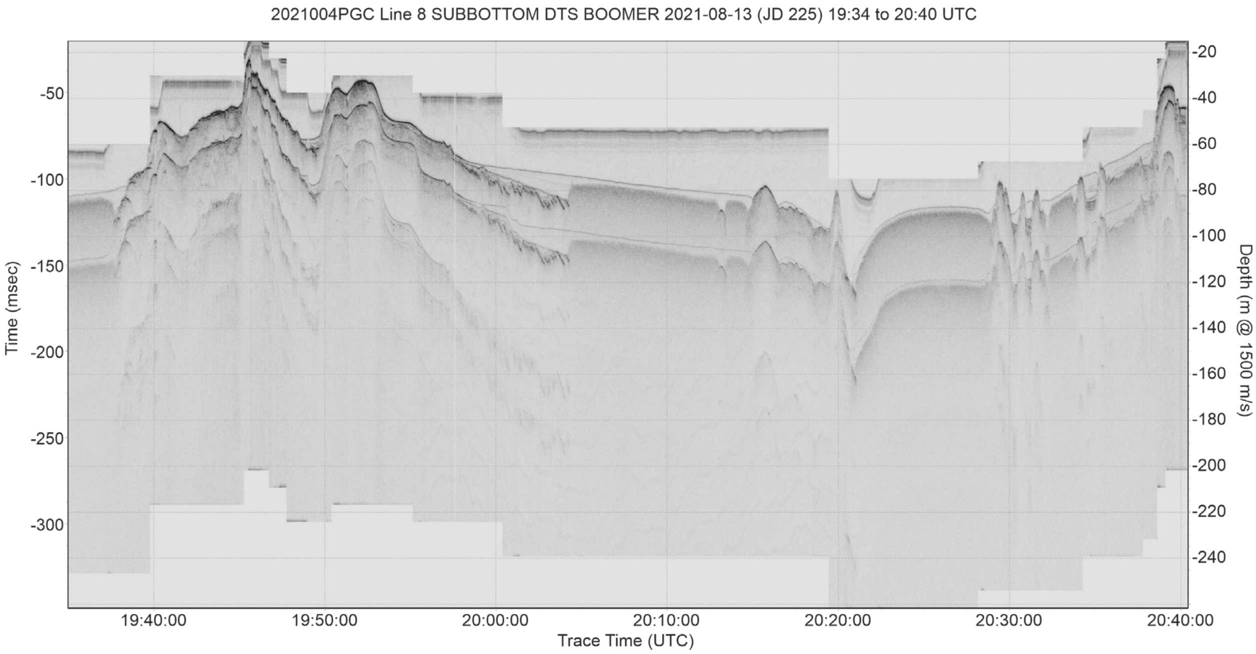

Figure 15. Deep-tow System Line 008 subbottom boomer data collected in Stuart Channel from South to North on 2021-08-13 from 19:34 to 20:40 UTC.

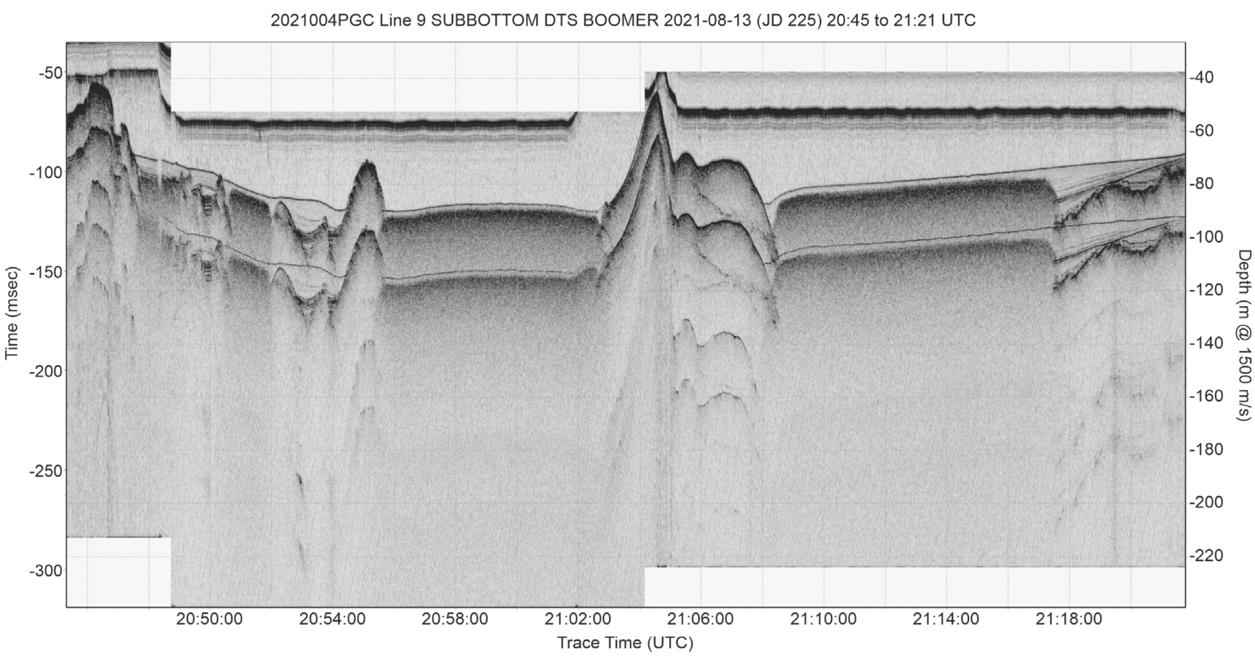

Figure 16. Deep-tow System Line 009 subbottom boomer data collected in Stuart Channel on 2021-08-13 from 20:45 to 21:21 UTC.

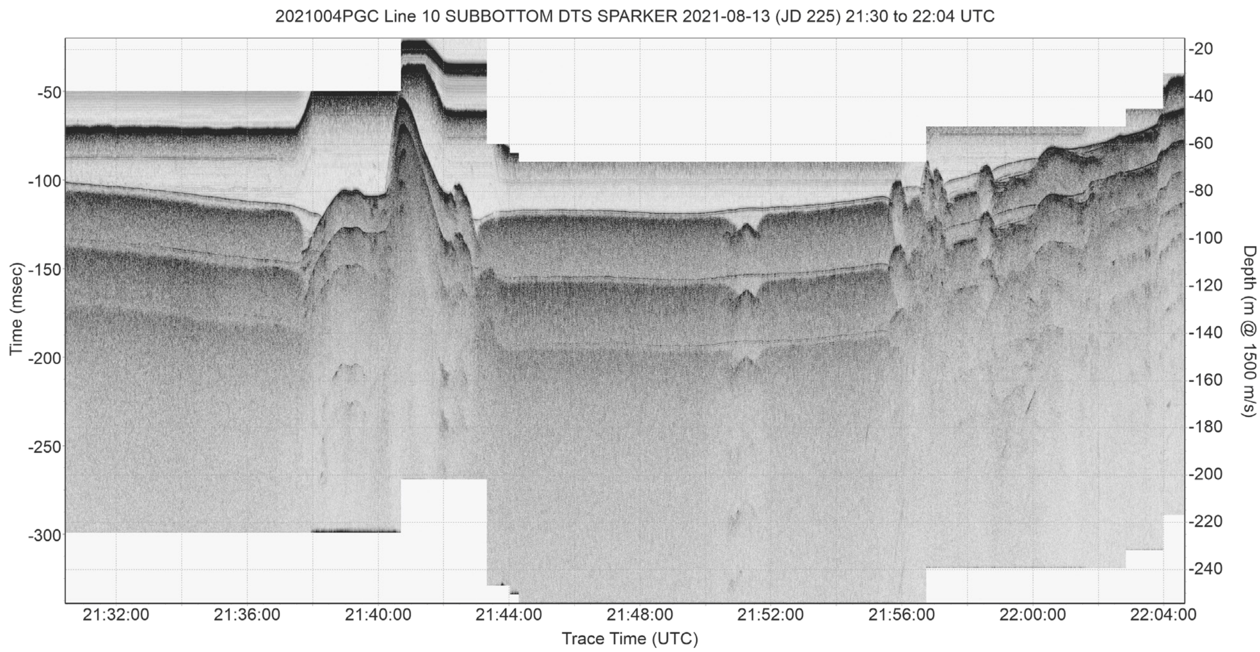

Figure 17. *Deep-tow System Line 010 subbottom sparker data collected in Stuart Channel on 2021-08-13 from 21:30 to 22:04 UTC.*

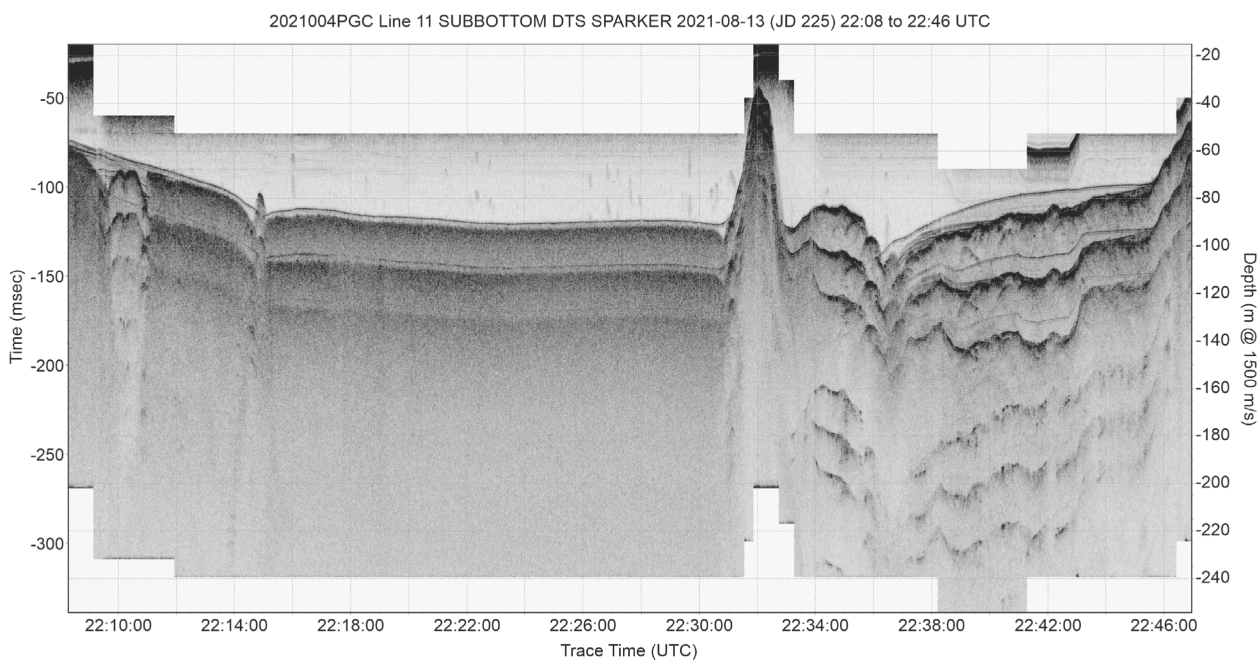

Figure 18. Deep-tow System Line 011 subbottom sparker data collected in Stuart Channel on 2021-08-13 from 22:08 to 22:46 UTC.

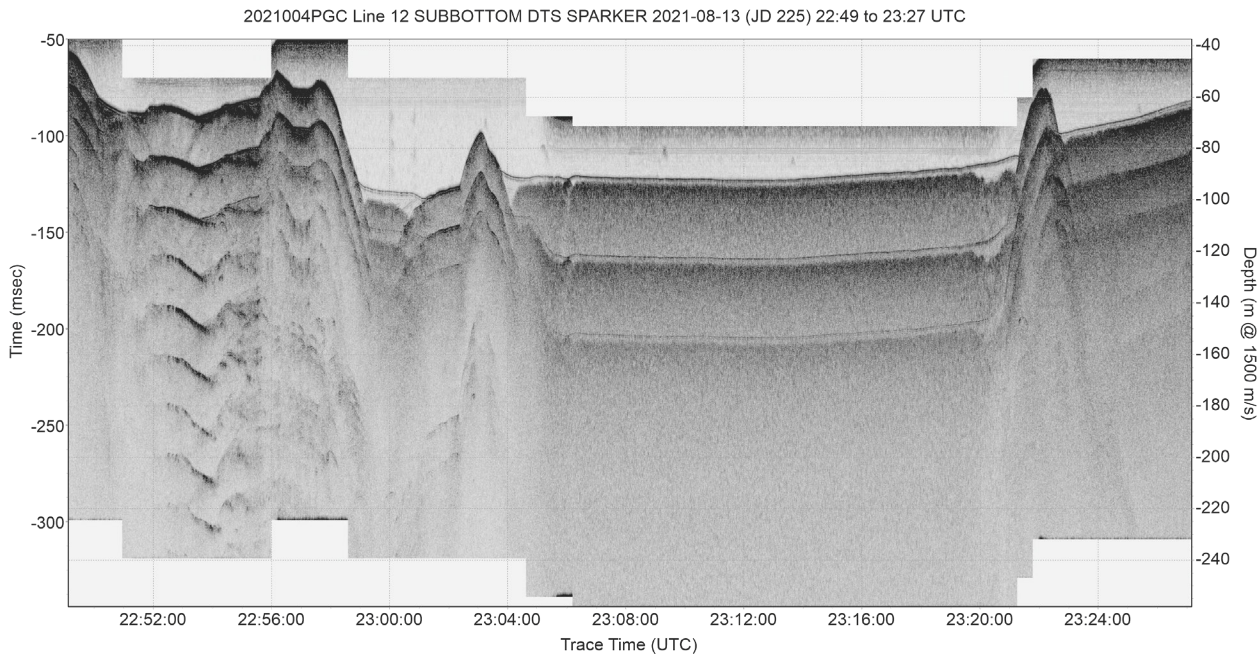

Figure 19. Deep-tow System Line 012 subbottom sparker data collected in Stuart Channel on 2021-08-13 from 22:49 to 23:27 UTC.

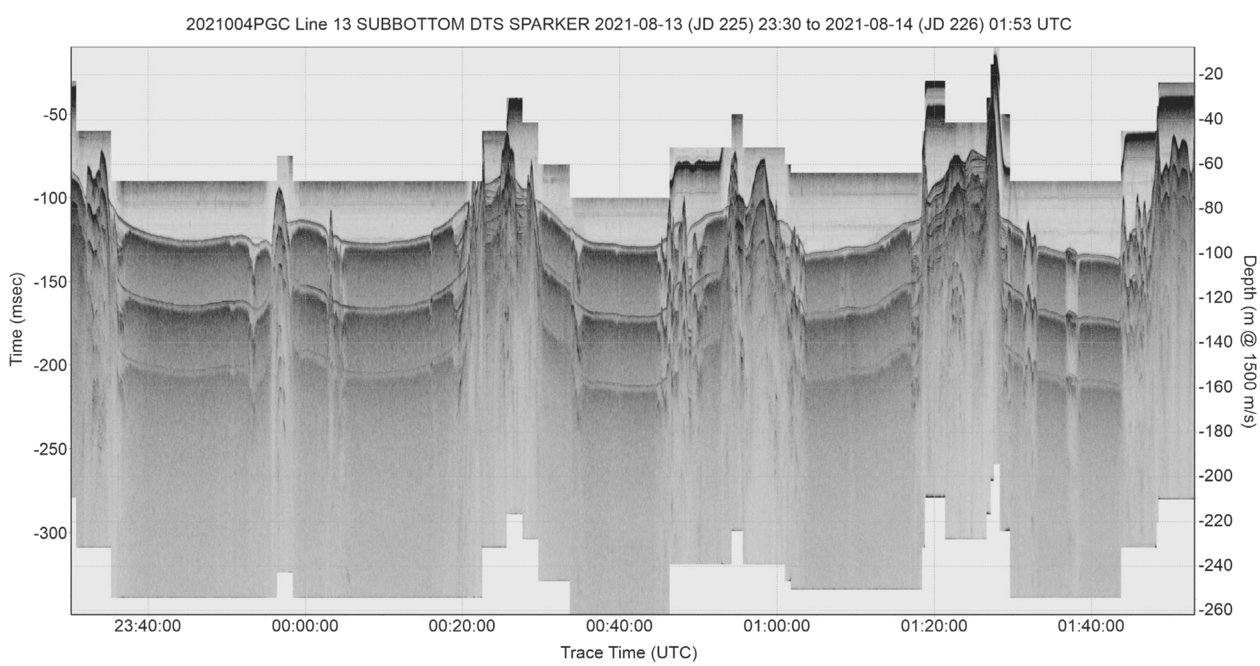

Figure 20. Deep-tow System Line 013 subbottom sparker data collected in Stuart Channel on 2021-08-13 from 23:30 to 2021-08-14 01:53 UTC.

CAPE LAZO

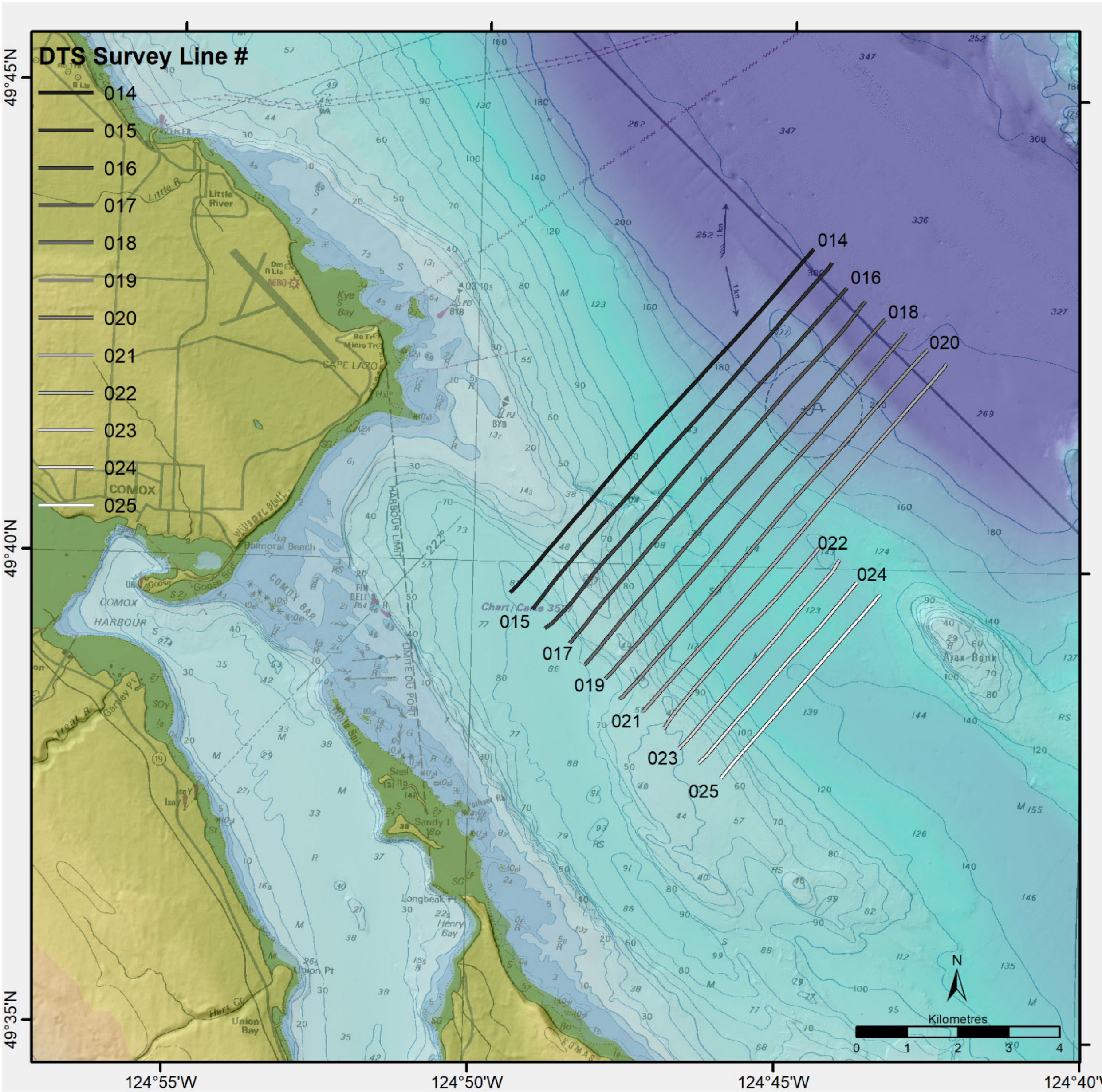

Figure 21. Cape Lazo (lines 014-025). Basemap from Pacific Coast Digital Elevation model (Kung et al, 2021) and Canadian Hydrographic Chart 3513 (for illustrative purposes only, not to be used for navigation).

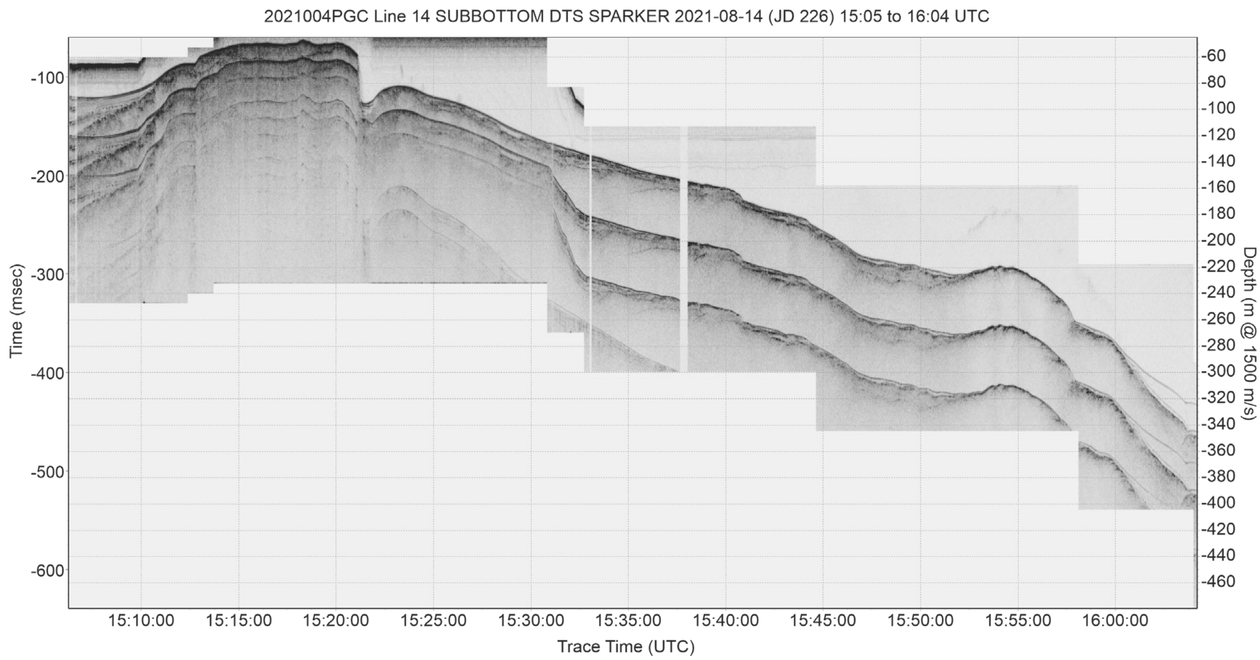

Figure 22. Deep-tow System Line 014 subbottom sparker data collected in the Strait of Georgia, near Cape Lazo, on 2021-08-14 from 15:05 to 16:04 UTC.

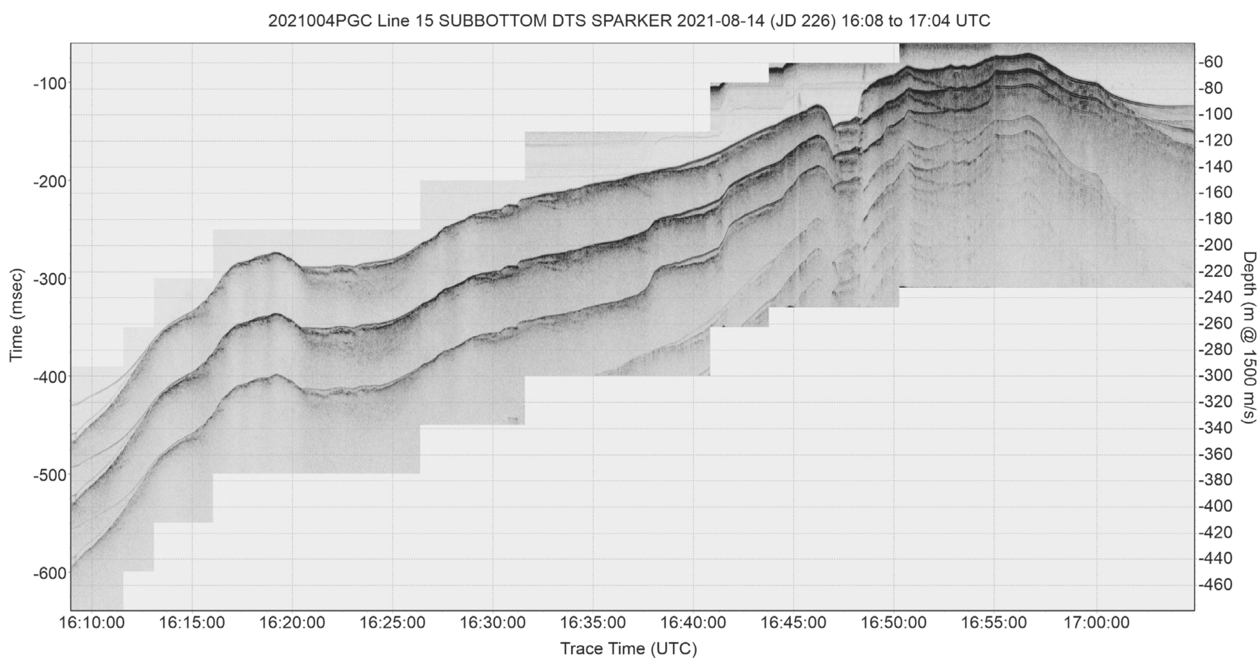

Figure 23. Deep-tow System Line 015 subbottom sparker data collected in the Strait of Georgia, near Cape Lazo, on 2021-08-14 from 16:08 to 17:04 UTC.

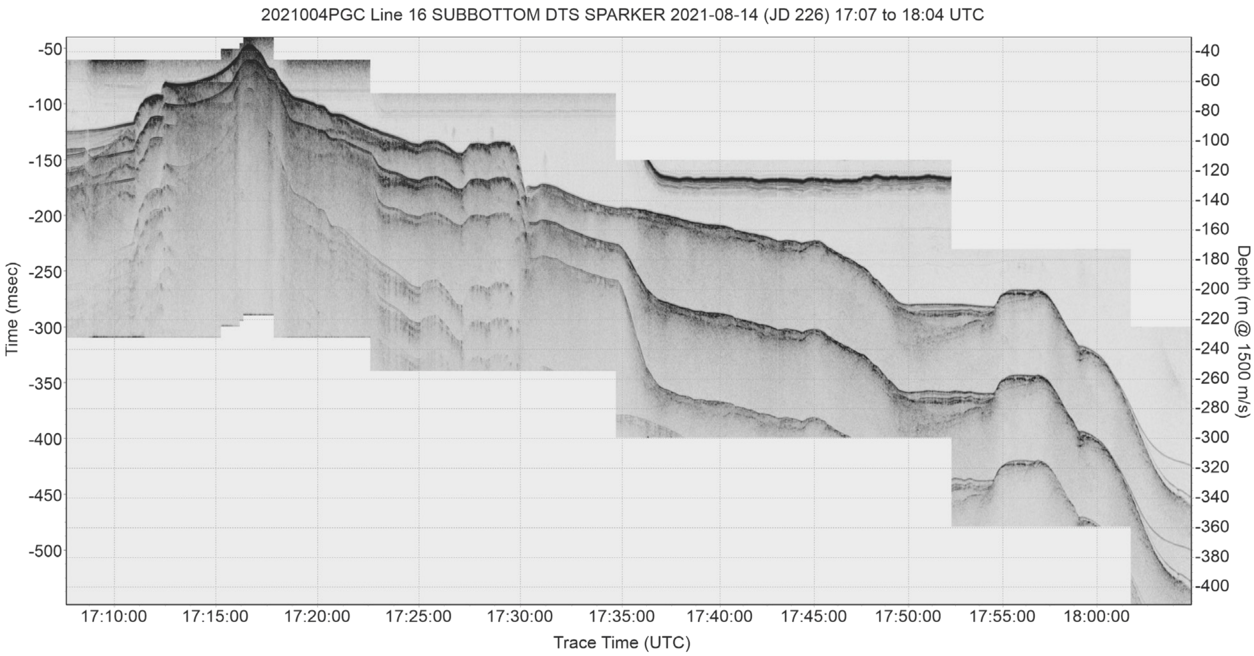

Figure 24. Deep-tow System Line 016 subbottom sparker data collected in the Strait of Georgia, near Cape Lazo, on 2021-08-14 from 17:07 to 18:04 UTC.

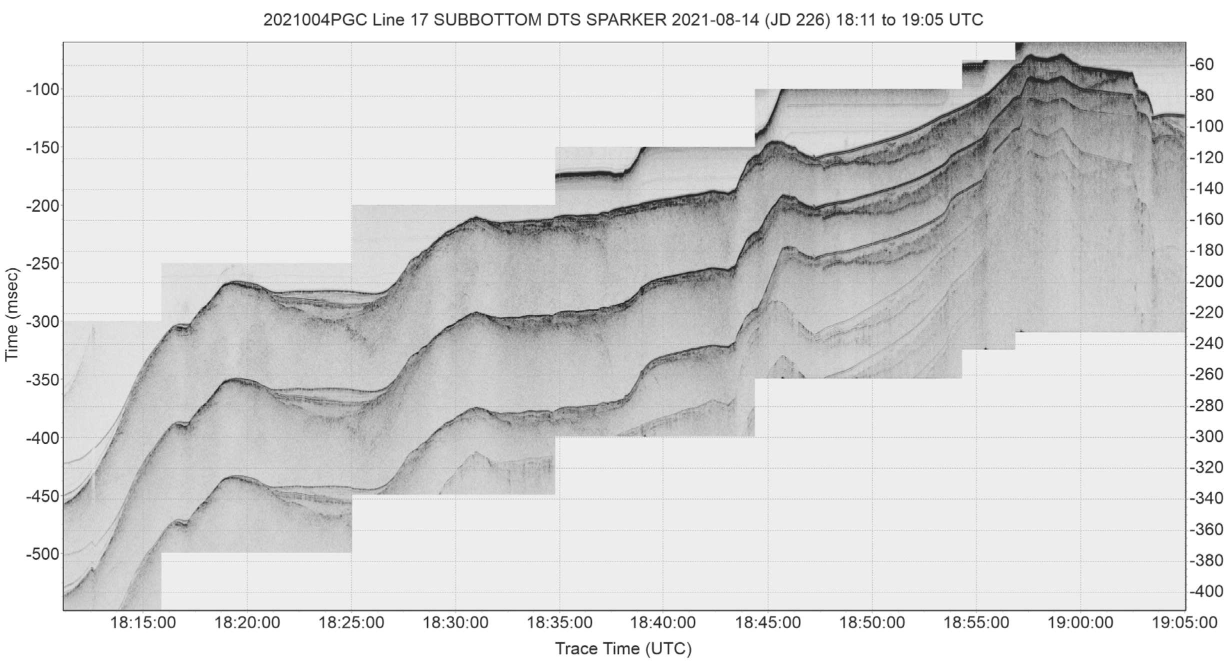

Figure 25. Deep-tow System Line 017 subbottom sparker data collected in the Strait of Georgia, near Cape Lazo, on 2021-08-14 from 18:11 to 19:05 UTC.

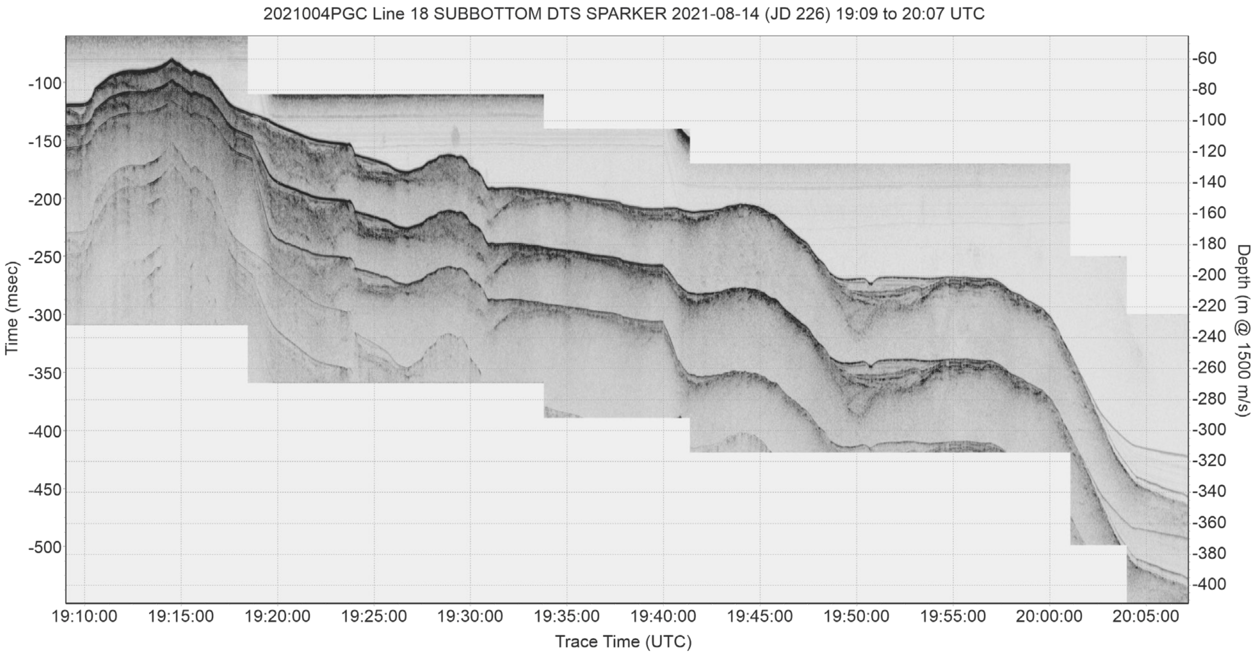

Figure 26. Deep-tow System Line 018 subbottom sparker data collected in the Strait of Georgia, near Cape Lazo, on 2021-08-14 from 19:09 to 20:07 UTC.

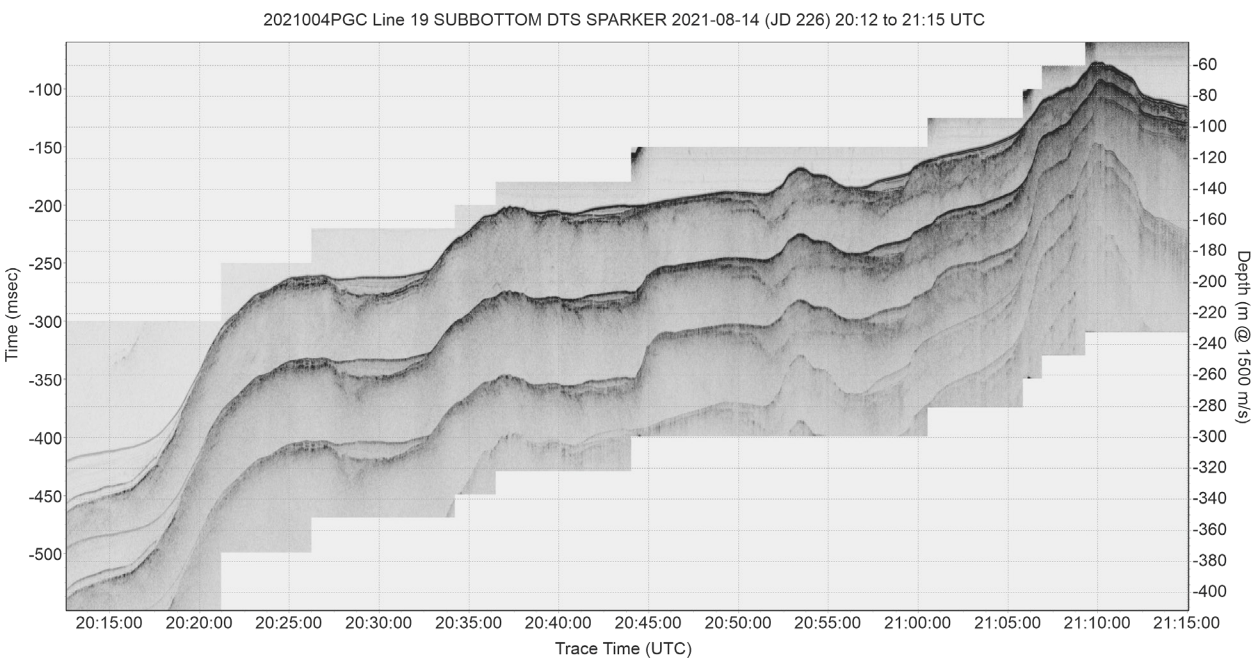

Figure 27. Deep-tow System Line 019 subbottom sparker data collected in the Strait of Georgia, near Cape Lazo, on 2021-08-14 from 20:12 to 21:15 UTC.

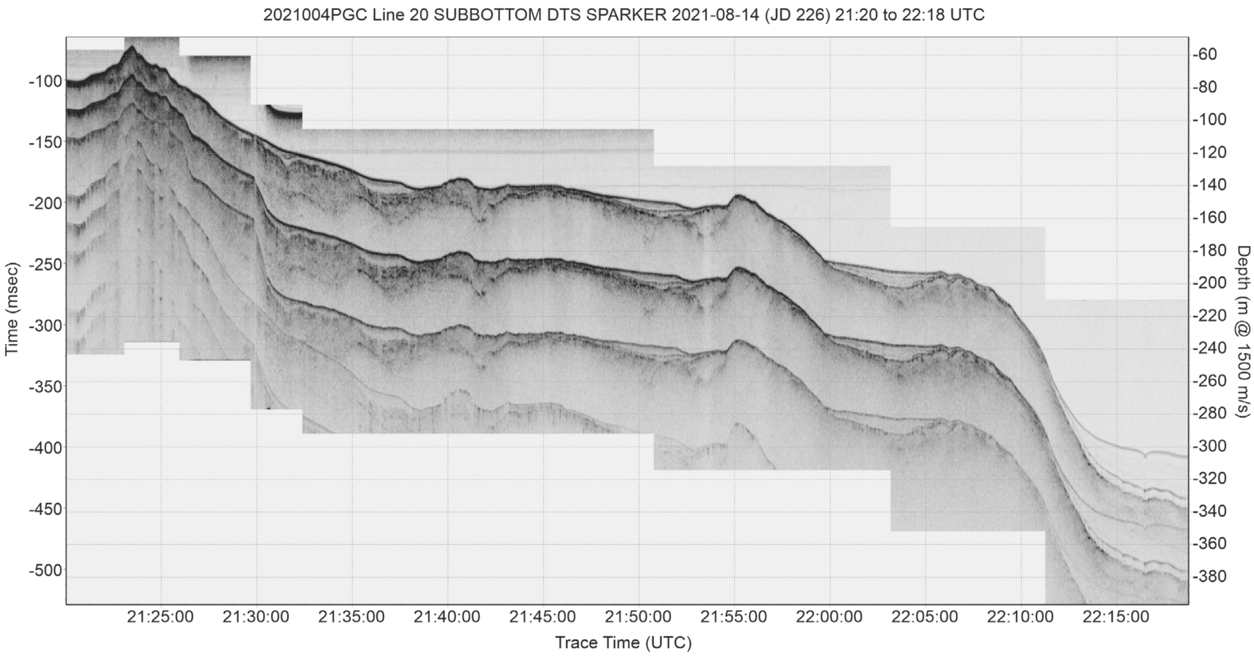

Figure 28. Deep-tow System Line 020 subbottom sparker data collected in the Strait of Georgia, near Cape Lazo, on 2021-08-14 from 21:20 to 22:18 UTC.

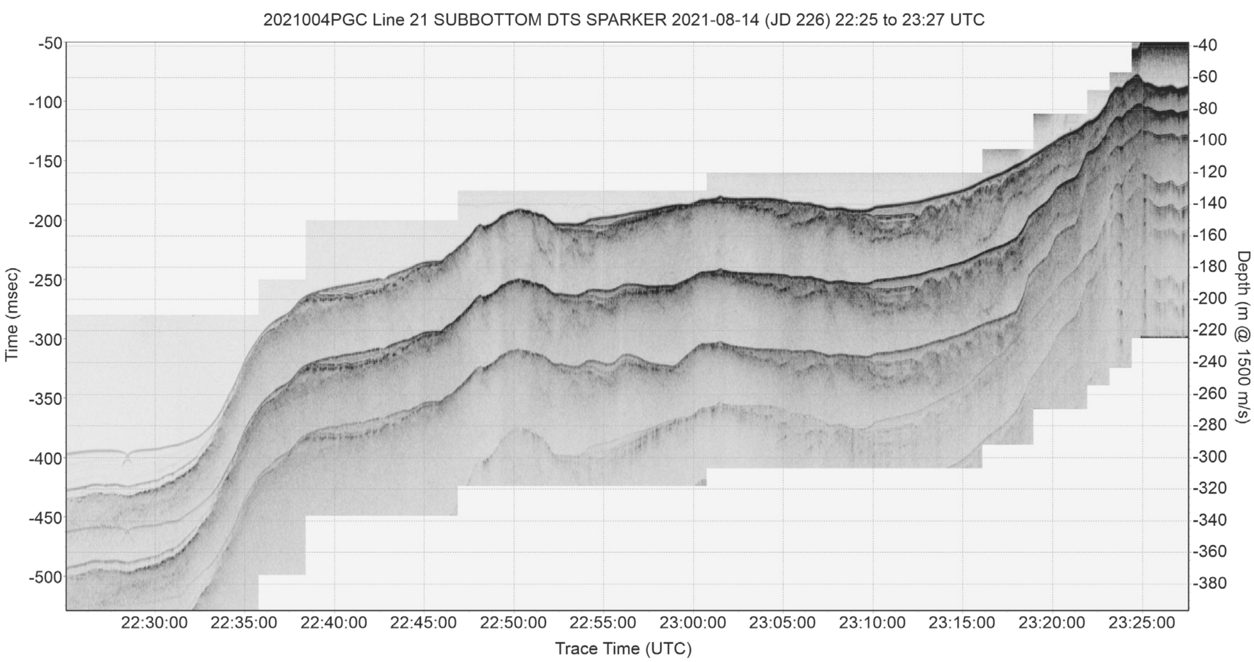

Figure 29. Deep-tow System Line 021 subbottom sparker data collected in the Strait of Georgia, near Cape Lazo, on 2021-08-14 from 22:25 to 23:27 UTC.

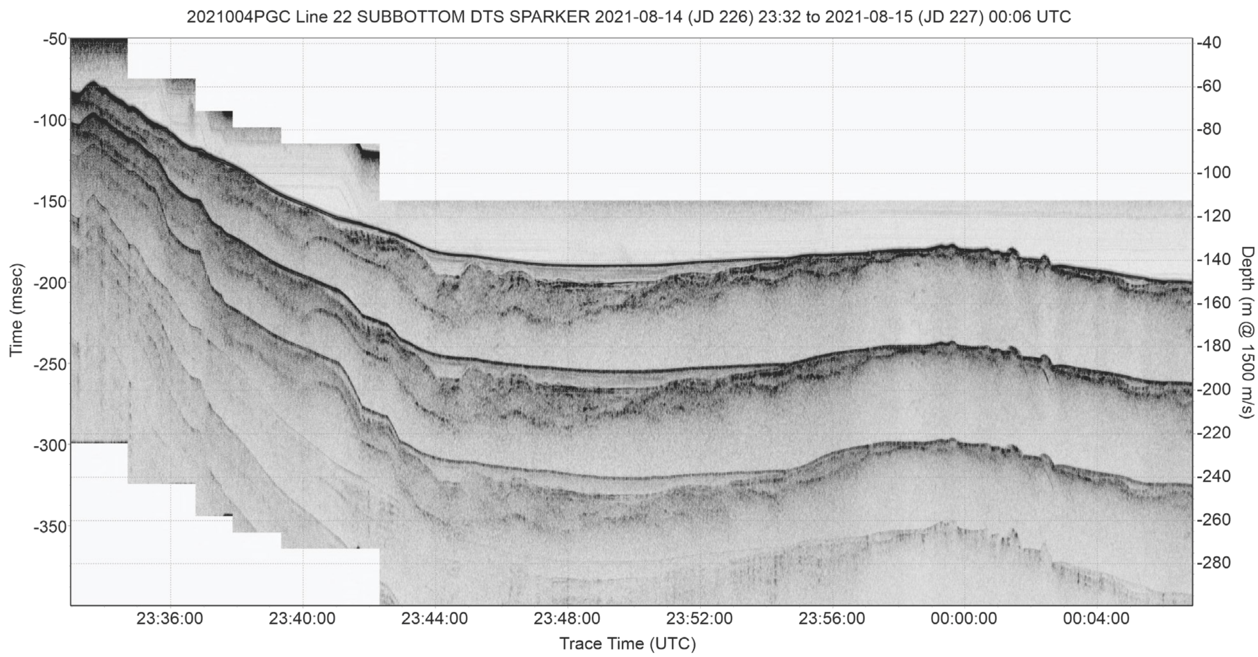

Figure 30. Deep-tow System Line 022 subbottom sparker data collected in the Strait of Georgia, near Cape Lazo, on 2021-08-14 from 23:32 to 2021-08-15 00:06 UTC.

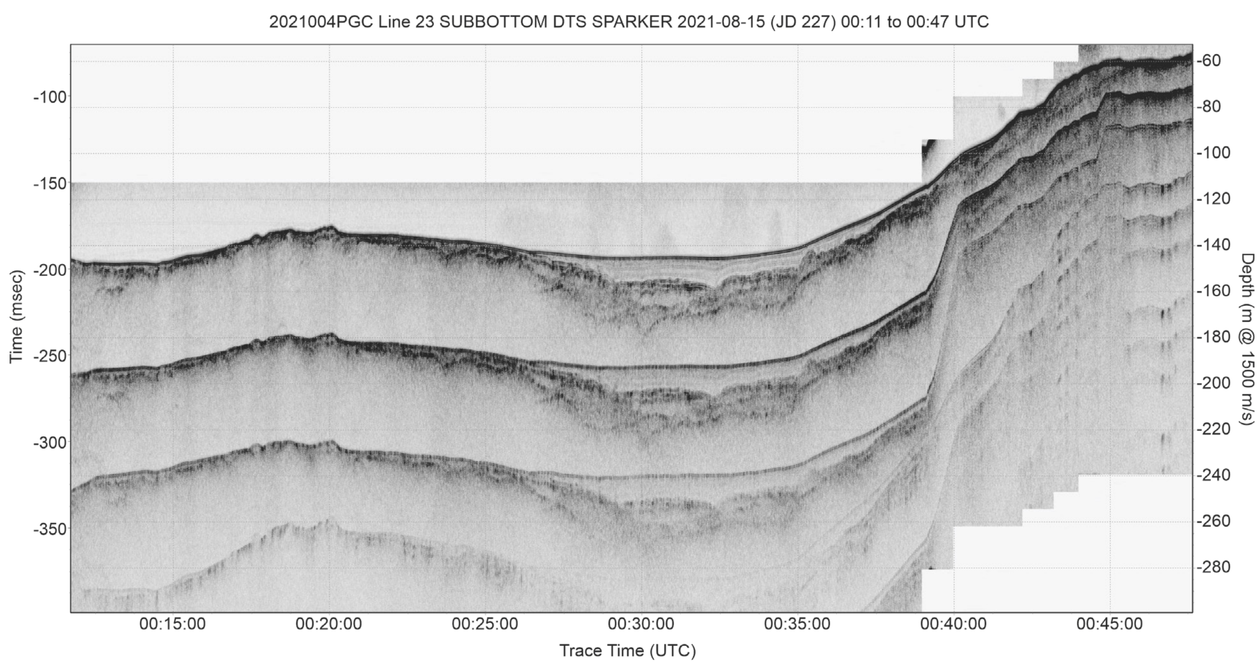

Figure 31. Deep-tow System Line 023 subbottom sparker data collected in the Strait of Georgia, near Cape Lazo, on 2021-08-15 from 00:11 to 00:47 UTC.

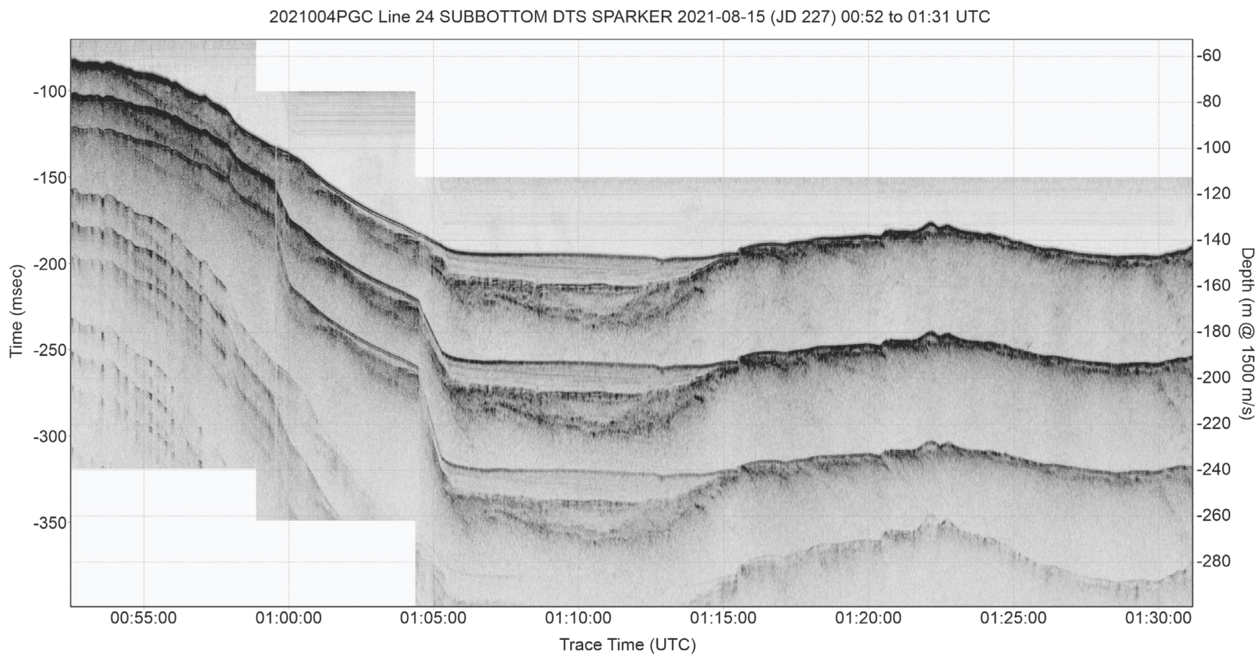

Figure 32. Deep-tow System Line 024 subbottom sparker data collected in the Strait of Georgia, near Cape Lazo, on 2021-08-15 from 00:52 to 01:31 UTC.

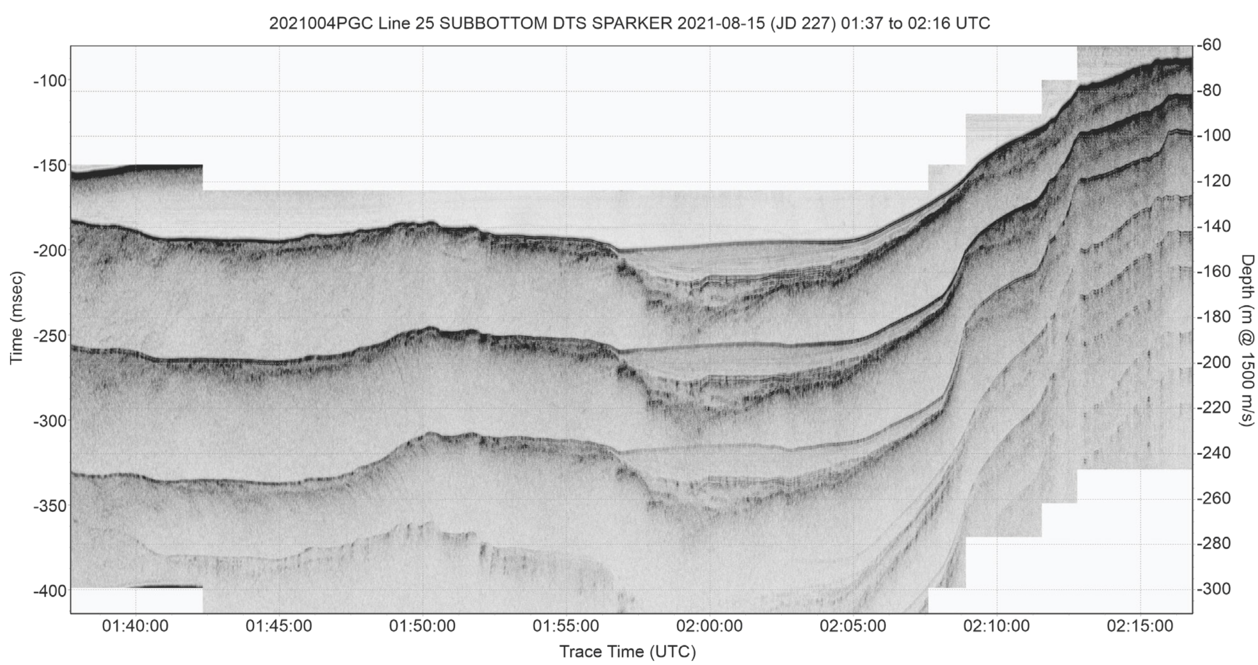

Figure 33. Deep-tow System Line 025 subbottom sparker data collected in the Strait of Georgia, near Cape Lazo, on 2021-08-15 from 01:37 to 02:16 UTC.

HOWE SOUND

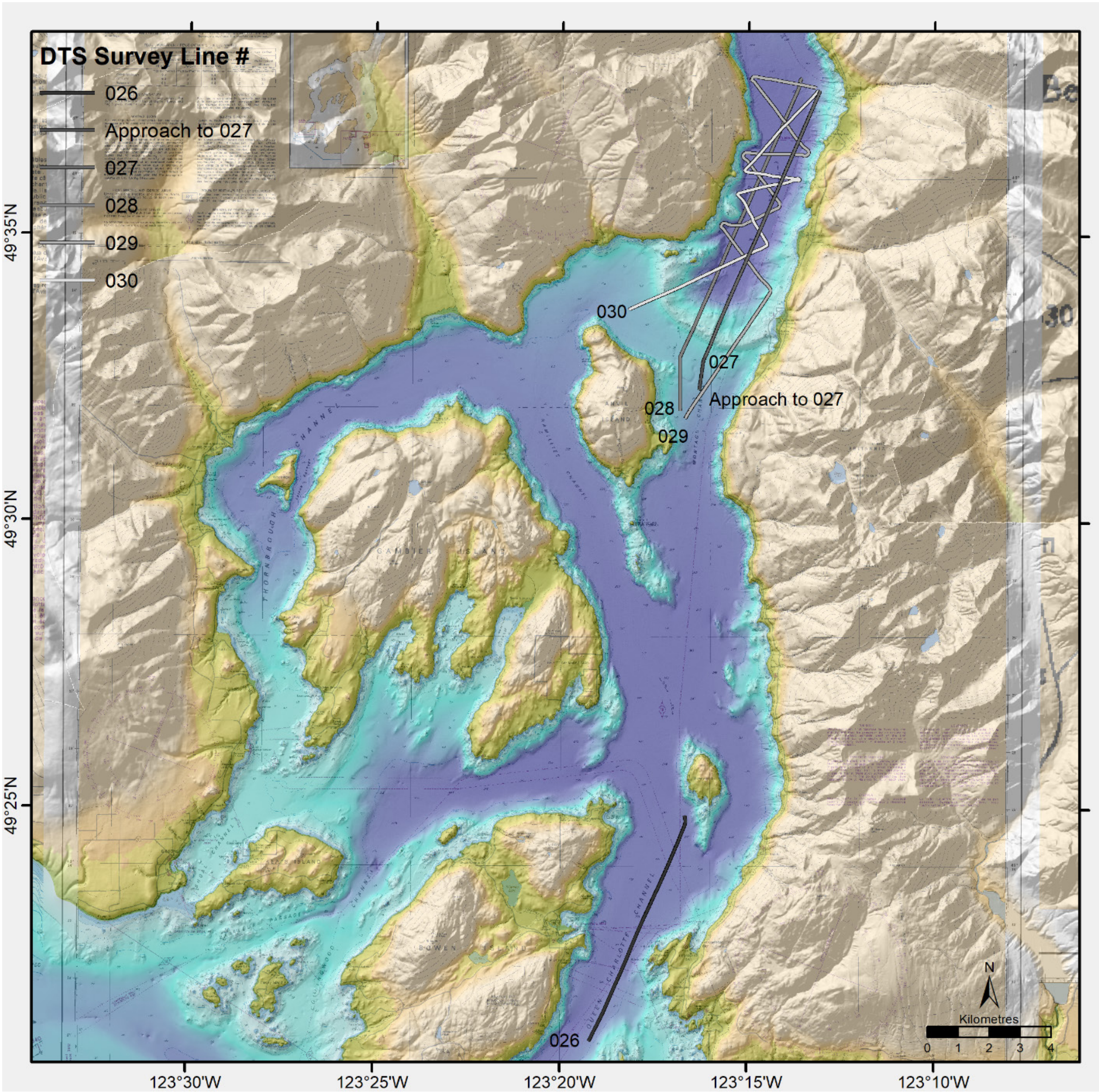

Figure 34. Howe Sound (lines 026-030). Basemap from Pacific Coast Digital Elevation model (Kung et al, 2021) and Canadian Hydrographic Chart 3526 (for illustrative purposes only, not to be used for navigation).

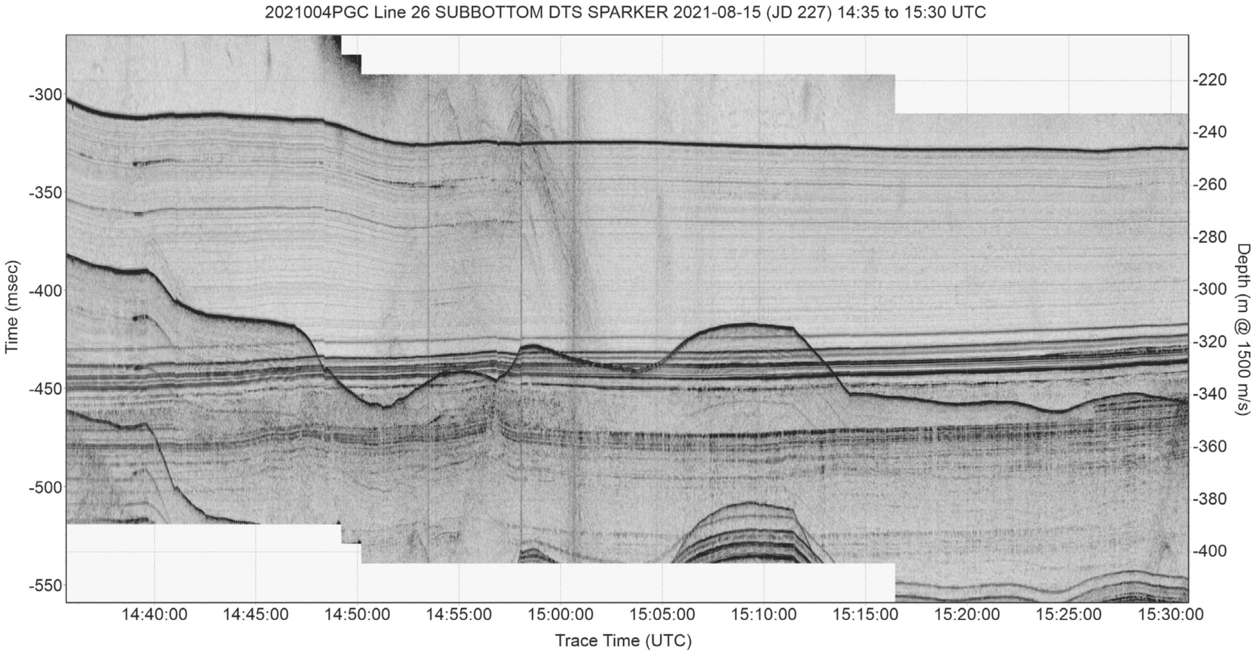

Figure 35. Deep-tow System Line 026 subbottom sparker data collected in Howe Sound on 2021-08-15 from 14:35 to 15:30 UTC.

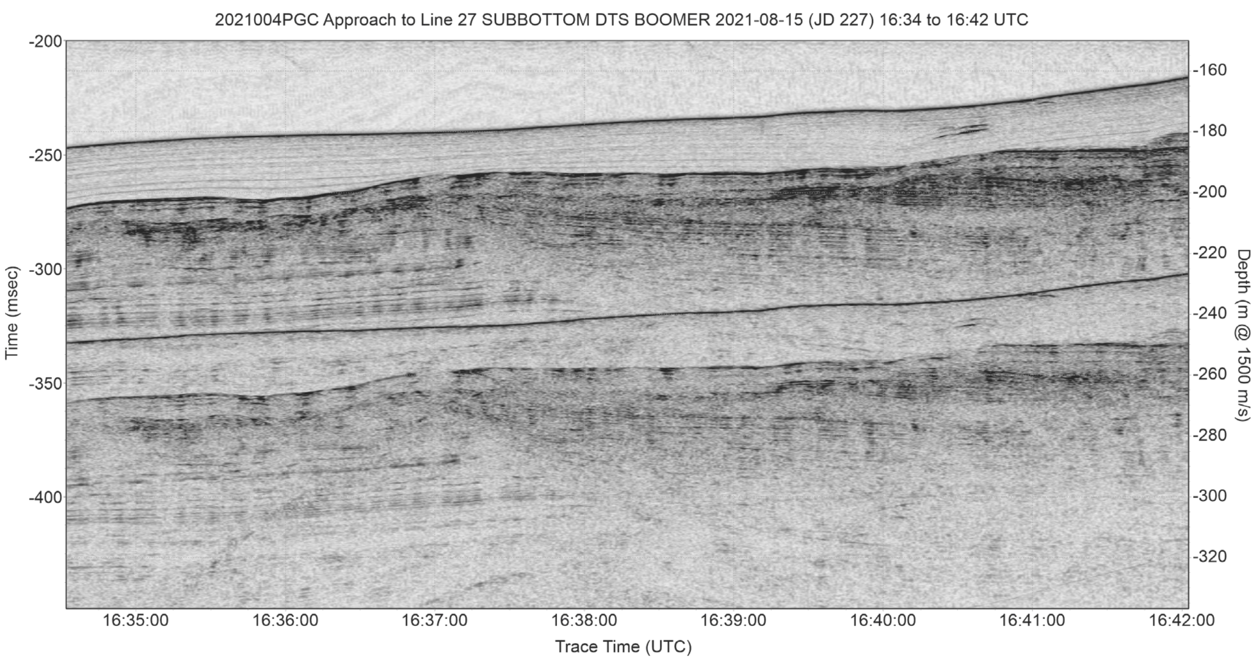

Figure 36. Deep-tow System approach to Line 027 subbottom sparker data collected in Howe Sound on 2021-08-15 from 16:34 to 16:42 UTC.

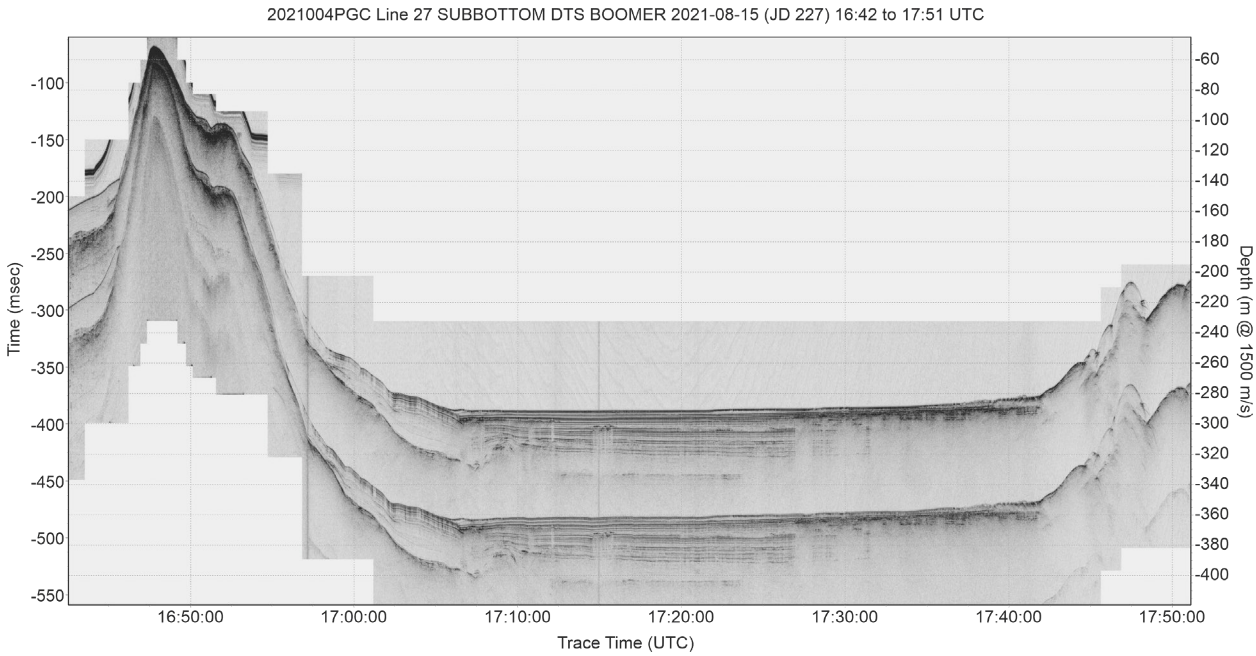

Figure 37. Deep-tow System Line 027 subbottom sparker data collected in Howe Sound on 2021-08-15 from 16:42 to 17:51 UTC.

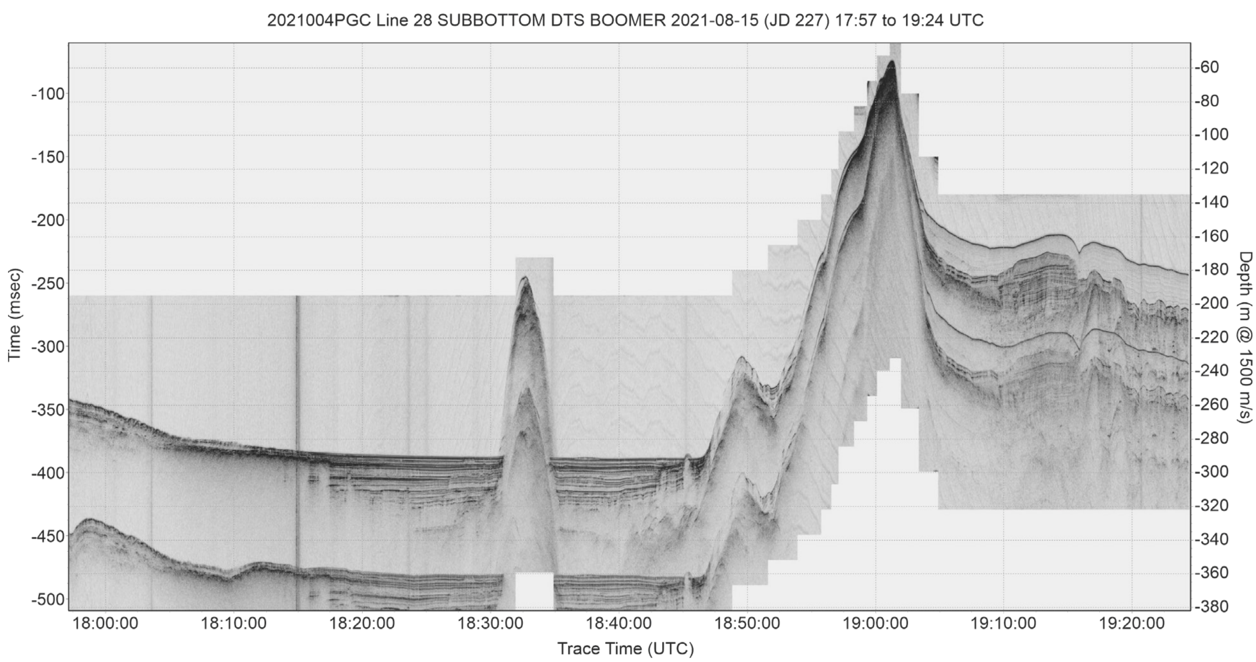

Figure 38. Deep-tow System Line 028 subbottom sparker data collected in Howe Sound on 2021-08-15 from 17:57 to 19:24 UTC.

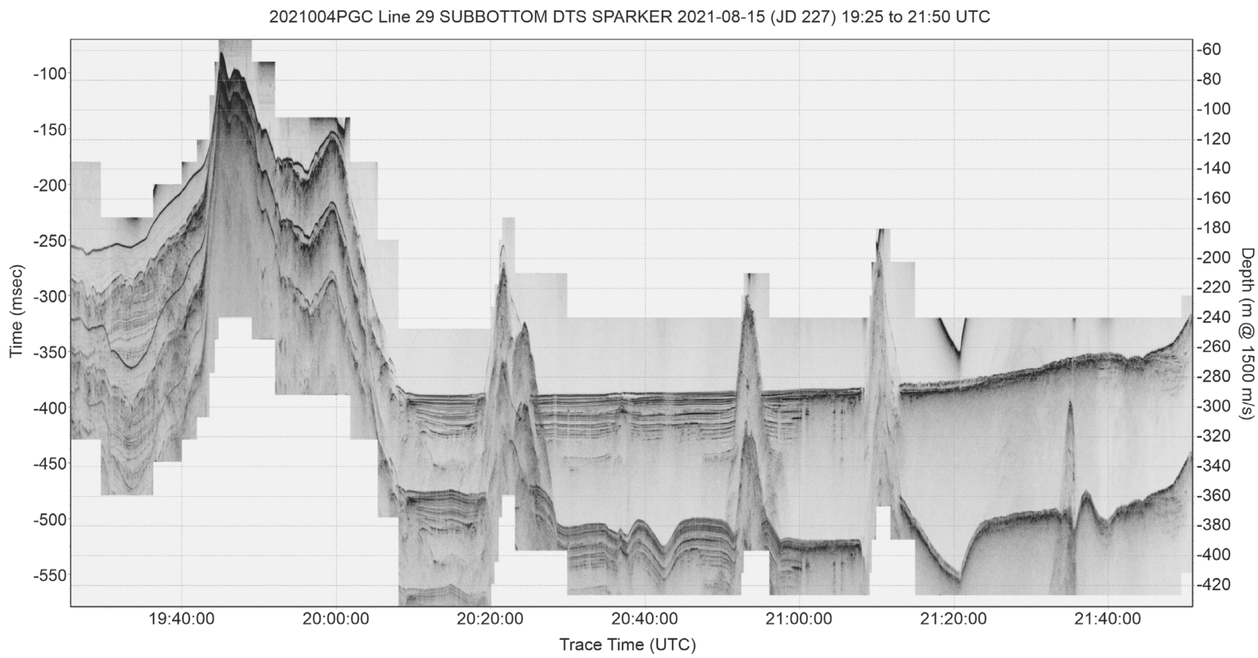

Figure 39. Deep-tow System Line 029 subbottom sparker data collected in Howe Sound on 2021-08-15 from 19:25 to 21:50 UTC.

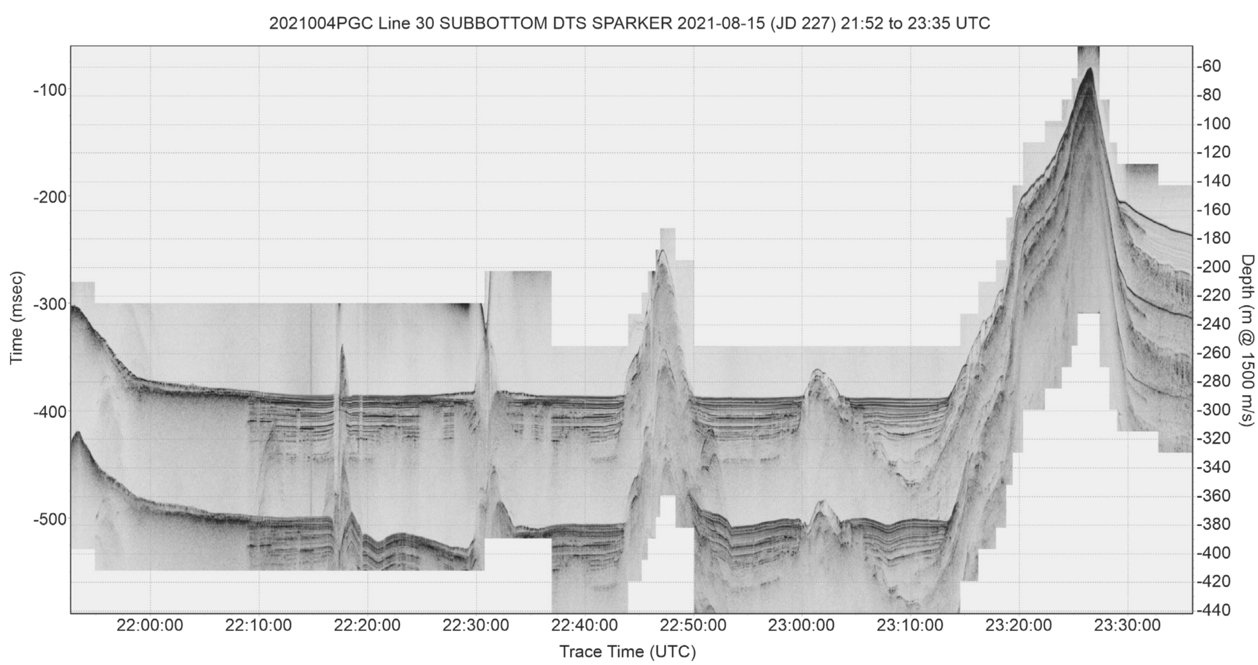

Figure 40. Deep-tow System Line 030 subbottom sparker data collected in Howe Sound on 2021-08-15 from 21:52 to 23:35 UTC.

BURRARD INLET

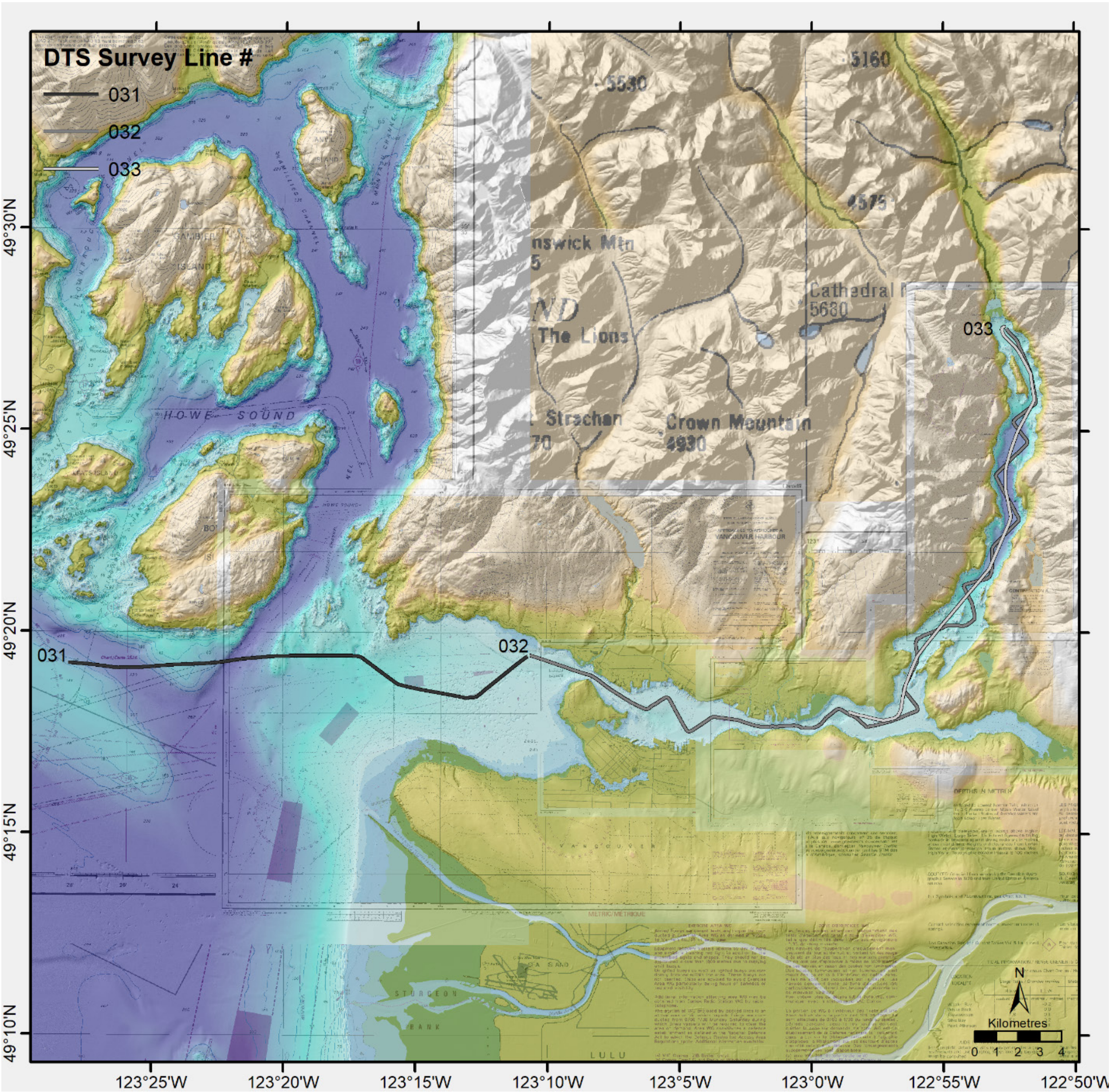

Figure 41. Burrard Inlet (lines 031-033). Basemap from Pacific Coast Digital Elevation model (Kung et al, 2021) and Canadian Hydrographic Charts 3463, 3481, 3493, 3494, 3495, 3512 (for illustrative purposes only, not to be used for navigation).

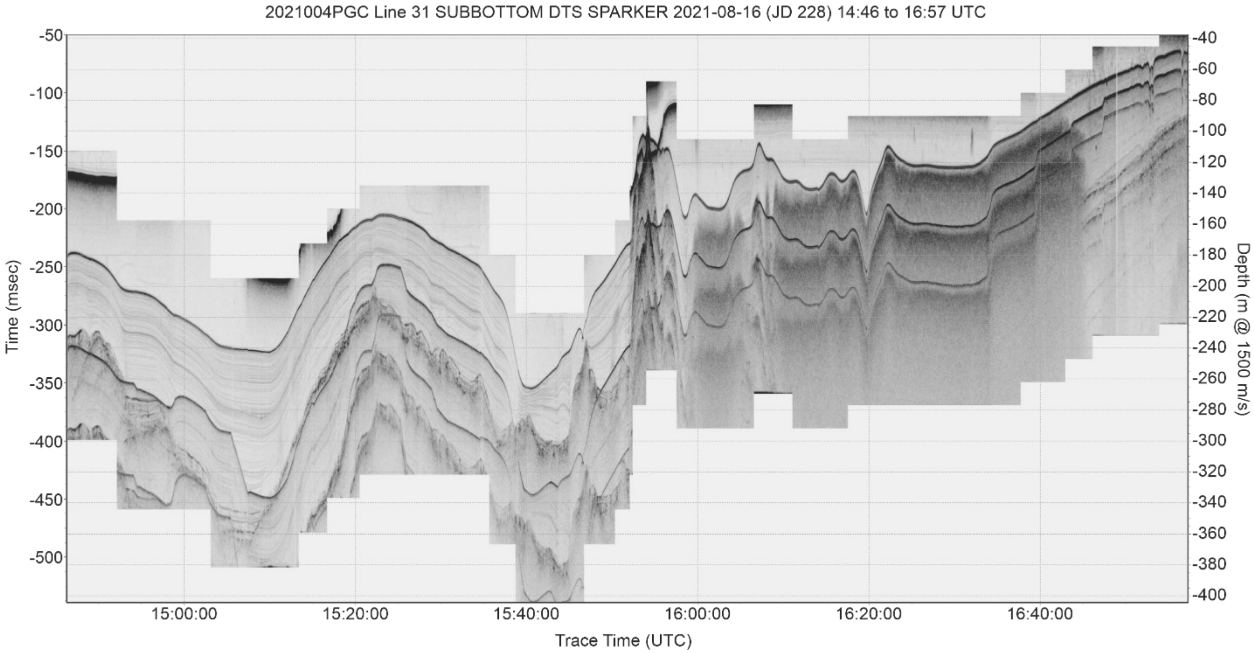

Figure 42. Deep-tow System Line 031 subbottom sparker data collected in English Bay on 2021-08-16 from 14:46 to 16:57 UTC.

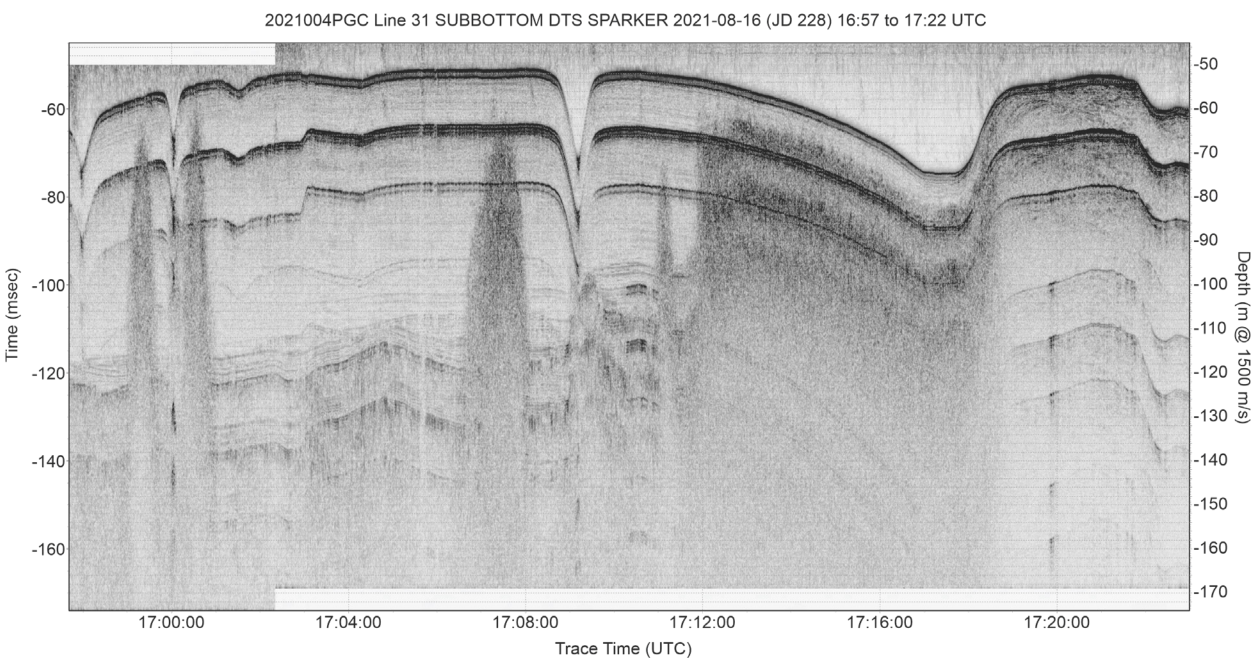

Figure 43. Deep-tow System Line 031 subbottom sparker data collected in Burrard Inlet on 2021-08-16 from 16:57 to 17:22 UTC.

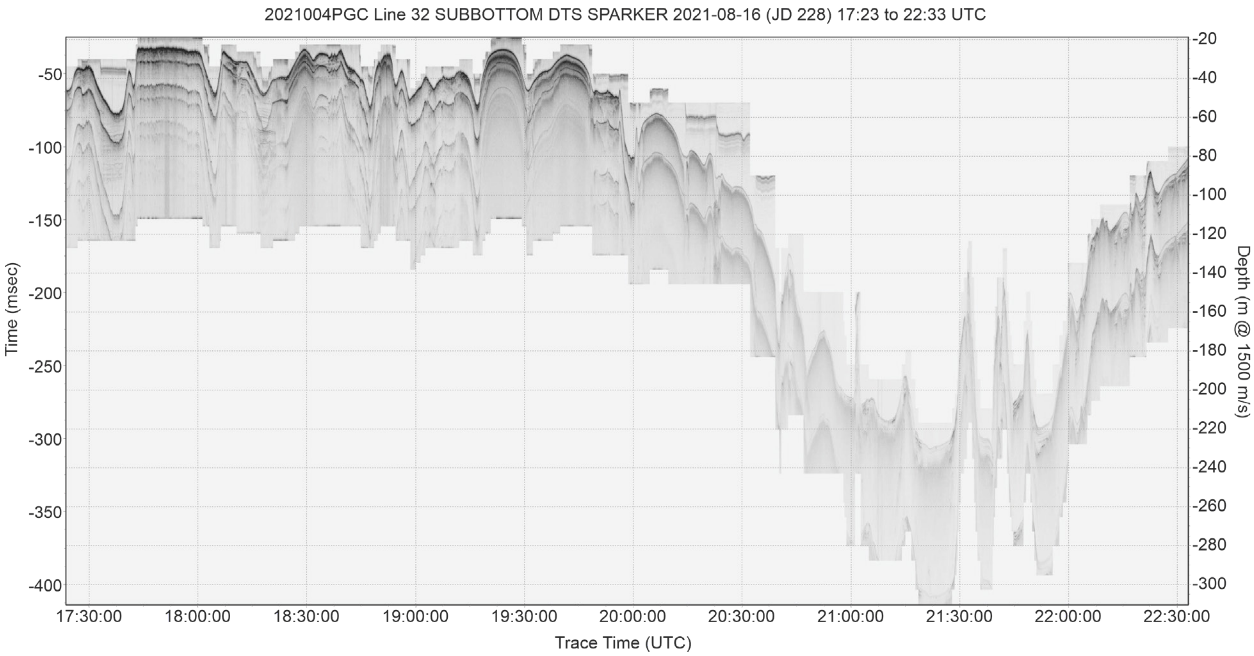

Figure 44. Deep-tow System Line 032 subbottom sparker data collected in Burrard Inlet on 2021-08-16 from 17:23 to 22:33 UTC.

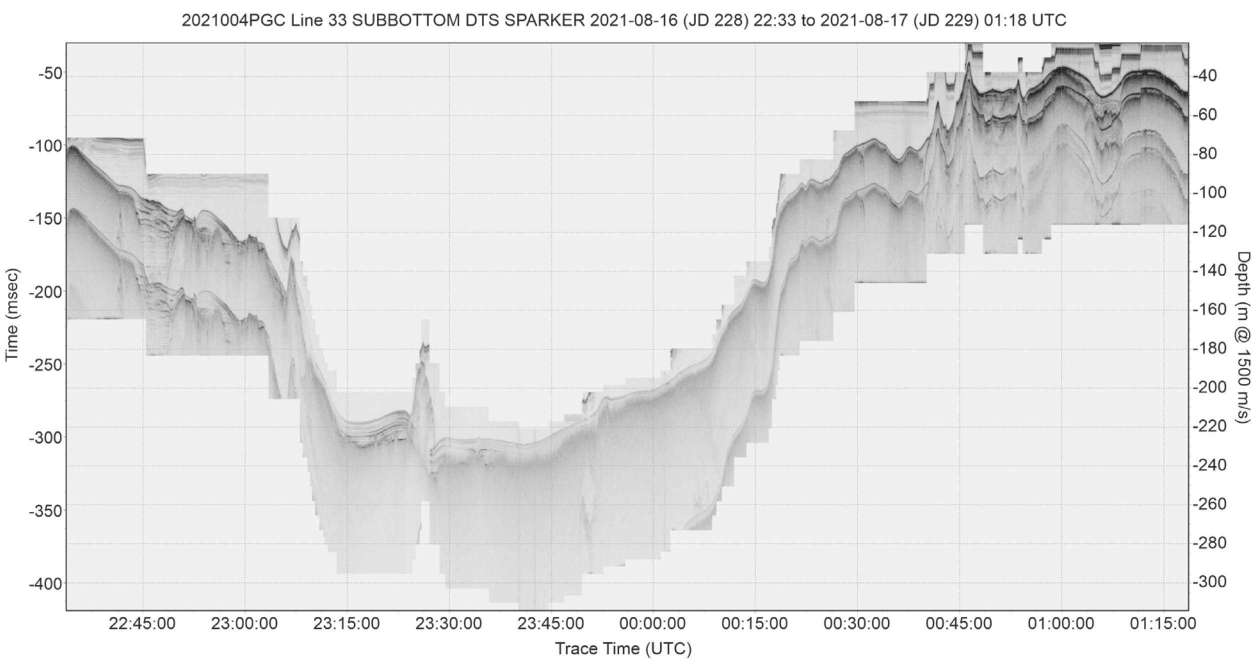

Figure 45. Deep-tow System Line 033 subbottom sparker data collected in Burrard Inlet on 2021-08-16 from 22:33 to 2021-08-17 01:18 UTC.

CENTRAL HARO STRAIT

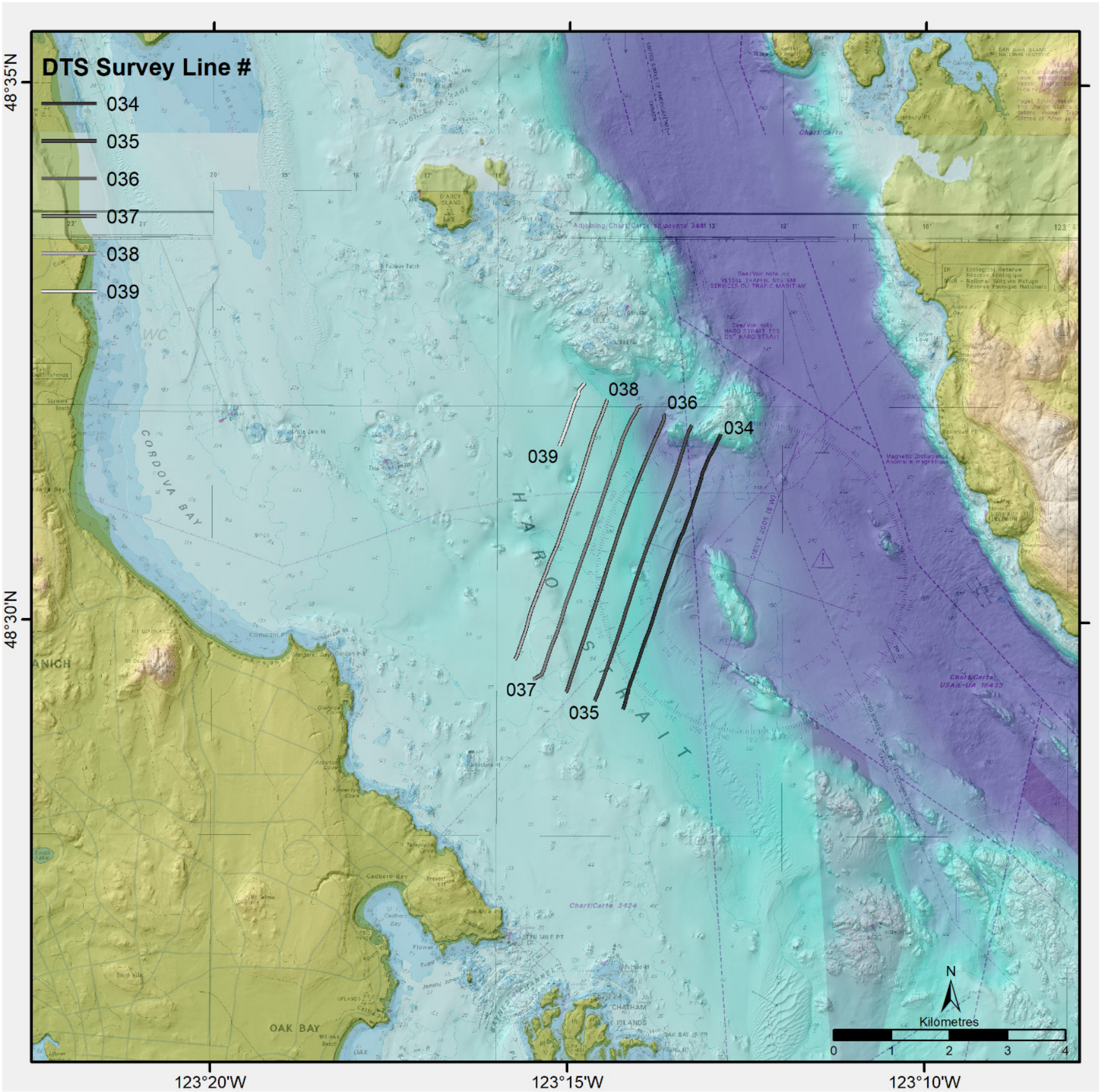

Figure 46. Central Haro Strait (lines 034-039). Basemap from Pacific Coast Digital Elevation model (Kung et al, 2021) and Canadian Hydrographic Charts 3440, 3441 (for illustrative purposes only, not to be used for navigation).

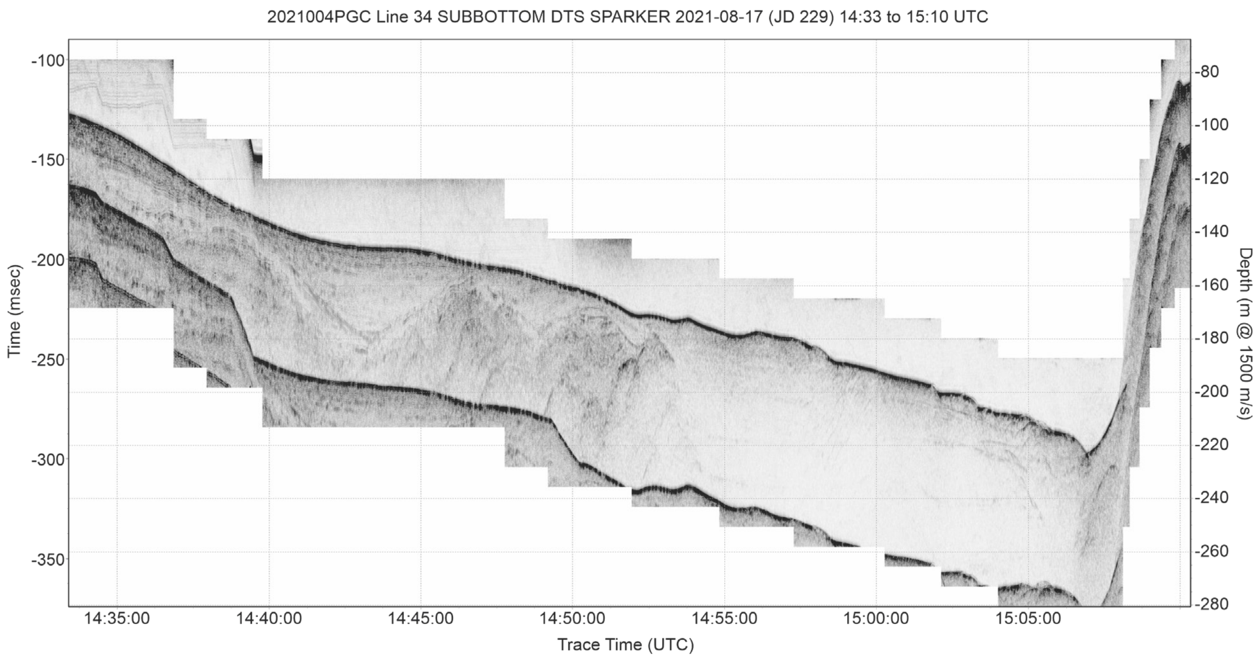

Figure 47. Deep-tow System Line 034 subbottom sparker data collected in Haro Strait on 2021-08-17 from 14:33 to 15:10 UTC.

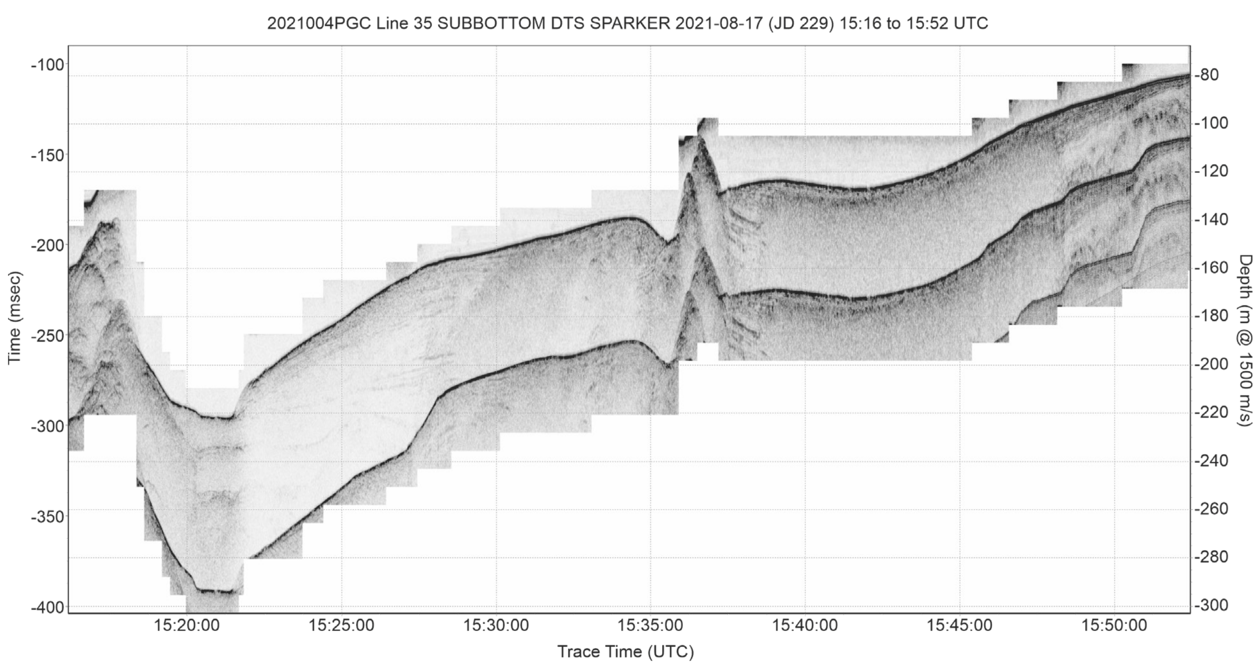

Figure 48. Deep-tow System Line 035 subbottom sparker data collected in Haro Strait on 2021-08-17 from 15:16 to 15:52 UTC.

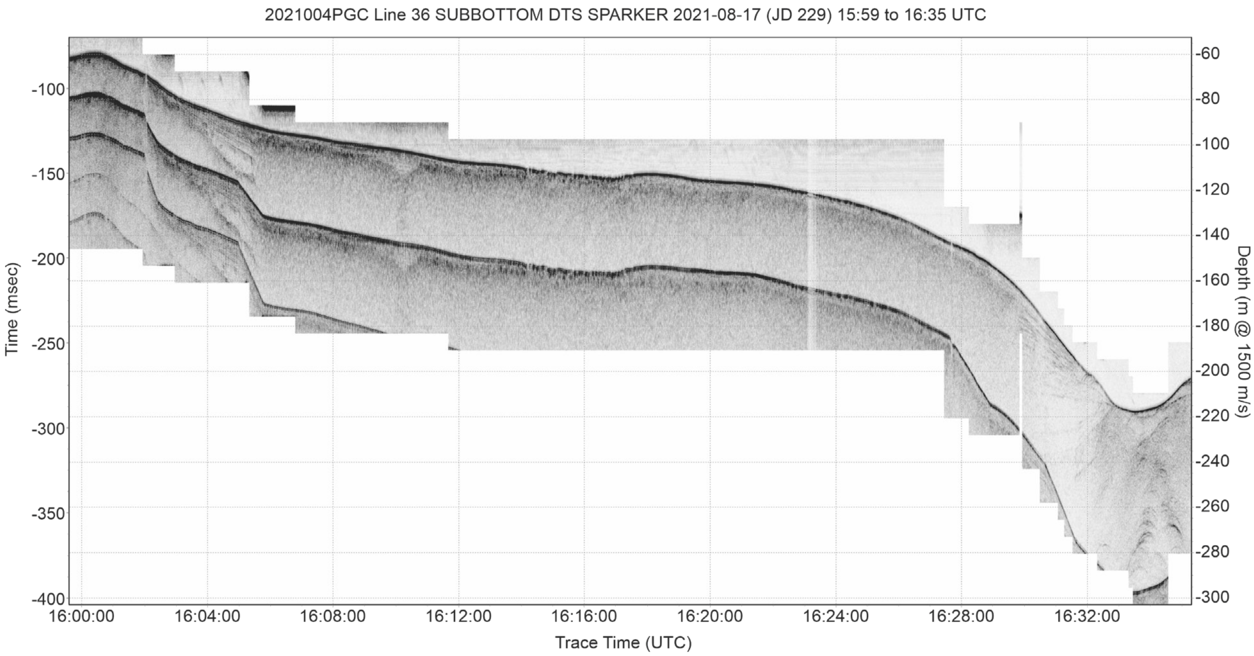

Figure 49. Deep-tow System Line 036 subbottom sparker data collected in Haro Strait on 2021-08-17 from 15:59 to 16:35 UTC.

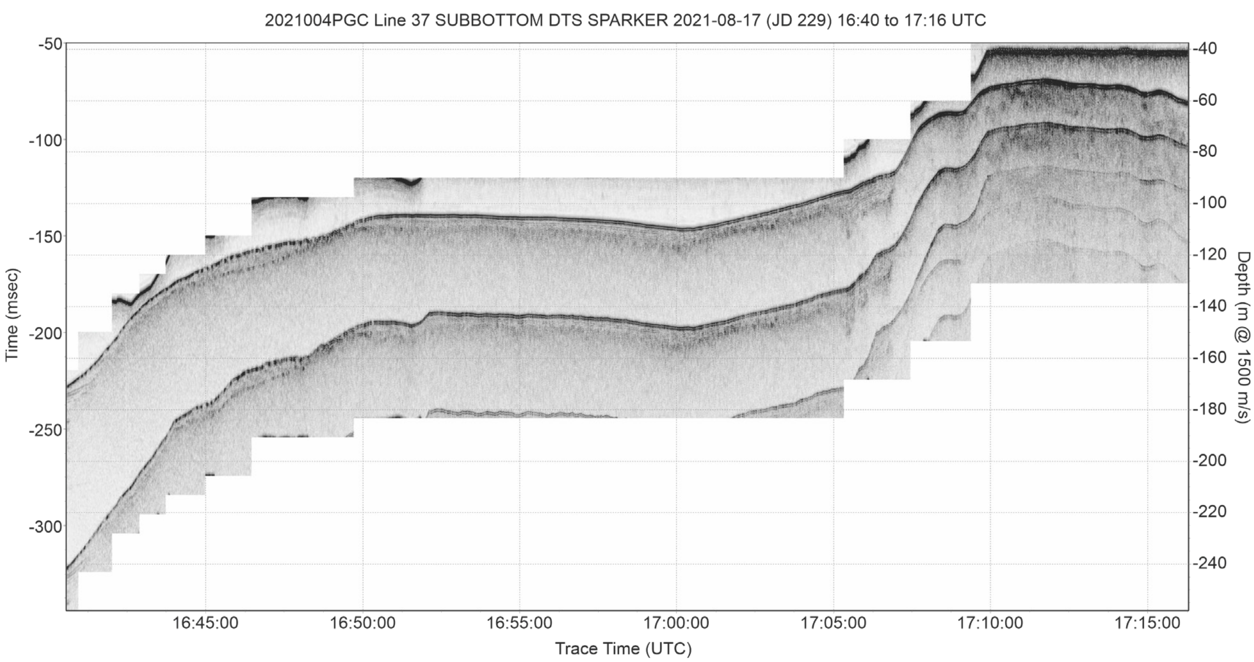

Figure 50. Deep-tow System Line 037 subbottom sparker data collected in Haro Strait on 2021-08-17 from 16:40 to 17:16 UTC.

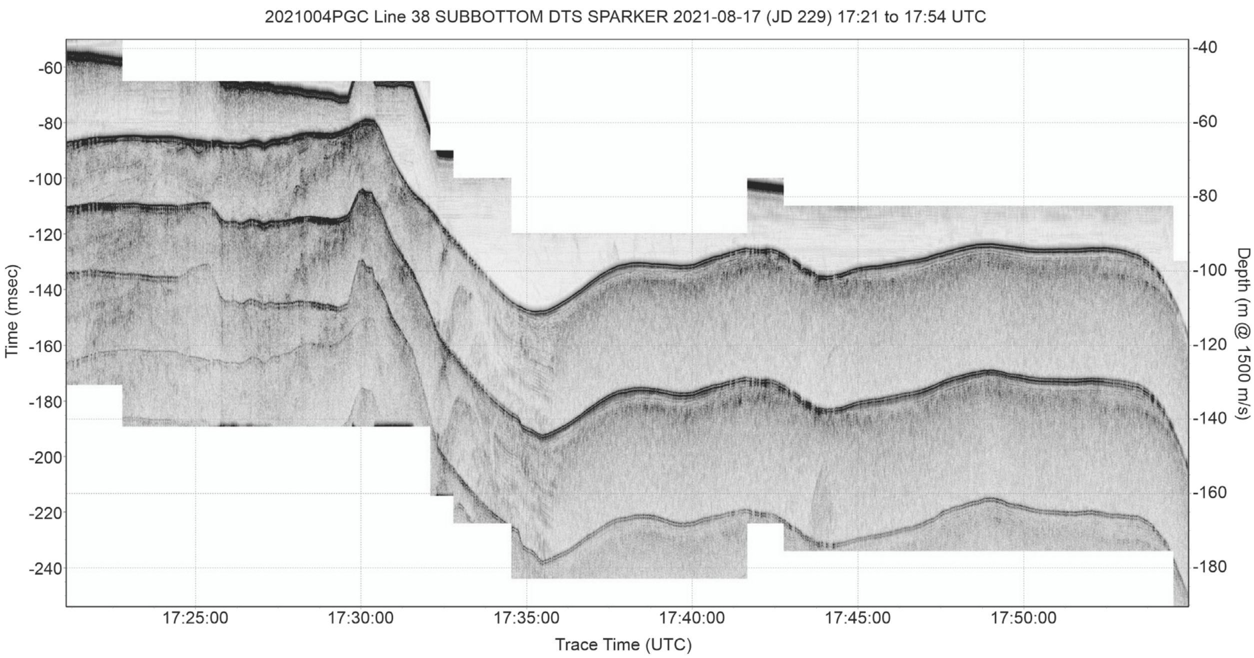

Figure 51. Deep-tow System Line 038 subbottom sparker data collected in Haro Strait on 2021-08-17 from 17:21 to 17:54 UTC.

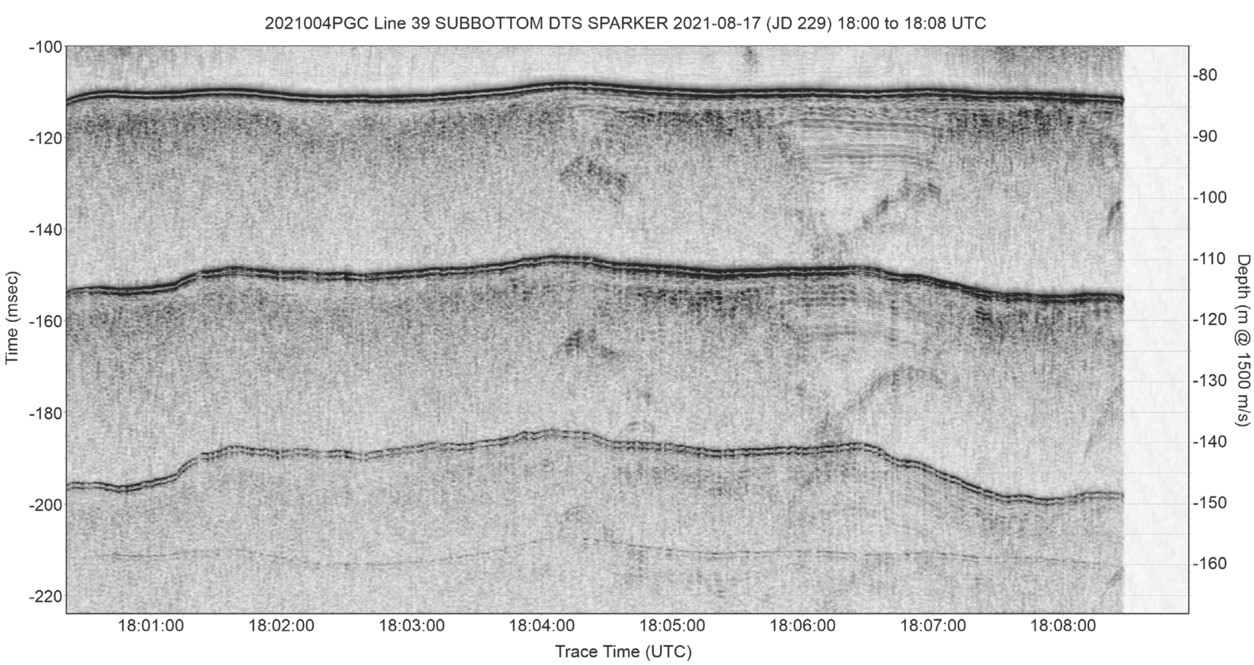

Figure 52. Deep-tow System Line 039 subbottom sparker data collected in Haro Strait on 2021-08-17 from 18:00 to 18:08 UTC. Transmission of instrument terminated at 18:08 UTC when Orca Whales spotted on horizon as per the marine mammal mitigation plan.

SANSUM NARROWS

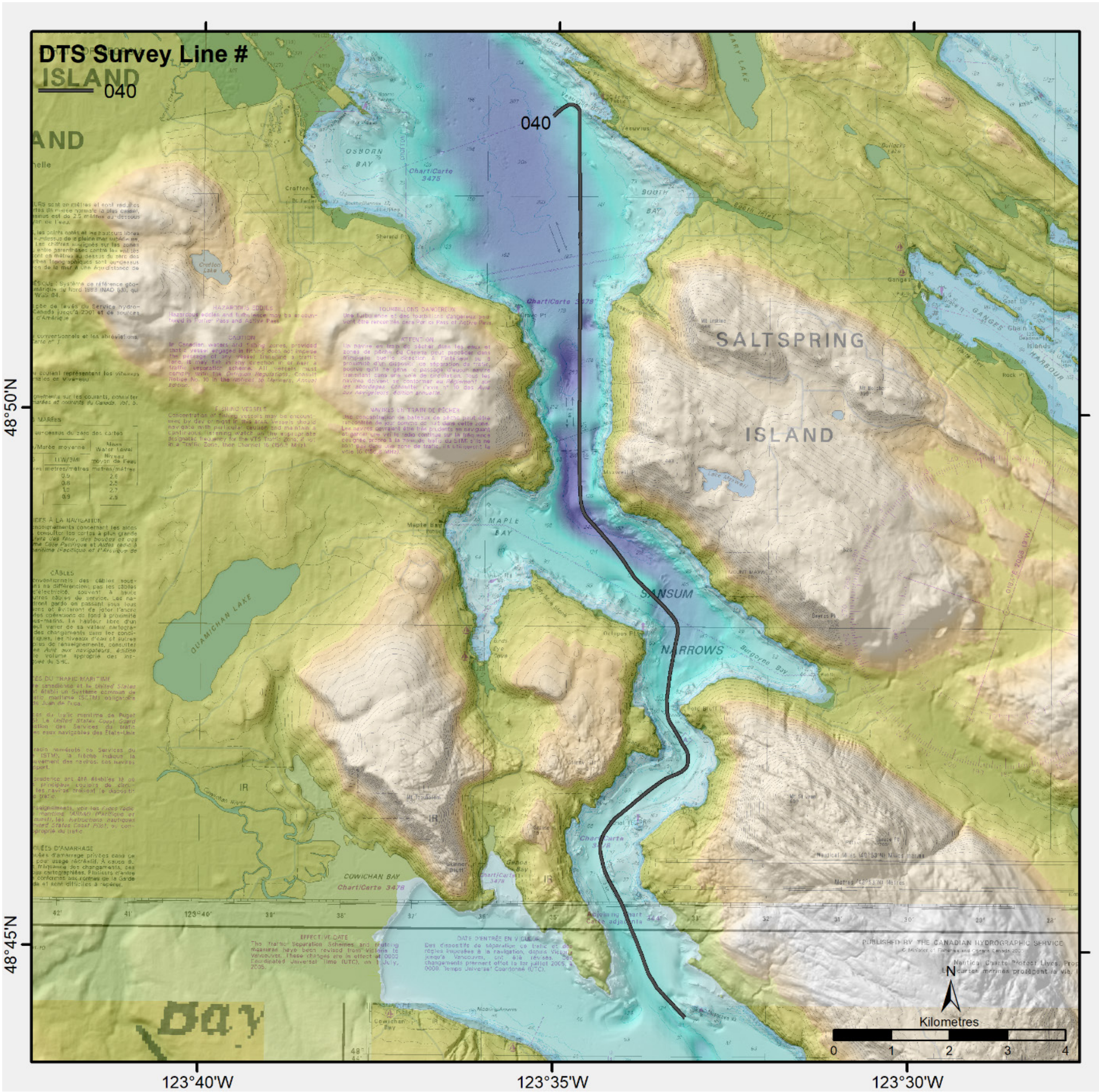

Figure 53. Sansum Narrows (line 040). Basemap from Pacific Coast Digital Elevation model (Kung et al, 2021) and Canadian Hydrographic Chart 3441,3442 (for illustrative purposes only, not to be used for navigation).

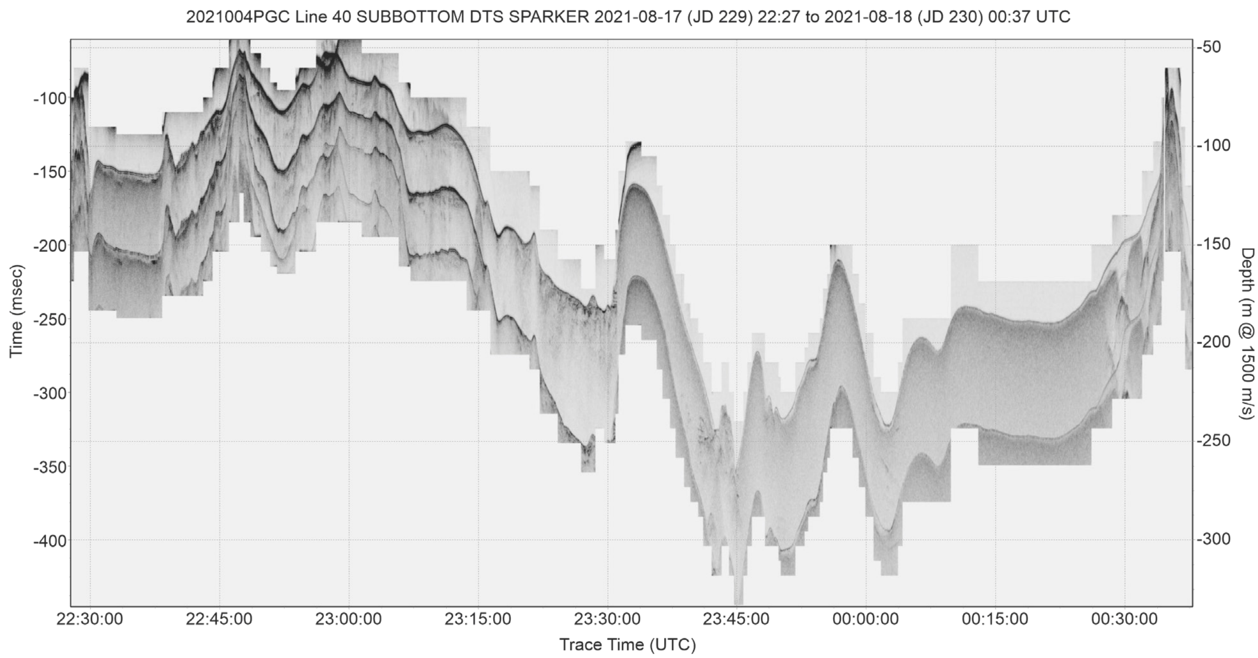

Figure 54. Deep-tow System Line 040 subbottom sparker data collected in Sansum Narrows from South to North on 2021-08-17 22:27 UTC to 2021-08-18 00:37 UTC.

Observations/Daily Summary:

2021-08-11 – Wednesday - Daytime Patricia Bay, Evening Pylades Channel

We Mobilized the CCGS Vector at the Institute for Ocean Sciences. Barrie, Koshure, Dill, Fralic, and Douglas boarded ~1300 PDT following rapid COVID testing. All equipment was onboard by 1900 PDT. The ship departed at 1920 PDT for Pylades Channel.

Night shift included a CHS hydrographic survey near Trincomali Anchorage 8 and transit back to Saanich Inlet. This area hadn't been surveyed since 1999 and will contribute to the MGMSP targeted assessment to look at the impact to the seabed from commercial anchorages.

2021-08-12 – Thursday - Daytime Saanich Inlet, Evening Pylades Channel

Weather was sunny, hot, and smoky; seas were very calm.

The objective for the day was to collect subbottom data in Saanich Inlet to image subsea landslides. In parallel with this work in Saanich Inlet, an acoustics experiment was carried out to determine the sound exposure levels of the DTS in a fjord setting. This was organized in partnership with the Malahat Nation, led by Andrew Sheriff of Malahat, DFO represented by Svein Vagle, and Gwyn Lintern representing the GSC. The evening objective was to collect multibeam bathymetry data in Pylades Channel, completing the survey near Trincomali Anchorage 8.

At 0700 PDT, our Marine Mammal Observer, Nicole Koshure, started a 30 minute visual survey for marine mammals in Saanich Inlet while the ship positioned in a central deep section of the inlet. No marine mammals were sighted during that time.

The Malahat Nation setup station with their vessel and a vertical hydrophone array in Coles Bay and later Christmas Point to record the DTS survey.

In order to triangulate the position and range of the DTS sound relative to the vertical array of hydrophones for the acoustics experiment, relatively accurate positioning is needed. We noted that the winch doesn't provide payout of line, so for positioning without USBL available, we added electrical tape to the wire at intervals to provide a triangulation of the DTS position at 45 degrees with the depth of the towfish. Positioning provided in the DTS files comes from a CHS attitude and heave feed. We altered the offsets from the ship's Inertial Measurement Unit (IMU) in the CHS POSMV software feed to use a position at the centre stern of the vessel at the waterline. Those values are x = -26.675, y = -0.211, z = -1.927, where x is positive toward the bow, y is positive toward starboard and z is the vertical with positive down. X was determined using the aft most measurement on the survey sheet and the scale bar adding 2 m to the stern. Y was determined as the measured offset of the IMU to the centre of the vessel. Z was determined as the measured water line by hydrography prior to departure. Although Z will vary slightly with ship draft, this uncertainty is expected to be minimal in comparison to the uncertainty in the Huntec towfish position calculation. Towfish depth is embedded in the SEGY files.

Starting with the powered-down towfish at surface, we started to mark out the winch wire with electrical tape. Every 10 m was marked out with a different colour. Every 2 m was marked with black electrical tape. The colours and metres out are as follows:

Number of stripes	I	II	III	IV
White	10	60	110	160
Blue	20	70	120	170
Green	30	80	130	180
Yellow	40	90	140	190
Red	50	100	150	200

When we got to 180 m, the winch power pack shut down without warning. The Ship's Engineer and Tom Fralic, our Geoforce Technician, tried troubleshooting and eventually temporarily resolved the issue by pressing the reset button hard as the first softer attempt didn't work.

At 0902 PDT, we put the DTS in the water and started ramping up sound starting at 2 kV on the way to the start of the inlet perimeter line. At 0912 PDT, we stepped up to 3 kV, and at 0931 PDT we stepped up to 4 kV. We started the survey with 84 m of wire out at 0933 PDT in sparker mode.

The West side of Saanich Inlet started off with not much acoustic penetration in the North, but as we went South, we started to see more structure. Just north of 48.5653, we saw what could be slide structure. The angle of slope is much less steep than the walls of the bluff to be a continuation of bedrock. Further south of that, we passed evidence of two potential faults. One, in the expected location off McKenzie Bight. The second, at Elbow Point. The West line shows gas brightening at the fault locations. The East line has a slight indication of displacement.

After the perimeter survey, we completed some East-West cross lines. We added one at the potential slide location, in consultation with Cooper Stacey on shore, and removed a few in the North where we didn't think we would get much penetration. We also added a short extra line through the middle of the two potential faults and back along strike of the inlet.

The Malahat Nation finished their hydrophone survey at 16:46 PDT. Of interesting note, Andrew Sheriff sent a message at 16:12 PDT that they had just stopped hearing the ticking of the DTS through the Malahat hull at that time from Coles Bay. The CCGS Vector was mid-Inlet a little further south at that time. It would be interesting to calculate the distance from our location to theirs at that time.

We finished surveying at 1840 PDT, recovered the DTS, and started transit toward our evening CHS hydrographic survey target in Pylades Channel. CHS completed the survey (Figure 5) throughout the evening hours.

2021-05-13 – Friday - Daytime Stuart Channel, Evening Point Grey, transit to Cape Lazo

Weather was sunny with heavy wildfire smoke increasing throughout day, seas calm.

Objective for the day was to collect subbottom data in Stuart Channel to investigate sediments surrounding deformed Nanaimo Group bedrock for evidence of recent fault activity and any potential relation to the Skipjack Island Fault Zone.

Our Marine Mammal Observer completed a visual survey between 0700 PDT and 0730 PDT with no orcas observed and no other marine mammals within the radius.

We deployed the DTS towfish at 0736 PDT. There was an issue with the winch during launch. The winch strained to pick up the towfish off the deck. To resolve this, we turned off the power pack and disabled the remote. Tom worked directly from the winch for launch and it worked after that. The winch power pack was having some issues with cutting out and the reset button was required when operating for long periods of time. There is also an issue when the fish comes to surface and the weight comes off the line, the winch stops. The workaround for that is to bring the throttle to neutral and then it will go up again once moved. As such, it's recommended that the DTS winch undergoes some maintenance after this trip. The issues to look at are that the cable is jumpy, the power pack cutting out (later fixed by the Engineer, but could be checked over once off ship), and it is lacking a cable counter which would be helpful for depth.

We started up towfish at 0742 PDT at 2 kV in boomer mode. The lowest power gave good resolution so we stayed with that for a while.

There was no evidence of deformation in the reflectors crossing Ruxton Passage.

Line 006 provided nothing of note. We see glaciomarine units at start of line leading to gassy sediment going south past Ruxton.

We restarted the zig-zag route down Stuart Channel a few times due to competing vessel traffic along the preferred track. We stayed slightly west of line for navigation safety with the reef to the East.

At 1220 PDT, the navigation feed from the POSMV started to drop out as seen in the DTS data acquisition software. The Kongsberg SIS software was also periodically flashing red. The issue was resolved by rebooting the computer and processing unit. Navigation feed resumed at 1320 PDT.

At 1422 PDT, we switched from boomer to sparker mode to get more penetration.

Line 13 looked like had the best potential for picking up deformation based on its morphology. The channel is too gassy to see below. There is no strong evidence observed for Holocene faulting above bedrock deformation in the bathymetry morphology. Therefore, it is assumed that this is a pre-Holocene tertiary fault. We need to review the data to confirm this back in the lab, as there was nothing that stood out suggesting this is an active fault at the time of data collection.

We see what looks like bedrock along axis of basin in three places with gassy sediments in between. It's possible that South Stuart Channel (South of Penelakut Island) is made up of 3 sub-basins.

We finished surveying at 1852 PDT, recovered the DTS, and started transit toward our evening CHS hydrographic survey target off Point Grey via Porlier Pass.

Due to the power pack cutting out on the Huntec winch, all were starting to get a little concerned about the possible scenario of it cutting out and not resetting with the towfish in the water and we decided to ask the Ship's Engineer to try to understand the cause and risk of this happening to determine next steps. With the faceplate off, we noted that sparking was occurring near the fuses when booting up. The Engineer took apart the thermal fuses on the power pack, cleaned the connectors and tightened everything up. The sparking stopped. The winch pulls were tested a few times and all seemed to be working well by 2130 PDT. Perhaps something loosened up between testing and mobilizing the winch on the ship. The issue remained resolved for the duration of the expedition.

2021-08-14 – Saturday – Daytime Cape Lazo, nighttime Point Grey

Weather sunny, smoke moderate, and calm seas (sea state 1-3 Beaufort).

Objectives for the day included collecting DTS and multibeam water column data over a grid of lines oriented SW to NE across the scarp feature in the bathymetry data just south of Cape Lazo to confirm potential fault and determine strike and extent.

At 0700 PDT, Orcas were spotted 4 km from survey area close to shore. 2 humpback whales were also spotted out of range and as were 2 Dall's Porpoises. Surveying was postponed until the Orcas moved on and the other marine mammals remained out of range. By 0755 PDT, we had 30 minutes with the safety radius clear of marine mammals and no Orcas on the horizon. We launched the towfish going 2 knots, 10 minutes from the starting waypoint to allow for gradual ramp up of sound starting at 2 kV.

At 0804 PDT, we ramped up to 3 kV and sparker mode and started line 014.

Line 14, the first line of the day shows strong definition of fault with survey lines perpendicular to strike. The fault trace is visible into the subsurface when gain is enhanced using Kingdom Suite software.

Line 18 provides a good location for coring.

Within our survey area there is a 1-2 km wide deformation zone with evidence to surface or near surface suggesting that it's active. There are discontinuous reflectors and possible flower structures as observed in the parallel survey lines along with deformed reflectors that splay up and outwards. There is a slight morphology in the form of a shallow valley. Morphological character is similar to the Devil's Mountain Fault Zone (Barrie and Greene, 2018) but the valley is less pronounced.

Previously named the "Cape Lazo Fault Zone" in Barrie et al (2021), this is likely a transpressional fault that appears to have some length to it. The strike of the fault is the same as for a fault seen in the 82003PGC airgun data off East Hornby and the older Huntec data off South Hornby down to Parksville. If connected, that length alone is ~ 60 km. It may continue up along the same strike towards Campbell River in the shallows as well. We would require a shallow multibeam and a shallow-tow system to determine the shallow water continuation of deformation. There is oral history of subsidence along nearby coastlines following the 1946 earthquake that would be along strike. We will communicate with the Komoks' Nation in this regard to ask if there is traditional knowledge of this event.

We finished surveying at 1916 PDT, recovered the DTS, and started transit toward our evening CHS hydrographic survey target off Point Grey

2021-08-15 Sunday – Daytime Howe Sound, Evening Point Grey

Weather sunny, moderate smoke, seas calm, light breeze.

Objectives for the day include collecting DTS and water column data in Howe Sound over known slide areas in the North end for Cooper Stacey.

Starting West of Horseshoe Bay, at 0659 PDT, our Marine Mammal Observer began a visual survey for marine mammals from the bridge. The towfish was deployed without transmitting at 0715 PDT to be prepared to begin surveying when possible. The "all clear" was received from the Marine Mammal Observer at 0729 PDT and we began ramp up of sound starting at 2 kV on boomer mode with line 26. The data show that we're getting good penetration of continuous reflectors. At 0758 PDT, both BC Ferries started heading toward Horseshoe Bay and their noise interfered with the DTS data until they were around the corner in Horseshoe Bay. Ferry schedules should be considered in future survey planning.

We pulled the towfish just North of Bowen Island at 0831 PDT to increase speed to the Britannia Sill. Marine Mammal Observing was ongoing on the way as we would be operating in the same visible general area. At 0939 PDT, we deployed the towfish back in the water and ramped up sound gradually.

The approach to line 027 shows a notable "textbook" fault in the Quaternary lower post-glacial unit covered by Holocene mud while heading North just south of Britannia Sill. We checked the older airgun data and noted that while navigation appears to not align on the airgun with the sill, we can follow morphology and bathymetry to find a similar location with some minor displacement of reflectors in 89010PGC Line 207 at shot point 34849 and 86008PGC Line 23_223 shot point 5643 or 5249. The displacement is minor and so with airgun data, the resolution is almost too coarse to capture it.

We carried out the perimeter survey in boomer mode with the assumption that the aim was to get good resolution of data for landslide research. Line 28, west of Minety Bay, we see gas brightening in the DTS data and plumes in the water column data (Multibeam line 005 from the Howe Sound Project). Depth is 279 m. After conversation and exchange of images with Cooper, we shifted settings to sparker mode to get better depth penetration for determining unit thicknesses for the zig-zag survey.

Zig-zag survey terminated at end of line 30 at 1636 PDT just SW of Brittania Sill.

We recovered the DTS, and started transit toward our evening CHS hydrographic survey target off Point Grey at 1642 PDT.

2021-08-16 – Monday – Daytime English Bay and Burrard Inlet, Evening Point Grey

Weather rainy, low visibility, calm seas, winds light

Objectives for the day include collecting DTS and water column data in Burrard Inlet on behalf of Gwyn Lintern to better understand the geological units of the inlet and to better understand the mechanism for pockmarks in English Bay.

The Marine Mammal Observer performed the visual survey from 0700 to 0730 PDT. With the safety radius clear, at 0733 PDT, we put the towfish in the water just South of Bowen Island and at 0745 PDT started line 31 due East at 4.5 knots.

The DTS had good penetration and resolution heading towards English Bay with all of the Holocene visible down to glacial units. Tom adjusted the fish depth to try and keep the multiple inside the Holocene unit and out of the unit contact. Not much of note was observed around the pockmarks other than what appears to be a bowtie reflector almost exactly due West of Point Grey.

We switched to boomer mode for Burrard Inlet as we expected it would be too shallow for sparker to be effective.

Just as we came into the inlet from the Narrows, we saw unexpected dipping reflectors in the upper unit that look interesting but the cause is not apparent.

There are small disruptions in the reflectors by Lonsdale Quay.

As traffic is an issue in Burrard Inlet for effective route planning, we suggested that the Captain zig-zag along the inlet and up Indian Arm so that we can get unit thicknesses and then come back down the middle of the inlet. This was effective and good quality data were collected.

At the head of Indian arm leading up to Granite Falls, we have good penetration of the subbottom with ~10 m of upper post-glacial, ~5-10 m of lower post-glacial down to till or bedrock.

We recovered the DTS, and started transit toward our evening CHS hydrographic survey target off Point Grey at 18:18 PDT. The multibeam bathymetry survey at Point Grey (Figure 5) was completed during the evening hours.

2021-08-17 - Tuesday – Daytime Central Haro Strait, Sansum Narrows, Evening return to IOS.

Weather overcast with sunny periods, calm seas.

The objective for the day was to collect subbottom data to image sediment deformation in Central Haro Strait tracing the Central Haro Strait Fault Zone from the previously surveyed known fault area to where it may continue towards the West.

Our Marine Mammal Observer began the visual survey for marine mammals at 0650 PDT. The DTS was deployed at 0719 PDT and ramp up of sound started once confirmation was received that the 30 minute survey was clear.

At 1045 PDT, we were informed by whale watching vessels on the horizon that Transient Killer Whales were present but travelling in a direction away from our location. Our Marine Mammal Observer informed us that the whales were not in our line of sight on the horizon. As such, we continued surveying while diligently keeping watch as per our mitigation plan.

At 11:08 PDT, Our Marine Mammal Observer informed us that Killer whales had switched direction and were just spotted on the horizon and DTS transmission was shut down immediately.

We maintained watch until after lunch and then made the decision with more marine mammals moving into the area, to leave Haro Strait for another study area without expected marine mammal activity. We transited to Sansum Narrows and following visual survey, collected one line of data from South to North through another suspected branch of the Skipjack Island Fault Zone.

South of Burgoyne Bay at Bold Bluff, we observed what looks like vertical displacement of rock on shore. There are some displaced reflectors in the subsurface data.

DTS surveying ceased at 17:48 PDT.

Acknowledgements:

We thank the Salish Sea Nations whose traditional territory on which we conducted these surveys for their participation and support in planning and carrying out this expedition effectively. The Wei Wai Kum Nation and Tsleil Waututh Nations helped us in choosing a suitable time to mitigate impacts on fish lifecycles. The Malahat Nation participated in a joint study on calculating the sound exposure levels produced by the experiment by collecting the hydrophone data. Many others provided valuable feedback and we hope to continue to work together on the many aspects of marine geoscience.

We thank our colleagues who helped make the logistics of this expedition come together.

Lastly, we would like to thank Captain Dustin Flahr and the crew of the CCGS Vector for their part in the safe operation of the ship without which this expedition could not have been a success.

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