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GEOLOGICAL SURVEY OF CANADA
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CCGS *Hudson* Expedition 2016-011, phase 1. Marine geohazards and seabed processes along the lower Scotian Slope, June 2–14, 2016

D.C. Campbell and A. Normandeau

2018

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

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- Calvin Campbell, Chief Scientist, Hudson 2016-011 Phase 1

1. Background and Objectives

The outer Nova Scotia margin is highly incised by submarine canyons and contains numerous slide scars and mass transport deposits. Although much of the outer Nova Scotia slope has been the object of scientific studies by the Geological Survey of Canada over the past few decades, significant gaps in geophysical and sedimentary data exists off Banquereau, Emerald, Lahave and Brown's Bank. Acquiring geophysical data in these regions is particularly relevant for our understanding of the recurrence of large submarine landslides and turbidity currents during the late-Quaternary. Additionally, acquiring high-resolution geophysical data on the outer Nova Scotia slope and rise will greatly improve our understanding of sedimentary processes along this part of the margin which supports Canada's submission to the United Nations Convention on the Law of the Seas (UNCLOS).

CCGS Hudson expedition 2016-011 Phase 1 (Figure 1) took place from June 2-June 14, 2016. The expedition had 19 science participants (Table 1) and the study area was the outer continental slope south of Banquereau (Figure 1, Table 2). The primary objective of CCGS Hudson expedition 2016-011 Phase 1 (Figure 1) was to improve our understanding of geological processes offshore Nova Scotia. Specifically, this expedition : 1) carried out high-resolution seismic surveys perpendicular to the outer slope; 2) collected sediment cores to confirm the nature of the sediments imaged by seismic surveys; 3) will allow us to measure the recurrence of sediment transport events during the late-Quaternary along deep-water submarine channels; 4) will allow us to evaluate the recurrence rates of large submarine landslides to evaluate their significance in terms of geohazards; and 5) assess the stability of Nova Scotia's outer slope.

2. PARTICIPANTS

Table 1: Participants of the CGS Hudson expedition 2016-011

Name	Affiliation	Role
Mike Belliveau	GeoForce	Huntec
Robbie Bennett	NRCan	Geological
Jeremy Bentley	NRCan	Sampling
Laura Broom	Volunteer	Seismic data processing
Calvin Campbell	NRCan	Chief Scientist
Ryan Carver-Rose	NRCan	General
Tom Fralic	GeoForce	Huntec
Paul Fraser	NRCan	Navigation/GIS/Data management
Jenna Higgins	NRCan	Geological
Makeala MacIntyre	NRCan	General
Desmond Manning	NRCan	Seismic
Patrick Meslin	NRCan	Seismic
Alexandre Normandeau	NRCan	Planning
Eric Patton	NRCan	Navigation/GIS/Data management
Angus Roberson	NRCan	Geological
Nicole Rudolf	Volunteer	General
Tom Carson	GeoForce	Seismic
Rick Ludkin	Environment Canada	Bird observer
Scott Hayward	NRCan	Seismic

3. SUMMARY OF ACTIVITIES

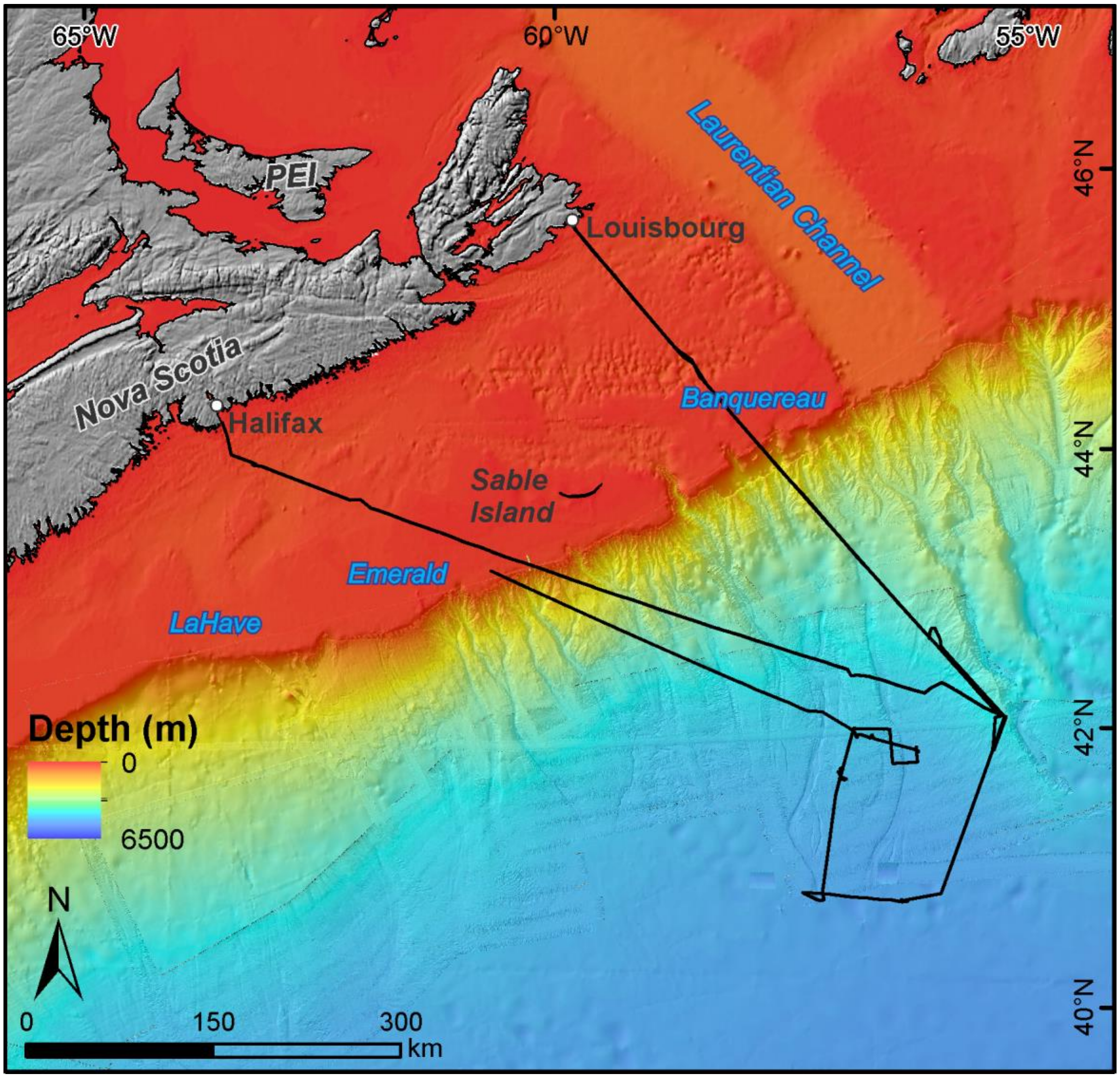

Figure 1: Location of Nova Scotia's outer margin

Table 2: Summary of activities

Date	JD	Location	Activity	Piston core	Huntec DTS	GI Gun	3.5 kHz	Notes
02-June	154	BIO	Sea trials					Medical incident delayed departure
03-June	155	BIO	Sea trials					
04-June	156	Transit	Departs from BIO at 0915					
05-June	157	Scotian Shelf	Transit with 3.5 kHz. Huntec started at 1800		X		X	Problem with GI gun. Did not acquire profiles
06-June	158	Laurentian Fan levee	Levee and MTD piston sampling and transit towards Louisburg	X			X	Transit for crew change
07-June	159	Louisburg	Transit for crew change in Louisburg				X	Crew change
08-June	160	Scotian Slope	Transit		X	X	X	
09-June	161	Laurentian Fan levee	Geophysical surveys		X	X	X	
10-June	162	Seaward of The Gully	Geophysical surveys		X	X	X	Conditions too rough for coring
11-June	163	Seaward of The Gully	Geophysical surveys and piston coring	X	X	X	X	
12-June	164	MTD on Laurentian Fan levee	Geophysical surveys and piston coring	X	X	X	X	
13-June	165	Transit					X	
14-June	166	BIO						

4. Preliminary Results

4.1 Cruise statistics

The cruise allowed the GSC scientists to collect more than 3500 km of sub-bottom data, including 2616 km of 3.5 kHz sub-bottom profiles, 480 km of GI gun seismic profiles and 569 km of Huntec DTS seismic profiles. Additionally, piston and trigger weight coring took place at three stations on the Laurentian Fan region. A total of 25.38 m sediment core was collected, including 21.07 m of piston cores and 4.305 m of trigger weight cores. Location of sub-bottom profiles and core locations are provided in Figure 2.

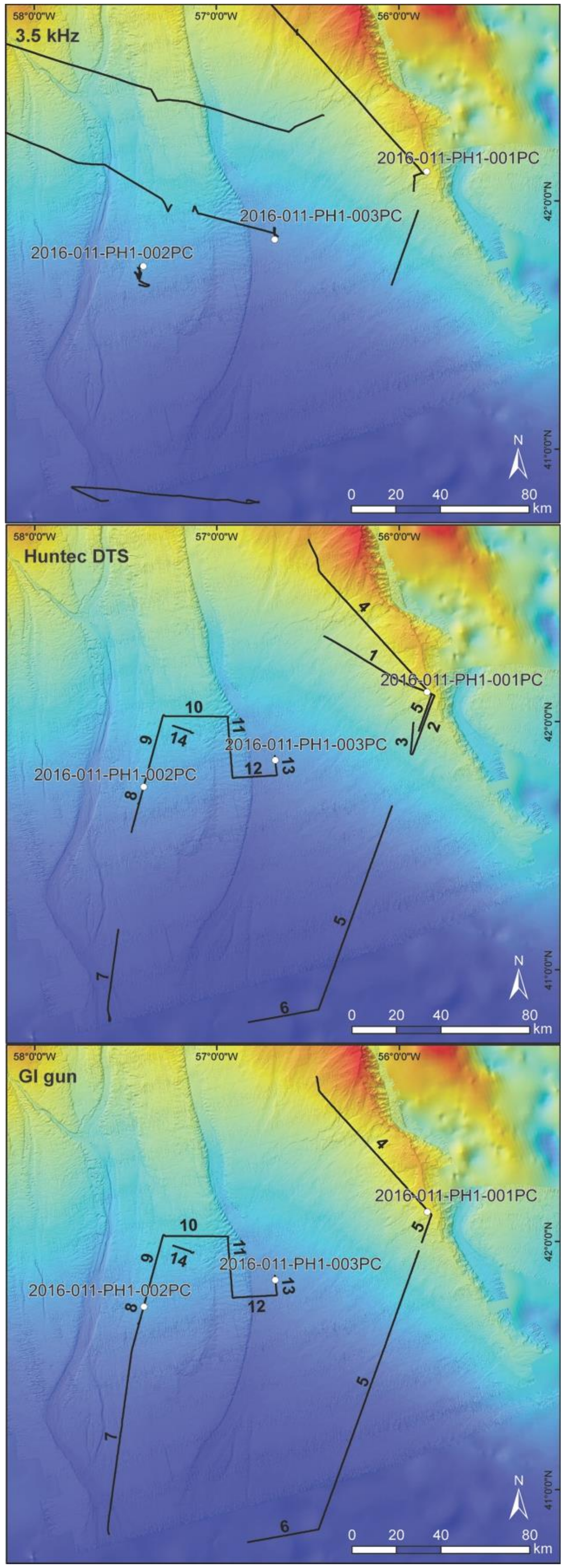

Figure 2: Location of cores and seismic profiles

4.2 Key preliminary results

4.2.1 Mass transport deposits

The western levee of the Laurentian Fan is characterized by series of scarps, leveed channels and MTDs. For the purpose of UNCLOS, these geomorphological characteristics need to be mapped and their origin confirmed. GI gun seismic profiles reveal that the base of slope coincides with the thinning of MTDs, suggesting that MTDs can define the base of slope along the Nova Scotia margin. Additionally, a seismic profile crossing a giant MTD on the levee of the Laurentian fans (Figs. 3, 4) is located in the upper seismic sequence and appears to be fairly recent (Figure 4). Below this MTD, parallel seismic reflections are observed without any disturbances for more than 0.5 s twtt (*ca* 375 m). The seismic sequence indicates that the MTD was triggered by an infrequent event that could be related to the 1929 Grand Banks earthquake. A core collected at the distal end of this MTD (2016-011-PH1-0003PC & TWC) will allow us to precisely date this event and hopefully identify its trigger.

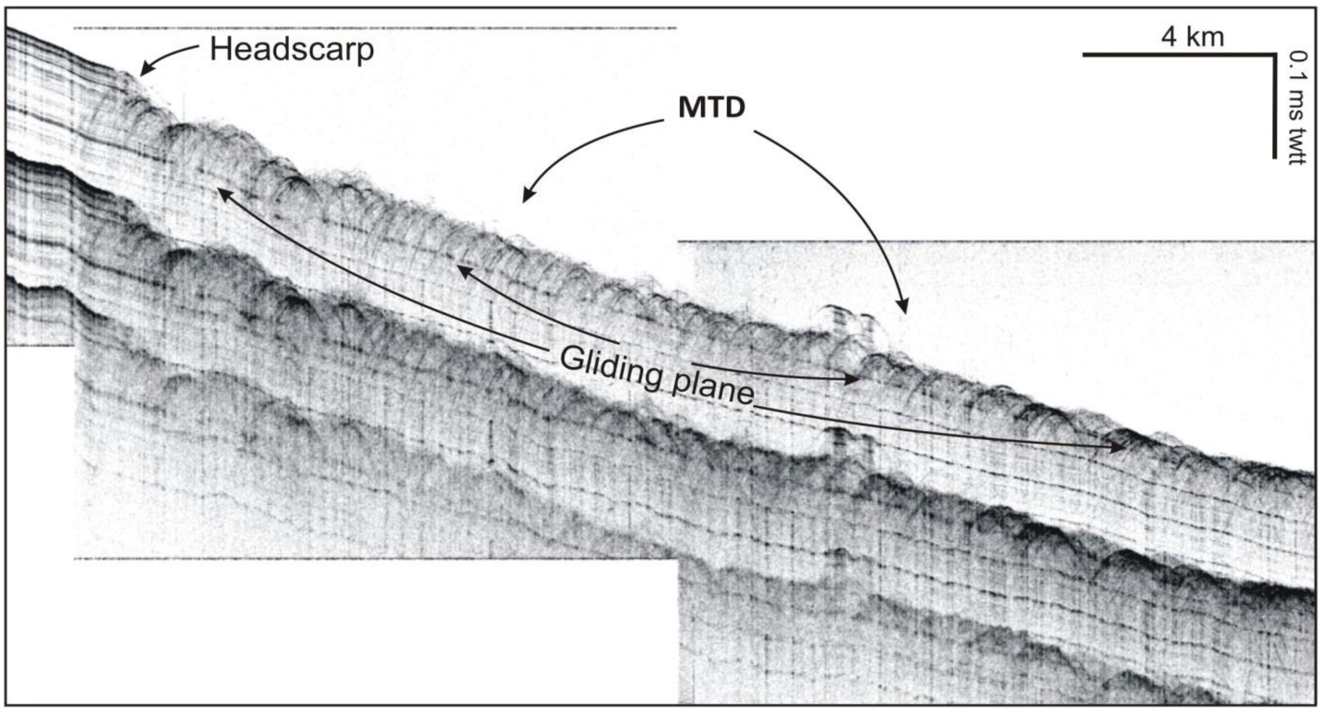

Figure 3: Mass transport deposit (MTD) along the western levee of the Laurentian Channel. See Figure 2 (Huntec DTS line 5) for location of the seismic profile.

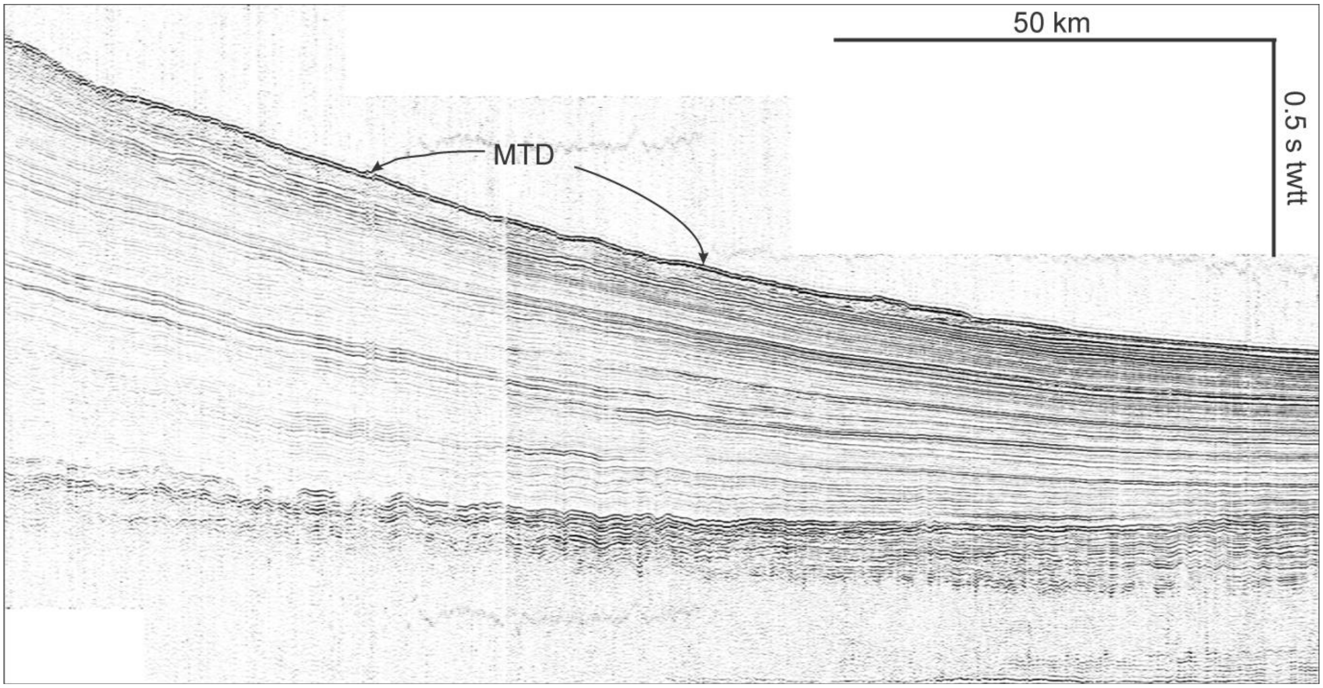

Figure 4: Seismic section showing a MTD in the upper seismic sequence and the stratified nature of the sediment below it. See Figure 2 (GI gun line 5) for location of the seismic profile.

4.2.2 Sediment waves seaward of the Gully

Sediment waves observed on the Atlantis multibeam bathymetry dataset (2012) were surveyed using seismic profiling instruments to identify their internal character. Seismic profiles reveal an upslope migration of the sediment waves (Figure 5), suggesting that they were formed by supercritical sediment density flows (turbidity currents). Assuming they are antidunes and using Hand (1974) equations for turbidity current velocity, we can infer a range of velocities varying between 0.5 and 2 m/s assuming excess densities of 1-6 kg/m^2. Below the upslope migrating bedforms, a MTD is clearly visible and could have provided an initial bed defection for the subsequent formation of the overlying bedforms.A closer examination of these bedforms will allow determining their exact nature and the variability of turbidity current processes along the Nova Scotia margin.

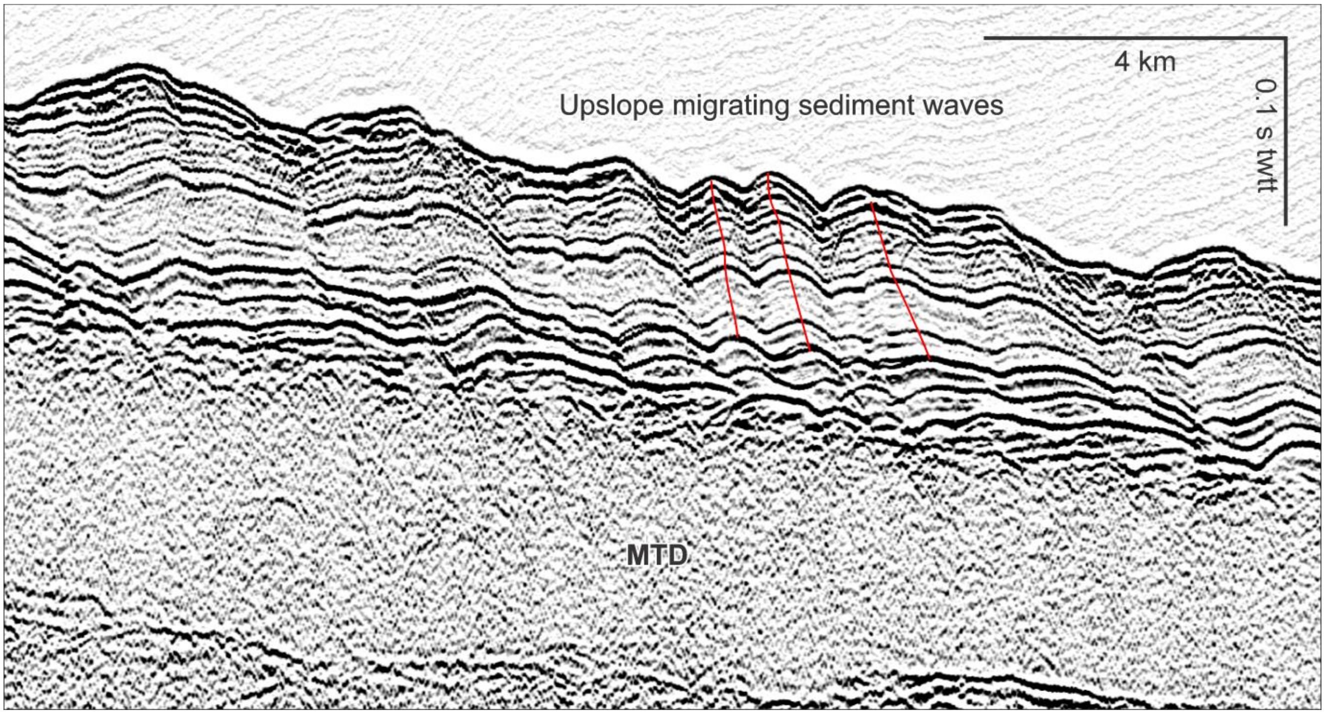

Figure 5: Upslope migrating sediment waves along the levee of the Gully outer channel. See Figure 2 (GI gun line 11) for location of the seismic profile.

5. DAILY NARRATIVE

All times in ADT.

5.1 JD153 – Wednesday June 1, 2016 – BIO

Approximately half of the ship staff conducted ship familiarization the day before planned departure.

5.2 JD154 – Thursday June 2, 2016 – BIO

All staff was on board for 0800. The familiarization for the remaining staff took place in forward lounge at 0800. The Hudson then departed BIO at 0915 and sailed to the Bedford Basin to conduct test deployment of the piston core and to conduct drills. At ~1045, there was a medical incident on the bridge. The ship sailed back to the BIO to disembark the Coast Guard staff member. A meeting for all science staff was held at 1300. At 1330, the captain informed all staff and crew that sailing would be delayed to 0800 the following day.

5.3 JD155 – Friday June 3, 2016 – BIO

The staff was on board for 0800. At 0930, the Hudson sailed to the Bedford Basin to conduct a test deployment of the piston corer, which began at 1000 and was completed at 1400. Upon completion of the test, the vessel sailed back to BIO and docked at 1630. At 1630 the captain informed all staff and crew that sailing would be delayed to 0800 the following day.

5.4 JD156 – Saturday June 4, 2016 – Scotian Shelf

All staff was on board for 0800. At 0915, the Hudson departed BIO and began transit to the work location on the western levee of Laurentian Fan. At 1230, fire and boat emergency drills were performed. The ship was again underway towards Laurentian Fan at 1400. At 1800, the Knudsen CHIRP profiling system (3.5 kHz) was turned on and started recording at 1810 (*43°54.088' N / 62°03.760' W*), while transiting towards the main outer location. Watches in the GP lab began at that time.

5.5 JD157 – Sunday June 5, 2016 – Laurentian Fan Levee

The Hudson continued transiting to the Laurentian Fan area while running the 3.5 kHz sounder. At 1530, a familiarization for the deck crew on the deployment of the seismic equipment was led by Des Manning. At 1630, the Huntec DTS and GI gun were deployed. Upon deploying the GI gun, an air leak was noticed and the gun was recovered. A loose hose was repaired and the gun was redeployed. Upon redeployment, an issue with the blast phone was discovered and the gun had to once again be recovered. The decision was made to carry on with just the Huntec DTS overnight while repairs were made to the GI gun. At 2000, the Huntec was deployed at location *42°25.533' N / 56°27.578W*.

5.6 JD158 – Monday June 6, 2016 – Laurentian Fan Levee

At 0630 (*42°2.93468' N / 56°0.7255 W*), the Huntec DTS was stopped and recovered in order to transit faster towards the coring site. The Hudson steamed to the first core site (2016-011-PH1-0001) which was a thick stratified succession near the crest of the western Laurentian Fan levee and upstream of a large MTD. A piston core was collected with coordinates *42°10.005' N / 55°55.474' W*. The PC was 7.5 m long while the TWC was 2.3 m long. At 1300, the science staff was informed that the ship had to transit towards Louisbourg to disembark/embark coast guard staff. The ship began steaming towards Louisbourg at 1300. The 3.5 kHz sounder was logged for the duration of the transit until 0900 the following morning at location *43°42.49264' N / 57°33.317859' W.*

5.7 JD159 – Tuesday June 7, 2016 – Louisbourg

The Hudson transited towards Louisbourg and arrived at destination at 1200. The crew change was made quickly in the afternoon. At 1430, the ship started to head back towards the outer Nova Scotia margin. The ship's speed was decreased to 9 kts to avoid sailing directly into Hurricane Colin. At 1450, the 3.5 kHz sounder was started at 45°*52.81759' N / 59°53.655138' W.*

5.8 JD160 – Wednesday June 8, 2016 – Scotian Slope

The Hudson continued transiting towards the western levee of the Laurentian Fan and collected good quality 3.5 kHz data down the slope. The ship was expected to go through Hurricane Colin so we waited before deploying any instrument that it had passed by. After lunch, winds died down, without generating any significant winds or waves in our sector. At 1623 (42°*46.780978' N / 56° 33.966049' W)*, the Knudsen was stopped and the GI gun and Huntec DTS were deployed. The Huntec DTS started firing at 1800 (*42°49.201128' N / 56° 30.176211' W*) while the GI gun started firing at 1900 (42°*44.855' N / 56°28.0058' W)* due to technical difficulties. At 1800 winds picked up to 25-30 kts and some swell developed.

5.9 JD161 – Thursday June 9, 2016 – Laurentian Fan levee

Good quality GI gun and marginal quality Huntec data were collected over night. The GI gun data showed some noise bursts due to sea conditions. At 0730 the compressor shut down due to a temperature alarm. It was quickly fixed and only 20 minutes of data were lost. Also at 0730, the Huntec was shut down due to poor data quality and we switched over to the 3.5 kHz sounder. The Huntec was recovered at 1300 for maintenance and redeployed. Data quality was noticeably better upon redeployment so we decided to switch back to Huntec. We continued to collect good quality data overnight despite some swell.

5.10 JD162 – Friday June 10, 2016 – Seaward of The Gully

At 0137, the Huntec started firing again at location *40° 55.1927' N / 56° 38.4641' W*. At 0615, both the Huntec and GI gun were recovered, hoping to collect sediment cores during the day. Rough weather in the morning, however, prevented us from collecting sediment cores. At 1015, the ship began sailing towards a core site at the base of the Gully channel selected from the Atlantis 2012 dataset, hoping the weather would calm down by the time we arrived. The weather did not calm down and coring was not recommended by the bosun and the captain. At 1652 (*40° 55.756' N / 57° 45.61819' W)*, the Huntec and GI gun were deployed to continue seismic surveys upslope just east of the distal Gully channel.

5.11 JD163 – Saturday June 11, 2016 – Seaward of The Gully

The ship collected very good quality GI gun and Huntec data over night. The GI gun data shows a thick mass transport deposit which thins and eventually pinches out towards the lower slope. We recovered the seismic gear at 0600 and went to the first core site which was a well-stratified interval on the broad ridge between the Gully and the channel to the east. The piston corer was deployed at 0830 and was back on deck by 1230. Corer recovered approximately 6.3 m of silty laminated mud (with turbidites?) at a depth of *ca* 4800 m. There was not enough time for a second core so we returned to where the seismic gear was recovered that morning and redeployed the Huntec and GI Gun.

5.12 JD164 – Sunday June 12, 2016 – Laurentian Fan levee

Huntec and GI Gun data were collected overnight. We recovered the seismic gear at 0600 and steamed to a core site in order to sample a mass transport deposit recognizable over most of the western levee of Laurentian Fan. Corer recovered ~ 7 m of sediment. We then steamed 2 hours to the west and deployed the seismic gear at 1430. At 1530 the captain informed staff that we would have to return to Halifax to deal with a medical issue on board. Seismic gear was recovered at 1600 and we began steaming back to Halifax. The 3.5 kHz sounder remained on and we acquired acceptable quality data overnight.

5.13 JD165 – Monday June 13, 2016 – Transit to Halifax

We ran the 3.5 kHz sounder until 1000 when the seabed became too incised to collect useable data. We continued steaming to Halifax.

5.14 JD166 – Tuesday June 14, 2016 – Transit to Halifax

The Hudson arrived at BIO at 0800, which ended cruise 2016-011 Phase 1.

6. EQUIPMENT AND PROCEDURES

6.1 Knudsen 3260 Echo-Sounder

During much of the cruise, a ram mounted 12 kHz transducer, transceiver and recorder were used to track bottom and gather some sub-bottom data when sampling. During transit, or when the Huntec DTS and GI gun were unavailable during survey, the 3.5 kHz hull mounted transducer was employed. No problems were encountered with this system for the duration of the cruise.

6.2 Single channel seismic reflection system

Single channel seismic reflection lines were collected throughout the study area to target seabed features and image the shallow subsurface. Seismic line start/end times are given in Table 3.

Table 3: Seismic lines recorded during the cruise

Line	StartDaytime	EndDaytime
1	1572301	1580457
2	1580457	1580752
3	1580752	1580930
4	1601924	1610831
5	1610831	1620434
6	1620434	1620908
7	1622015	1630640
8	1630640	1630903
9	1631742	1632223
10	1632224	1640136
11	1640136	1640519
12	1640519	1640753
13	1640753	1640900
14	1641756	1641905

6.2.1 GI Gun

Seismic reflection One Sercel 210 cubic inch GI gun (Generator – Injector) suspended from an I-beam. A large (A6) Norwegian buoy was used for primary floatation with a small secondary buoy used to keep deployment and recovery line away from the gun during the survey. The GI gun was towed approximately 30 meters behind the stern at a depth of 1.5 to 2 meters. The tow umbilical was attached to a portside outrigger (Ironing board) to insure separation of all equipment being towed during turns.

The MITS was used to supply the master trigger to the Long Shot Seismic Source Controller and the Four Shot Seismic Source Power Supply unit. Initial parameters used in the setup of the GI Gun were entered into the control software of the Long Shot/Four Shot system. A blast phone mounted to the GI Gun was the primary sensor used in monitoring performance. The Long Shot firing control tunes the Generator and Injector over several shots. The MITS also supplied the trigger for the Huntec DTS ensuring shot and signal separation between the two seismic sources.

A Price W2 Air Gun Master capable of supplying air at 200 SCFM and 2000 psi was employed to fire the GI gun at 1700-1750 psi every six seconds. The compressor was driven by a 200 HP AC motor which was, in turn, controlled by a Cutler Hammer SV9000 Variable Frequency Controller located in the workshop container.

The air umbilical to the gun was contained and deployed using a winch located on the port side of the ship. A small M7 Pullmaster tugger winch was used to take up the strain during deployment and recovery of the GI gun and umbilical. The electrical and air lines were taped to the tow cable as it went over the side to its' final towing position.

The streamer was deployed from a winch located on the starboard flight deck and towed from the outrigger located on the starboard rail of the quarterdeck. The 25 HP pumping unit could supply hydraulic power to only one winch at a time. Hydraulic ball valves were employed to direct flow to one system or the other.

6.2.1 Hydrophone Streamer

The streamer was deployed from a winch on the flight deck and towed from an outrigger (Ironing board) mounted to the starboard side of the ship. The streamer was refitted in 2007 by Swain Geophysical in Texas. During the refit the streamer was outfitted with two coils allowing for the use of DigiBirds. The Streamer has a 27ft dead section at the head and a 16ft dead section at the tail. The active section is approximately 150ft long containing 48 Teledyne B-1 acceleration cancelling hydrophone cartridges. As in previous years, the streamer was towed approximately 100 metres behind the ship at a depth of 1 to 3 meters. A small drogue provided some drag for stability but its use was discontinued due to excessive drag and strain on the streamer.

The 48 hydrophones make up 6 groups of 8 elements each. These 6 groups are summed together, amplified and then sent to the GSCDIGS for digitizing and storage. The signal is also sent to a Krohn-Hite filter and then to an EPC 9801 Thermal Recorder for a hardcopy. The filtered of processed was also logged on the digitizer.

Streamer tow depth was controlled using a combination of drag, ship log speed, and primarily, two DigiBirds programmed through a modem using the DigiCourse software. The streamer worked well with two DigiBirds. Depth settings and fin angles were changed according to tow and sea conditions.

6.2.2 Data Acquisition, Display, Storage and Processing:

Filters- Krohn-Hite Model 3323 Filter
Settings- High Pass 20db 80Hz
Low Pass 0db 1.5KHz
Applies filtered Acoustic signal to the EPC Model 9801 Thermal Hardcopy
EPC- Model 9801 Thermal Hardcopy
Settings 1 to 2 Second Sweep
GSC Digs- GDAIMS Ver 1.4 18
<u>GI Guns</u>
Firing rate: 12.0 sec
Sample rate: 250uS for a 2 second window.

Paper records are given in Table 4.

Table 4: Printed record of the GI gun profiling system

GI_Airgun			
Record Number	**StartDaytime**	**StopDaytime**	**Lines**
1	1602210	1610904	4 - 6
	1610915	1620905	
2	1621955	1620901	7 - 8
3	1631740	1640900	9-13
4	1641755	1641905	14

While the GSC Digs was the primary data logging system on the trip this new system was logging data concurrently. The trigger and analogue signal are input to a small A/D interface and logged on a laptop computer.

The new system has the advantage of being able to interface directly with the EPC through the parallel port. Annotation of the record is achieved without the aging and increasingly unreliable TSS annotators. Gain and filters can be made digitally and only affect the printed record. The raw data is left intact. The system has the further advantage of taking the space required only for a laptop and the A/D converter.

6.3 Huntec Deep Towed System

This section was modified from a report prepared by Tom Fralic at Geoforce Group Ltd. Geoforce Group Limited provided technicians Tom Fralic and Mike Belliveau to supervise the installation, operation and maintenance of the Huntec systems during the field program.

6.3.1 Deep Tow System

The DTS system, originally manufactured by Huntec (70) Limited, is a high resolution, sub-bottom profiler with the acoustic source, energy supply, pressure sensor, and two receiving hydrophones housed in an underwater tow fish.

The AGC #2 DTS system was used during this mission. The maximum power output of this system is 1000 joules (60 µF storage capacitance) with an ED10F/C Boomer and a twenty tip mini sparker source. The internal single element LC10 hydrophone was configured as Seismic #1. The externally towed Geoforce GF24/24P2i streamer hydrophone was connected as Seismic #2 (overall streamer length 24 feet, two inter-spliced channels with a combined fourteen foot active section, total of twenty-four AQ1 elements with an effective spacing of 12 inches).

The ED10FC boomer source is depth compensated and outputs a highly repeatable broadband pulse, capable of resolving 10 cm. Peak output intensity is 118 db relative to 1 micro bar at 1 meter, with a pulse duration of 110 ms. The sparker source has twenty, #18 awg, solid core tips. The peak amplitude and pulse width of the sparker source are depth dependent. Acoustic output is centered at approximately 1500 hertz, with a bandwidth of 500-2500 hertz. The sparker source was used exclusively on this mission. The deck equipment consists of a Benthos Oceanographic winch, which includes a multi-way slip ring and a 250 meter, twenty-one conductor, armoured tow cable. The winch is powered by a 440 VAC, 50 HP hydraulic pump unit. The tow cable is handled by a 36 inch diameter roller cluster rigged on the center position of the aft A frame. The lab instrumentation consists of the Geoforce Systems Console and DC high voltage power supply (PCU). The Systems Console houses the Bottom Motion Compensator circuits, the +60 DC volt fish supply, and modules for signal processing and recorder outputs. The Huntec Mk III PCU provides DC power to the Energy Storage Unit (ESU) in switchable ranges from 2 to 6 kilovolts.

6.3.2 Recording Systems

A GeoDigs 24 Bit Acquisition System (DIGS #1) was used as the digital recording device. This included a National Instruments USB 9234 Analogue to Digital Converter, and GeoDigs v1.3 software operating on a laptop running Windows 7. Trigger was provided from a MITS trigger system to enable synchronization with the GI gun system running simultaneously. Navigation Data came via the bridge through the laptop's Ethernet port and was embedded to the recorded files on GeoDigs.

Paper records were generated by an EPC 9800 Graphic Recorder using the parallel interface functionality of the Portable DIGS #1 system. Automatic and user-initiated annotation of the paper records were provided using the annotator function of the DIGS software.

Recording Parameters DTS

System Console

BMC: Enabled Trigger

Source: MITS

Trigger Rate: 1000ms, 1100ms, 1200ms, 1250ms, 1500ms, 2400ms (changes in log)

TVG Rate: 4 (max)

Source Level: 4kV

Portable DIGS #2

Software: GSCA USB 9234 Mk. 1.3.1

Format: SEG Y

Storage Medium: Internal Hard Disk Drive

Sample Rate: 25.6 kHz

Record Length: 500 ms

Trigger I/P: Geoforce Systems Console Master Trigger

Analogue I/P 1: DTS Internal Raw

Analogue I/P 2: DTS External Raw

Analogue I/P 3: External TVG OP

EPC 9800

Display: DTS External Streamer

Print Density: 100 LPI

Print Gain: 36 dB (Typical)

Print Delay: 1500 ms (Typical)

Print Threshold: 0 (Typical)
Fix Marks: Timestamp @ 5 min. intervals
Scale Lines: 100 ms
Low Cut Freq.: 500 Hz Hi
Cut Freq.: 8000Hz

Paper records are given in Table 5.

Table 5: Printed record of Huntec DTS profiles

Huntec			
Record Number	StartDaytime	StopDaytime	Lines
1	1572305	1580930	1 - 3
2	1602020	1611005	4 - 5
3	1611630	1620930	5 - 6
4	1621953	1632112	7
5	1622114	1630902	7 - 8
6	1631740	1640859	9-13
7	1641758	1641906	14

6.3.3 Equipment Performance

DTS

The watchkeeper's log is provided in Table 6. The survey was performed using the recently upgraded AGC#2 system. This system had just recently received a new stainless steel 1000J Energy Storage Unit. The unit performed without flaw and collected data in water depths up to 4963 meters. At one point after a re-termination the Leak Alarm was intermittently sounding off on the System's Console, this was a result of two twisted pair wires shorting out within the termination block, and was repaired when discovered.

Portable DIGS #2

This recorder operated the entire program without issue.

EPC 9800

This recorder operated the entire program without issue.

Consumables

Two o-rings and a Cinch Jones female connecter were used during this phase.

Table 6: Watchkeepers log for the Huntec DTS (from Geoforce)

WATCHKEEPER'S LOG - GEOFORCE DEEP TOW PROFILER																			
2-Jun-16				12-Jun-16				CCGS Hudson				NRCan			2016-011-P1				
Day / Time		Data Annotation			Environmental				DTS Profiler Settings					Graphic Recorder					Comments
Julian Day	Time UTC	Data Log	Line #	WD	Hdg.	Log Spd.	Fish Depth	Sea State	Source BM.	SP.	Fire Rate	PCU KV	TVG. Gain	Sweep Speed	SIGNAL CH A	CH B	Print	Print Delay	
157	20:06:00			4410m	68.4deg		119m	3		x	1100m	4	4	500m	Int.	Strmr		5700ms	fish in water - firing
157	20:47:00			4362m	121deg	4.5kn	70m	3		x	1000m	4	4	500m	Int.	Strmr		5700ms	Fire rate to 1s
157	20:56:00			4318m	122deg	5kn	64m	3		x	1000m	5	4	500m	Int.	Strmr		5700ms	Increase PCU to 5kV
157	20:58:00		1	4330m	123.5de	5kn	66.1m	3		x	1000m	5	4	500m	Int.	Strmr	Strmr	5700ms	SOL 1 - Turn on EPC
157	23:10:00		1	4206m	122deg	5kn	61m	3		x	1250m	5	4	500m	Int.	Strmr	Strmr	5700ms	Inc fire rate to 1250ms
157	23:28:00		1	4302m	122.4de	5kn	75m	3		x	1250m	5	4	500m	Int.	Strmr	Strmr	5700ms	Lowered DTS
157	23:39:00		1	4307m	122deg	5.8kn	68.5m			x	1250m	4	4	500m	Int.	Strmr	Strmr	5700ms	Decrease PCU to 4kV
158	2:56:00		1	4178m	118deg	4.8	78m	3		x	1250m	4	4	500m	Int.	Strmr	Strmr	5600ms	Decrease Delay to 5600ms
158	4:22:00		1	4107m	119deg	5kn	76m	3		x	1250m	4	4	500m	Int.	Strmr	Strmr	5500ms	Decrease Delay to 5500ms
158	4:57		1	4100m	A/C	5kn	74m	3		x	1250m	4	4	500m	Int.	Strmr	Strmr	5500ms	EOL1 A/C
158	4:59:00		2	4100m	205deg	5kn	75m			x	1250m	4	4	500m	Int.	Strmr	Strmr	5500ms	SOL 2
158	5:35:00		2	4181m	205deg	5kn	75m	2		x	1250m	4	4	500m	Int.	Strmr	Strmr	5700ms	Increase Delay 5700ms
158	6:42:00		2	4345m	205deg	4.9kn	77m	2		x	1250m	4	4	500m	Int.	Strmr	Strmr	5900ms	Increase Delay 5900ms
158	6:44		2	4355m	205deg	4.7kn	79m			x	1100m	4	4	500m	Int.	Strmr	Strmr	5900ms	Dec fire rate to 1100ms
158	7:52:00		2	4480m	205deg	4.9kn	75m	2		x	1100m	4	4	500m	Int.	Strmr	Strmr	5900ms	EOL 2 A/C
158	7:58:00		3	4473m	13deg	5.1kn	67m	2		x	1100m	4	4	500m	Int.	Strmr	Strmr	5900ms	SOL 3
158	9:29		3	4337m	16deg	4.5kn	75m	2		x	1100m	4	4	500m	Int.	Strmr	Strmr	5900ms	EOL3
158	9:31		3	4335m	15deg	3.4kn	74m	2		x	1100m	4	4	500m	Int.	Strmr	Strmr	5900ms	Bringing fish on board
158	9:50			4326m	18deg	4.1kn		3		x	1100m	4	4	500m	Int.	Strmr	Strmr	5900ms	Fish Secured on deck
160	19:23							3		x									Deploy fish
160	20:20			3895m	45deg	4kn	71m	2		x	1250m	4	4	500m	Int.	Strmr	Strmr	5000ms	Paying out more cable
160	20:37			3887m	64deg	4.2kn	88m	2		x	1100m	4	4	500m	Int.	Strmr	Strmr	5000ms	Dec fire rate to 1100ms
160	20:42		4	3886m	143deg	4.1kn	95m	3		x	1100m	4	4	500m	Int.	Strmr	Strmr	5000ms	SOL 4
160	20:51		4	3896m	174deg	4kn	94m	3-Jan		x	1200m	4	4	500m	Int.	Strmr	Strmr	5200ms	Chang delay and fire rate
160	20:56		4	3910m	180deg	4.2kn	89m	4		x	1200m	4	4	500m	Int.	Strmr	Strmr	5200ms	Break file label line 4
160	21:28		4	3957m	180deg	4.9kn	82m	4		x	1250m	4	4	500m	Int.	Strmr	Strmr	5200ms	Inc fire rate to 1250ms
160	22:10		4					4		x		4	4	500m	Int.	Strmr	Strmr	5200ms	Adjust delays and fire rates
160	22:20		4	3956m	198deg	4.4kn	96m	4		x	3sec	4	4	500m	Int.	Strmr	Strmr	5200ms	Adjust fire rate Sea state up
160	22:27		4	3965m	201deg	4.4kn	94m	4		x	1200m	4	4	500m	Int.	Strmr	Strmr	5200ms	Adjust fire rate. Ships speed up/down
160	22:50		4	3989m	200deg	4.6kn	90m	4		x	1200m	4	4	500m	Int.	Strmr	Strmr	5200ms	AC to Sol 4
160	23:03		4	4000m	173deg	4kn	99m	4		x	1200m	4	4	500m	Int.	Strmr	Strmr	5400ms	Delay change
161	1:17		4	4104m	152deg	4.4kn	87m	4		x	1200m	4	4	500m	Int.	Strmr	Strmr	5600ms	Delay change
161	1:25		4	4109m	154deg	4.4kn	83m	4		x	1200m	4	4	500m	Int.	Strmr	Strmr	5500ms	Delay change
161	3:40		4	4200m	159deg	4.4kn	82m	4		x	1200m	4	1	500m	Int.	Strmr	Strmr	5500ms	Trigger issues SC went to int trig 1 sec
161	4:07		4	4200m	159deg	4.2kn	95m	4		x	1200m	4	1	500m	Int.	Strmr	Strmr	5500ms	Trigger issues fixed
161	8:31		4	4090m	159deg	3.9kn	100m	4		x	1200m	4	1	500m	Int.	Strmr	Strmr	5500ms	Eol 4
161	8:33		5	4090m	207deg	4kn	95m	4		x	1200m	4	1	500m	Int.	Strmr	Strmr	5500ms	Sol 5
161	9:12		5	4177m	193deg	4.5kn	85m	4		x	1200m	4	1	500m	Int.	Strmr	Strmr	5500ms	Trig Delay inc 500ms to 600ms
161	9:42		5	4232m	201deg	3.9kn	104m	4		x	1200m	4	1	500m	Int.	Strmr	Strmr	5600ms	Inc delay to 5600ms
161	10:19		5	4304m	202deg	4.2kn	92m	4		x	1250m	4	1	500m	Int.	Strmr	Strmr	5700ms	Inc delay to 5700ms & FR to 1250ms
161	10:50		5	4410m	200deg	4.8kn	92m	4		x	1250m	4	1	500m	Int.	Strmr	Strmr	5700ms	Turning off DTS, Switching to 3.5k
161	16:15		5	4668m	224deg	4.3kn		3				4	1	500m	Int.	Strmr	Strmr	5850ms	Fish Deployed Port sideskin cracked.
161	16:33		5A	4692m	217deg	4.4kn	98m	3		x	1200m	4	1	500m	Int.	Strmr	Strmr	6200ms	SOL5A
161	18:36		5A	4782m	227deg	4kn	103m	3		x	1200m	4	1	500m	Int.	Strmr	Strmr	6300ms	Inc delay to 6300ms
161	20:30		5A	4808m	210deg	4.5kn	89m	3		x	1200m	4	1	500m	Int.	Strmr	Strmr	6500ms	Inc delay to 6500ms
161	20:49		5A	4817m	213deg	4.6kn	85m	3		x	1200m	4	1	500m	Int.	Strmr	Strmr	6500ms	Over waypoint
162	0:14		5A	4900m	199deg	4.9kn	80m	3		x	1200m	4	1	500m	Int.	Strmr	Strmr	6500ms	Water depth 4900m
162	1:15		5A	4920m	198deg	4.3kn	89m	3		x	1200m	4	1	500m	Int.	Strmr	Strmr	6700ms	Inc delay to 6700ms
162	1:40		5A	4926m	202deg	5kn	86m	3		x	1200m	4	1	500m	Int.	Strmr	Strmr	6700ms	30 knots of wind
162	3:20		5A	4948m	210deg	3.4kn	110m	4		x	1200m	4	1	500m	Int.	Strmr	Strmr	6700ms	Speed variable? Sea state building.
162	4:34		5A	4957m	210deg	4.7kn	90m	4		x	1200m	4	1	500m	Int.	Strmr	Strmr	6700ms	EOL 5
162	4:37		6	4957m	261deg	4.6kn	94m	4		x	1200m	4	1	500m	Int.	Strmr	Strmr	6700ms	SOL 6 Heading into seas speed var.
162	9:06		6					4		x	1200m	4	1	500m	Int.	Strmr	Strmr	6700ms	Fish recovered, Secured on deck
162	19:19		#	4923m	94deg	2.5kn	140m	3		x	1200m	4	1	500m	Int.	Strmr	Strmr	6700ms	Fish Deployed Replaced missing tail bol
162	20:15		7	4963m	340deg	4.9kn	81m	3		x	1200m	4	1	500m	Int.	Strmr	Strmr	6700ms	SOL7 & Break file SOR 3
162	21:12		7	4918m	340deg	4.7kn	86m	3		x	1200m	4	1	500m	Int.	Strmr	Strmr	6700ms	EPC paper change. SOR 4
162	22:05		7	4895m	340deg	4.9kn	82m	3		x	1200m	4	1	500m	Int.	Strmr	Strmr	6500ms	Delay change.
163	3:08		7	4810m	18deg	4.5kn	88m	3		x	1200m	4	1	500m	Int.	Strmr	Strmr	6500ms	Check Low slope
163	5:10		7	4774m	11deg	4.1kn	86m	3		x	1200m	4	1	500m	Int.	Strmr	Strmr	6500ms	Check Low slope
163	5:35		7	4763m	12deg	4.7kn	82m	3		x	1200m	4	1	500m	Int.	Strmr	Strmr	6300ms	Dec delay
163	6:40		7	4738m	12deg	4.3kn	91m	3		x	1200m	4	1	500m	Int.	Strmr	Strmr	6300ms	EOL 7 SOL 8
163	6:47		8	4738m	18deg	4.1kn	94m	3		x	1200m	4	1	500m	Int.	Strmr	Strmr	6300ms	On line heading 8
163	9:03		8		18deg			3		x	1200m	4	1	500m	Int.	Strmr	Strmr	6300ms	EOL 8 Haul gear on board
163	17:15		#	4679m	289deg	2.5kn	120m	2		x	1200m	4	1	500m	Int.	Strmr	Strmr	6300ms	Deploy fish
163	17:43		9	4687m	30deg	4.9kn	90m	2		x	1200m	4	1	500m	Int.	Strmr	Strmr	6300ms	SOL9 SOR 5
163	18:00		9	4671m	13deg	5kn	74m	2		x	1500m	4	1	500m	Int.	Strmr	Strmr	6300ms	Fire rate change
163	18:30		9	4639m	13deg	5.1kn	76m	2		x	1200m	4	1	500m	Int.	Strmr	Strmr	6100ms	Delay dec to 6100ms
163	20:00		9	4600m	11.5deg	4.7kn	83m	2		x	2400m	4	1	500m	Int.	Strmr	Strmr	6100ms	Fire rate inc to 2400ms
163	22:23		9	4525m	22deg	4.2kn	82m	2		x	2400m	4	1	500m	Int.	Strmr	Strmr	6100ms	EOL 9 AC to SOL 10
163	22:34		10	4526m	94deg	4kn	97m	2		x	2400m	4	1	500m	Int.	Strmr	Strmr	6100ms	On line heading 10
164	1:41		10	4556m	94deg	4.9kn	86m	2		x	2400m	4	1	500m	Int.	Strmr	Strmr	6100ms	EOL 10 AC to SOL 11
164	1:51		11	4575m	180deg	4.6kn	97m	2		x	2400m	4	1	500m	Int.	Strmr	Strmr	6100ms	On line heading 11
164	2:46		11	4613m	180deg	4.4kn	90m	2		x	2400m	4	1	500m	Int.	Strmr	Strmr	6300ms	Inc delay
164	5:19		11	4689m	180deg	4.1kn	104m	2		x	2400m	4	1	500m	Int.	Strmr	Strmr	6300ms	EOL 11 AC to SOL 12

164	5:25		12	4690m	90deg	4.5kn	87m	2		x	2400m	4	1	500m	Int.	Strmr	Strmr	6300ms	On line heading 12
164	7:53		12	4717m	90deg	4.3kn	90m	2		x	2400m	4	1	500m	Int.	Strmr	Strmr	6300ms	EOL 12 AC to SOL 13
164	7:56		13	4714m	0deg	4.6kn	88m	2		x	2400m	4	1	500m	Int.	Strmr	Strmr	6300ms	On line heading
164	9:00		13	4685m	0deg	4.3kn	94m	2		x	2400m	4	1	500m	Int.	Strmr	Strmr	6300ms	EOL 13 Haul gear on board
164	17:35		#	4560m	190deg	2.2kn	137m	2		x	2400m	4	1	500m	Int.	Strmr	Strmr	6100ms	Deploy fish SOR 6
164	17:58		14	4560m	233deg	3.2kn	113m	2		x	2400m	4	1	500m	Int.	Strmr	Strmr	6100ms	SOL14
164	19:08		14					3		x	2400m	4	1	500m	Int.	Strmr	Strmr		EOL14 Haul Gear on deck

6.4 Piston Coring

6.4.1 Core sampling

The piston coring system used was the AGC Long Corer which uses coupled core barrel sections in 10 ft (305 cm) lengths (Table 7). In deep water the device is typically rigged using a maximum of four or five barrels. During this cruise the system was typically rigged with four barrels (1220 cm). The core head itself is 3 m long, 0.6 m in diameter and weighs approximately 1350Kg. Each barrel has an internal diameter of 4.25” (10.8cm), a 3/8” (9.5mm) wall thickness with twin exterior Victaulic type grooves cut at each end. Pipe sections are joined using exterior couplings which are secured by set screws into grooves. The barrels are lined with Cellulose acetate butyrate (CAB) plastic pipe which is also in 10 ft (305cm) lengths to return sediment core samples with an outer diameter of 99.2 mm. A split piston with O-rings and a variable orifice size (split piston orifice used for the first two cores was 7/64” then we switched to 3/32”) and a standard core catcher was used at all coring sites. The trip arm for the core system also supported a 4.25” (10.8cm) diameter gravity corer with a single 7ft (2.14m) 10” barrel and 300 lb (135 kg) head comprised of circular lead weights.

Table 7: List of cores and stations

Station number	***Sample type***	***Latitude/ Longitude***	***Water depth (m)***	***Core length (cm)***	***No. of sections***	***Location***
0001	Piston	42.166750 / -55.924728	4220	750.5	5	North Atlantic Ocean – Laurentian Fan
0001	Trigger	42.166750 / -55.924728	4220	228.5	2	North Atlantic Ocean – Laurentian Fan
0002	Piston	41.868108 / -57.494161	4645	631.5	5	North Atlantic Ocean – Seaward of the Gully
0002	Trigger	41.868108 / -57.494161	4645	0	0	North Atlantic Ocean – Seaward of the Gully
0003	Piston	41.939951 / -56.774890	4862	725	5	North Atlantic Ocean – Laurentian Fan
0003	Trigger	41.939951 / -56.774890	4862	202	2	North Atlantic Ocean – Laurentian Fan

The ship’s large Pengo winch was used for coring with ¾” wire cable. The North Pacific foredeck crane was used to deploy and recover the heavy coring equipment and a ship's trawl block was used off the side arm of this crane to hoist the pilot core. A small GSCA tugger winch was used to rig and recover the pilot core plumbed to a DFO power pack. The corer was handled on deck using a system that included a rotating core-head cradle, outboard support brackets, a monorail transport system with 2 one ton chain hoists, a lifting winch and a processing half-height container. Each recovered core was broken down at the barrel joints and moved to the processing half-height container via the monorail, where each 10ft (305cm) section of liner was extruded from the barrel and cut in half and labelled.

The corer worked reasonably well. Liner implosions were minimal.

6.4.2 Onboard piston core processing and subsampling

All cores were processed according to standard GSC Atlantic core procedures (refer to Mudie et al. 1984). All piston and trigger weight cores were identified alphabetically by section at the time of dismantling individual 10 ft core barrels from the bottom to the top, commencing with the bottommost core barrel and proceeding to the uppermost barrel containing sediment. Each 10 ft length of liner was extruded from the barrel and cut in half, using a modified pipe cutter, in the half height container. The sediment in the liner was cut using a wire saw and the section ends were carefully capped to minimize disturbance to the sediment surface. The top end cap was labelled with the cruise number, station number, section label and top. The base of the core is designated with the letter A and the top of the base section is designated as B. The base section is AB. Each section was brought into the GP Lab and stored horizontally on the benches. Each core, starting with the base section AB, was processed using the following procedure. The core liner was labelled with an up arrow, cruise number, station number, section label and the top and base of the section were labelled with the appropriate letter.

The top and base of every section of TWC and PC was considered for physical property measurements and given the appropriate conditions, strength measurements and constant volume samples were taken. Inert packing was placed in the voids created by the constant volume sampling, and the ends of each core section were re-capped, taped then sealed with wax at both ends to prevent water loss, and then the lengths of each section were measured.

The sealed core sections were stored upright in the refrigerated reefer container and maintained at 4°C. All core cutters and catchers were measured, labelled, placed in sections of liner, waxed and stored upright in buckets in the refrigerated container. All extruded core sections due to sediment expansion or core processing methods were likewise labeled and stored. All samples and subsamples were catalogued and their location information within the container was recorded in an excel spreadsheet. All station location information, core section lengths, extruded pieces and cutter/catcher lengths, sediment description and core performance information have been documented on deck sheets and then input into the expedition database (ED). The ED has been backed up and will be verified before downloading into the main ORACLE sample database.

6.4.3 Physical properties measurements

Undrained shear strength measurements and constant volume samples were taken at the ends of each section if the condition of the sediment allowed (Table 8). The constant volume sampler was inserted into the end of the section, the undrained shear strength measurement was taken and then the constant volume sampler was removed. The undrained shear strength was measured using a hand-held Hoskin Scientific Torvane according to ASTM Test Method D2573-94 Standard Test Method for Field Vane Shear Test in Cohesive Soil. The dial on the Torvane was zeroed, the fins on the vane were gently pushed into the sediment until they were completely inserted. The dial was rotated at a constant rate until the sediment failed.

The Torvane dial reading ranges from 0 to 1 and reports values in kg-force/cm^2 units (1 kg/cm^2 = 98.07 kPa). The Torvane has three adapter vanes as described below:
L - Sensitive vane has a range of 0 to 0.2 Kg-force/cm^2
Su = dial reading * 0.2 Kg-force/cm^2
M - Regular vane has a range of 0 to 1.0 Kg-force/cm^2
Su = dial reading * 1 Kg-force/cm^2
S - High capacity vane has a range of 0 to 2.5 Kg-force/cm^2
Su = dial reading * 2.5 Kg-force/cm^2
During the cruise, the sensitive and regular vanes were used for a total of 24 undrained shear strength measurements.

Constant volume samples for bulk density and water content determinations were taken by inserting stainless steel samplers of a known volume. Prior to insertion, the sampler was lightly sprayed with Pam cooking oil and gently wiped with a small Kimwipe tissue. The bevelled edge of the sampler was placed on the flat sediment surface and the carefully inserted into the sediment at a constant rate using two flat headed spatulas. The sampler is inserted at a constant rate to minimize compression of the sediment within the sampler. The sampler was then carefully removed and the sediment was trimmed using a wire saw and extruded into a pre-weighed 1 oz screw-top glass bottle.

The bottle cap was then labelled and sealed using electrical tape to prevent the lid from loosening. A total of 33 constant volume samples were taken during the cruise. The samples will be weighed, dried at 105°C for 24 hours and re-weighed to determine bulk density, dry density and water content according to ASTM Test Method D 2216-90 (revision of 2216-63, 2216-80) Standard method for laboratory determination of water (moisture) content of soil and rock.

All relevant information for the strength measurements and constant volume samples was recorded on data sheets and input into Excel spreadsheets and will be incorporated into the physical property database.

Table 8: Summary of 2016011Phase1 physical property sampling

Station #	Sample type	# of Torvane measurements	# of constant volume samples
0001	TWC	2	2
0001	PC	7	7
0002	TWC	0	0
0002	PC	5	8
0003	TWC	2	8
0003	PC	8	8

REFERENCES

Hand, B.M., 1974. Supercritical flow in density currents. *Journal of Sedimentary Petrology*, 44(3), pp.637–648.

Mudie, P.J. et al., 1984. Standard Methods For Collecting, Describing and Sampling Quaternary Sediments At the Atlantic Geoscience Center. *Geological Survey of Canada Open File*, 1044, p.47.

APPENDICES

Stratigraphic location of cores

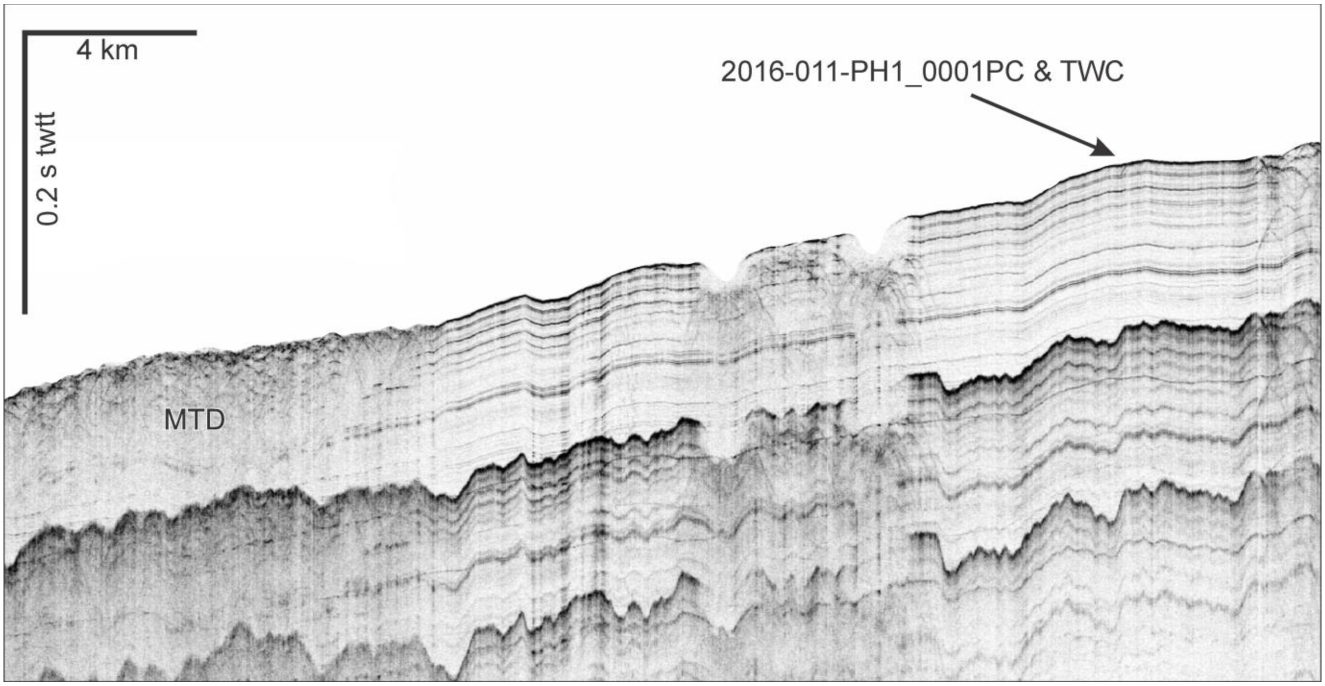

Figure 6: Huntec DTS seismic profile illustrating the stratified nature of the location of core 2016-011-0001PC-TWC

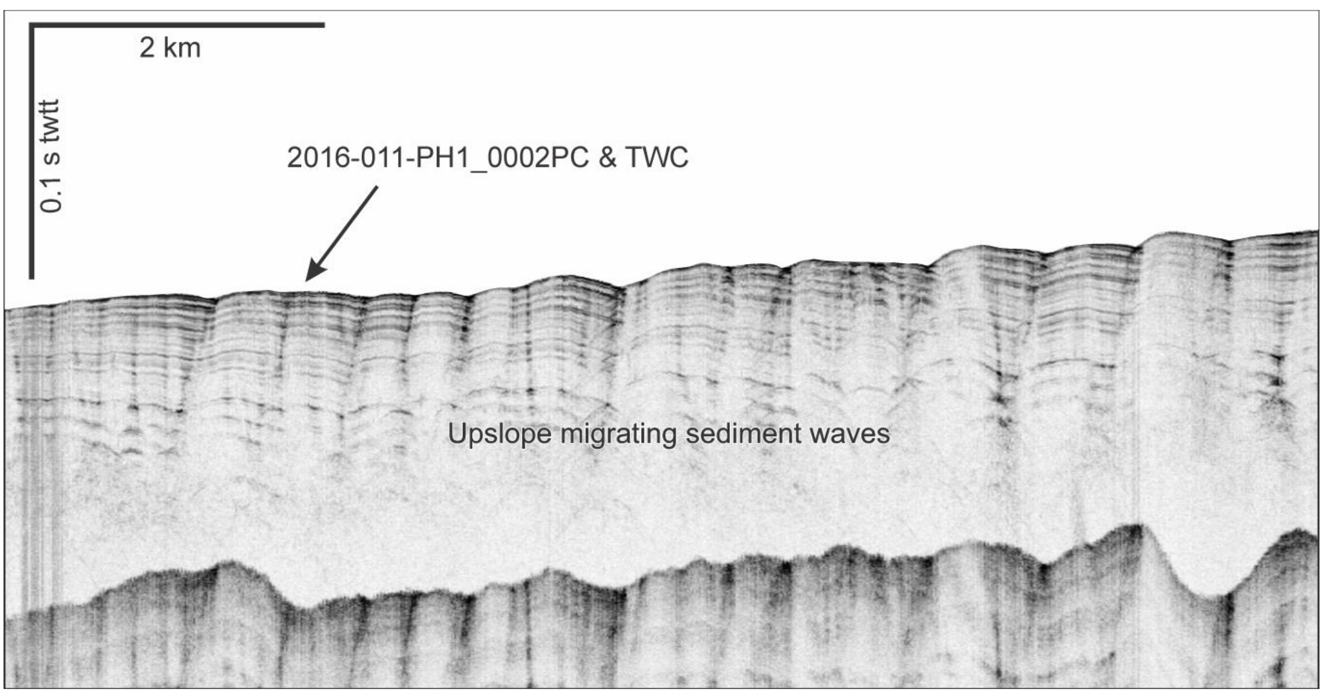

Figure 7: Huntec DTS seismic profile illustrating the stratified nature of the location of core 2016-011-0002PC-TWC

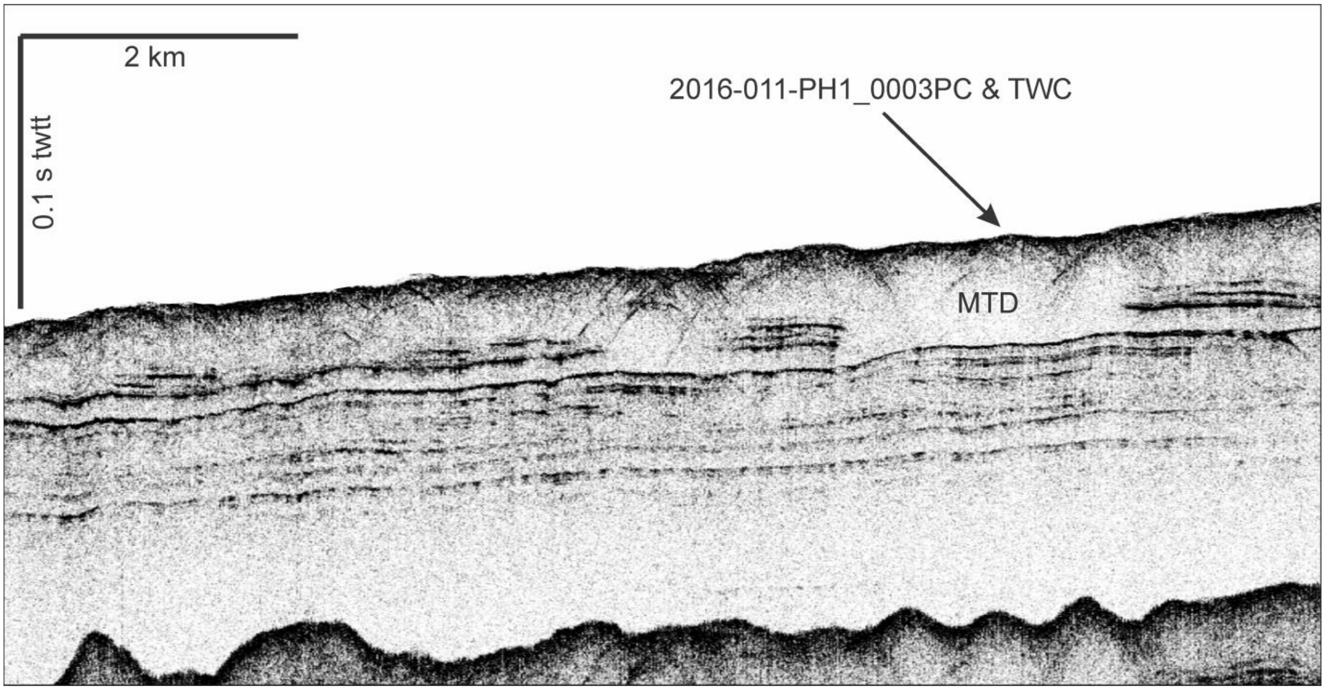

Figure 8: Huntec DTS seismic profile illustrating the chaotic nature (MTD) of the location of core 2016-011-0003PC-TWC

Seismic profiles collected during the cruise

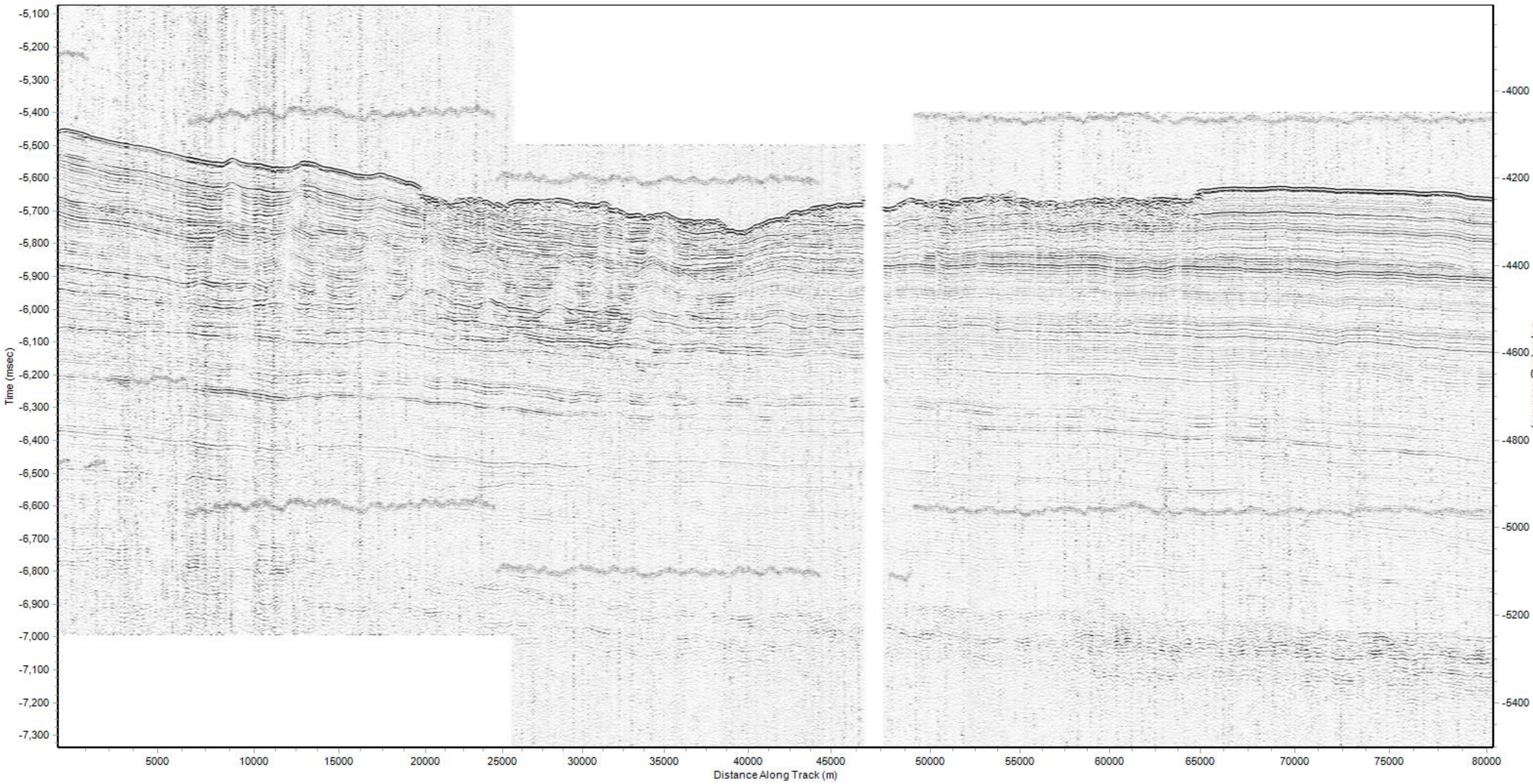

Figure 9: GI gun line 4

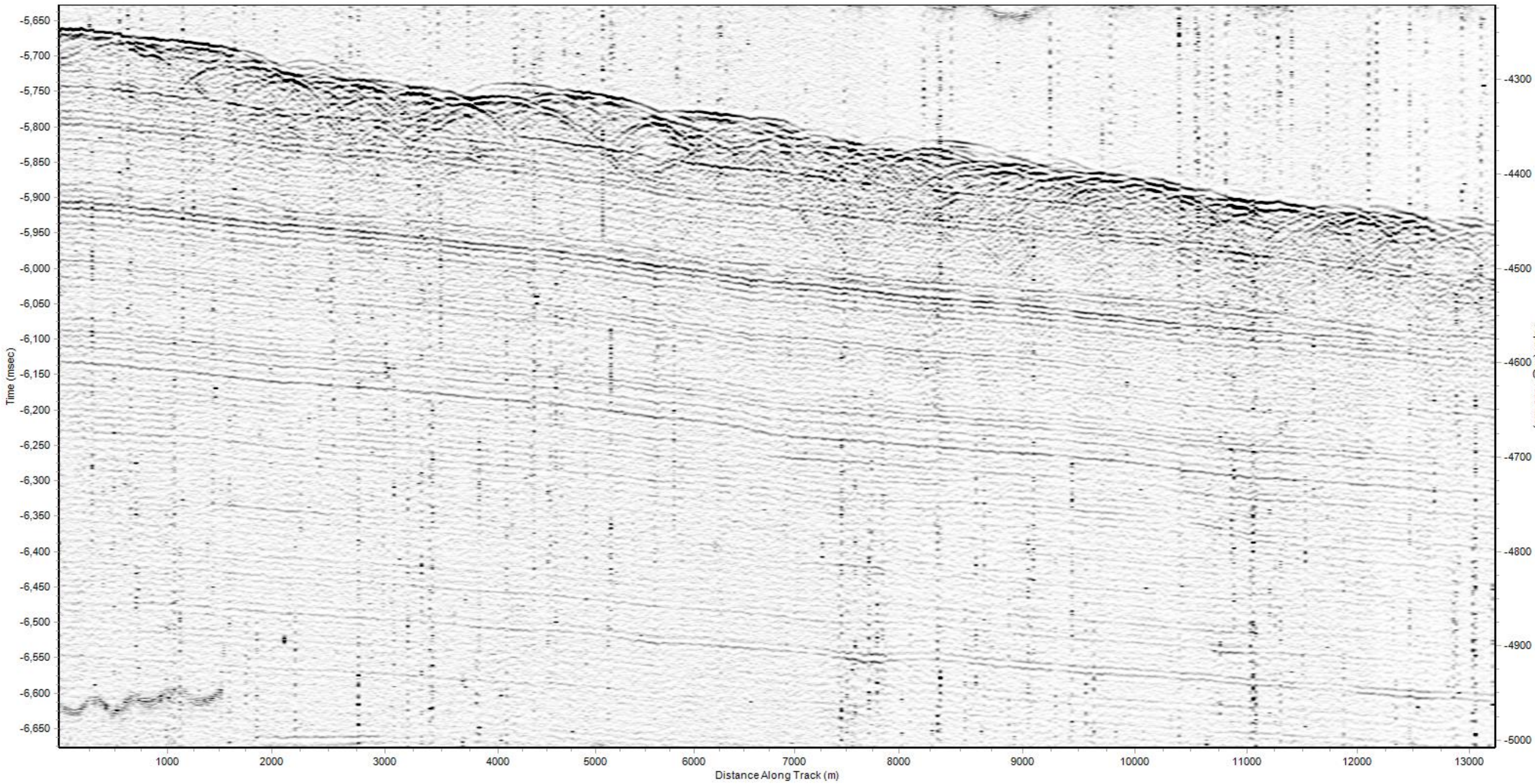

Figure 10: GI gun line 5

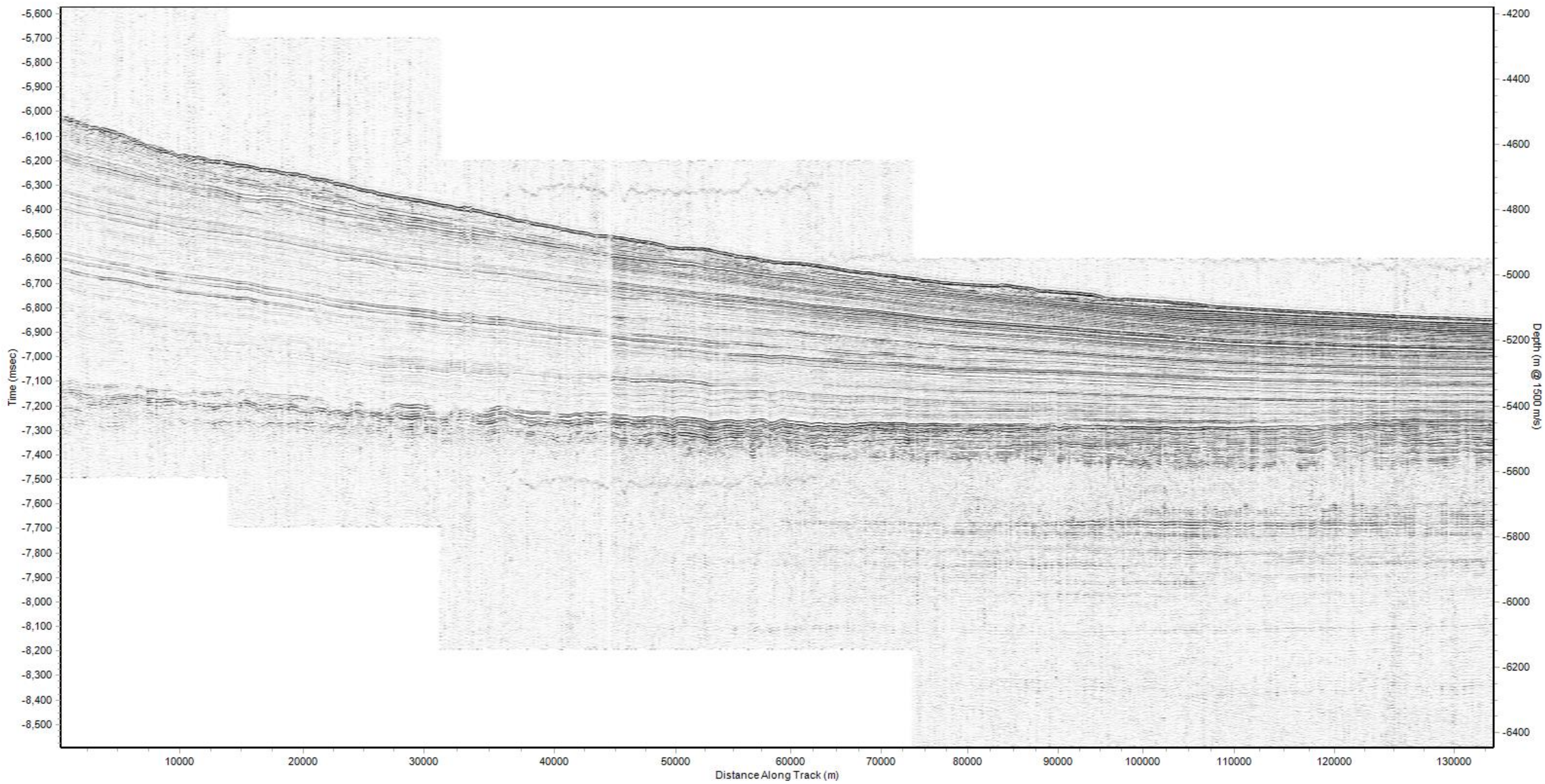

Figure 11: GI gun line 5 continued

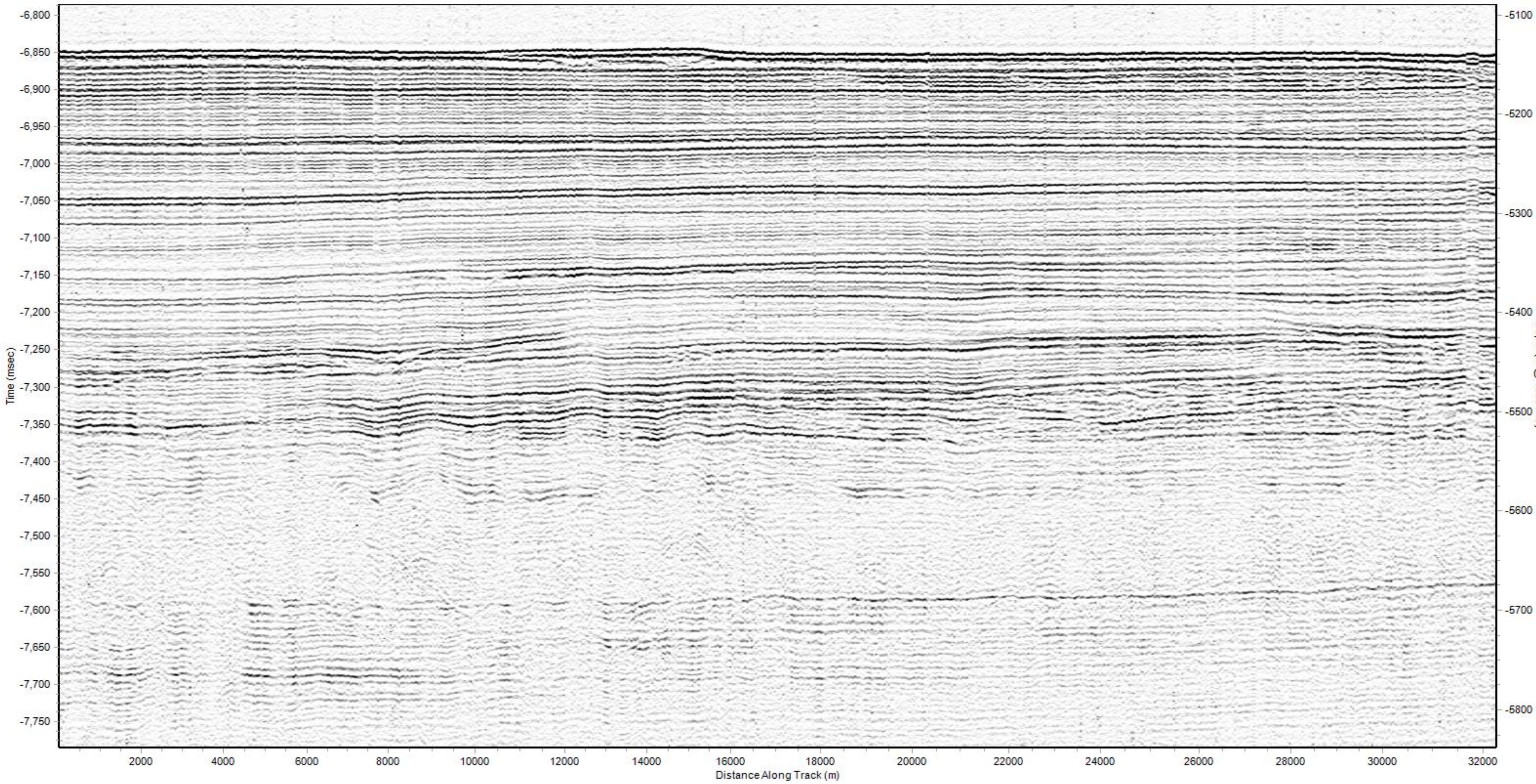

Figure 12: GI gun line 6

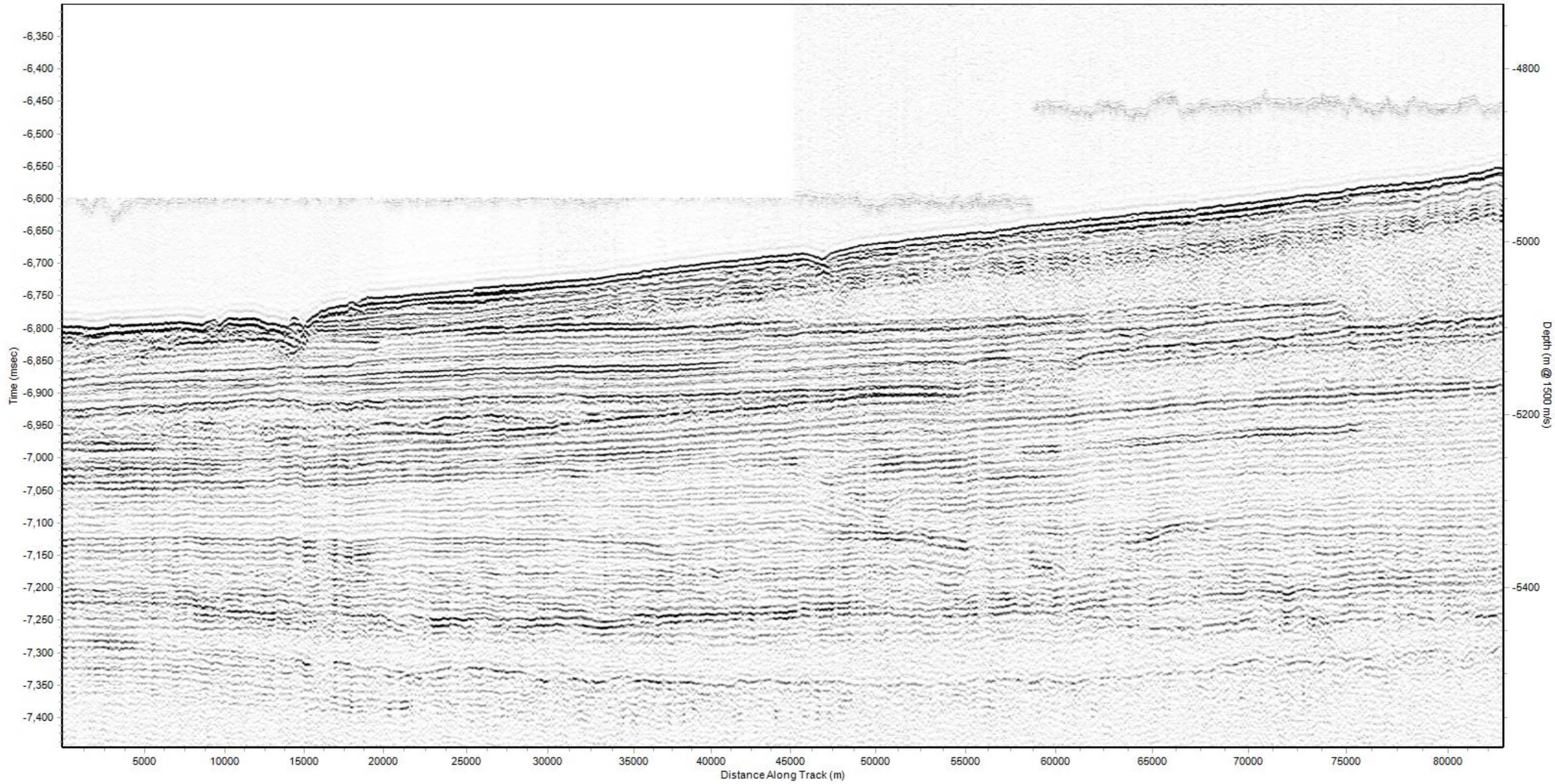

Figure 13: GI gun line 7

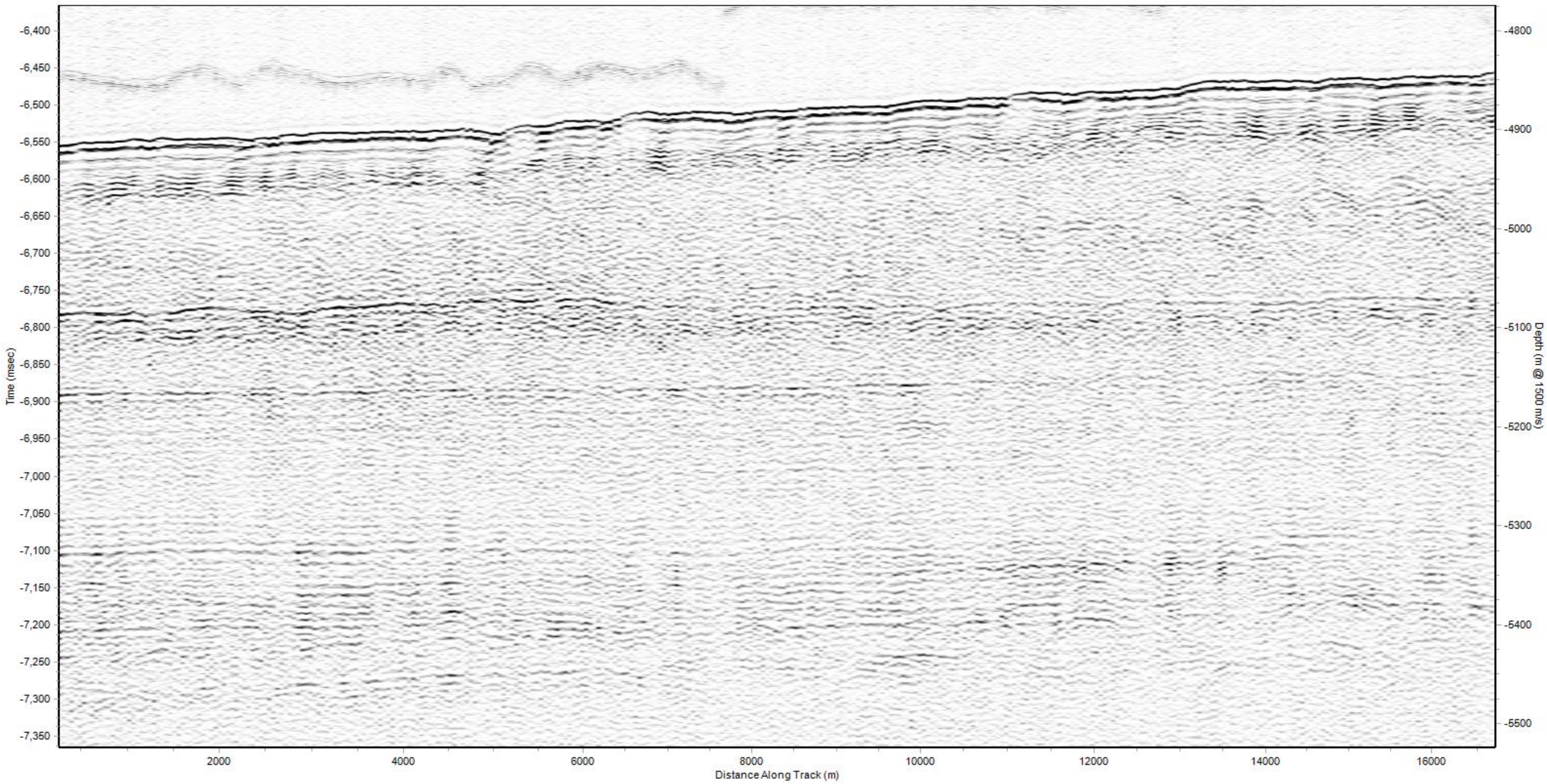

Figure 14: GI gun line 8

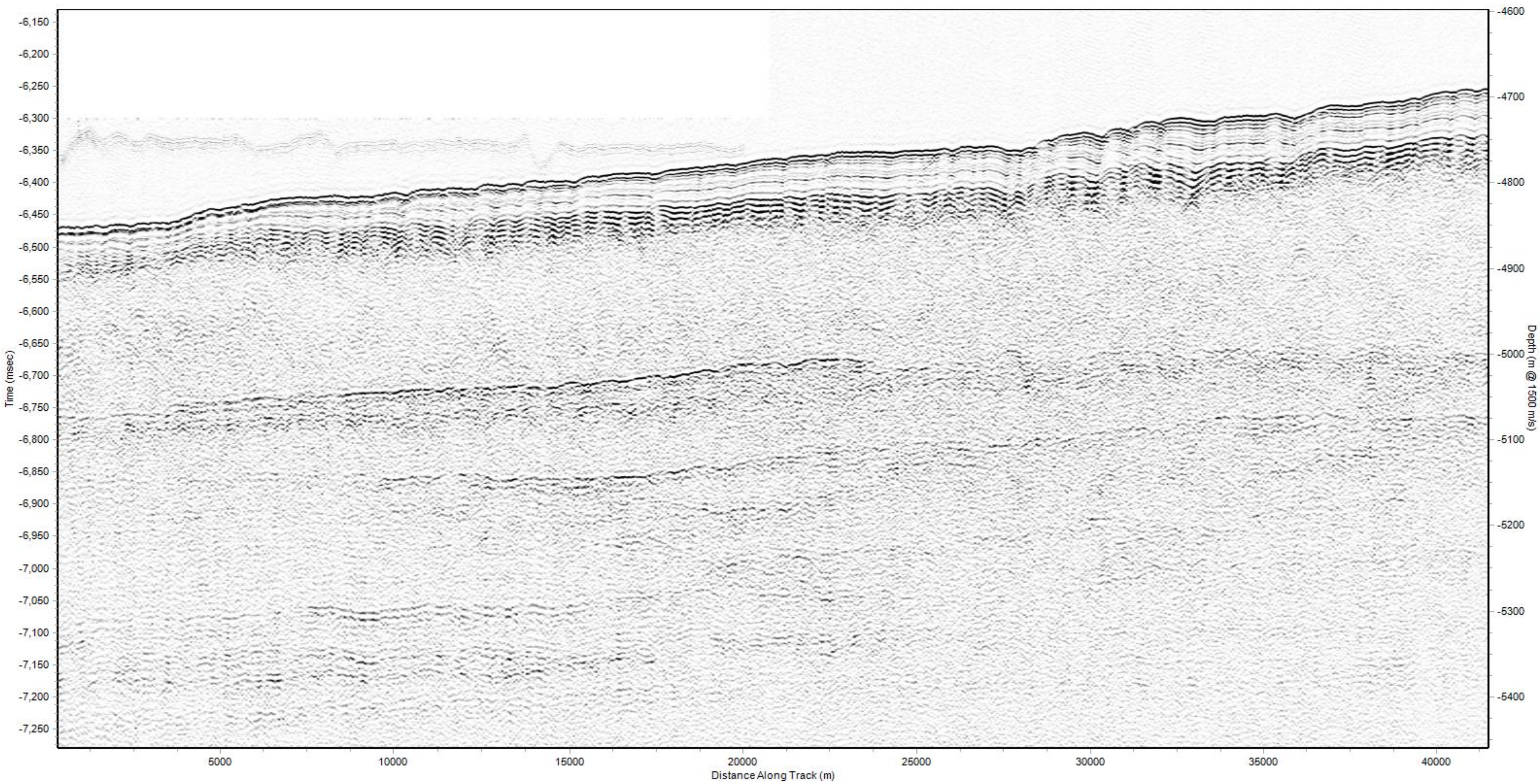

Figure 15: GI gun line 9

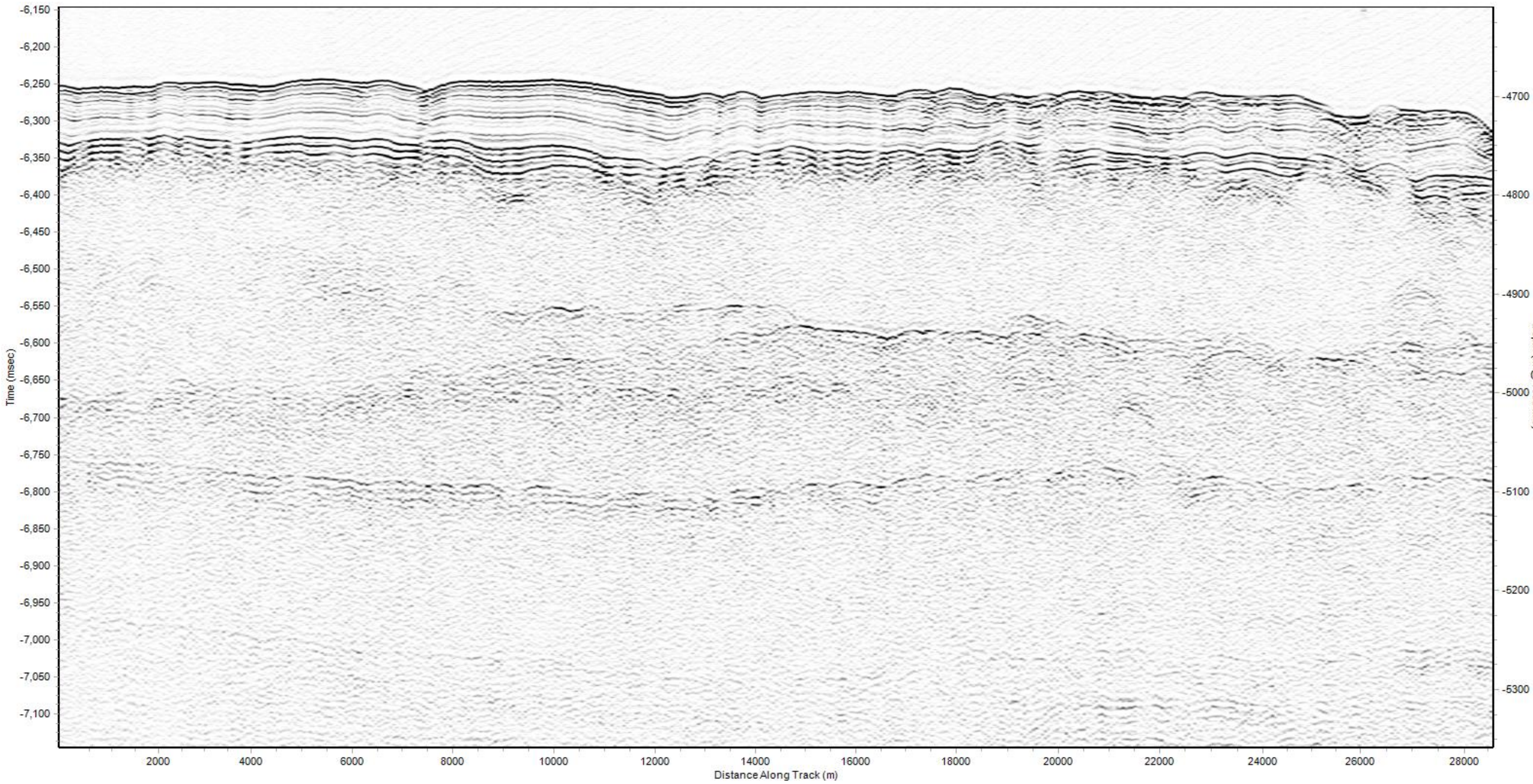

Figure 16: GI gun line 10

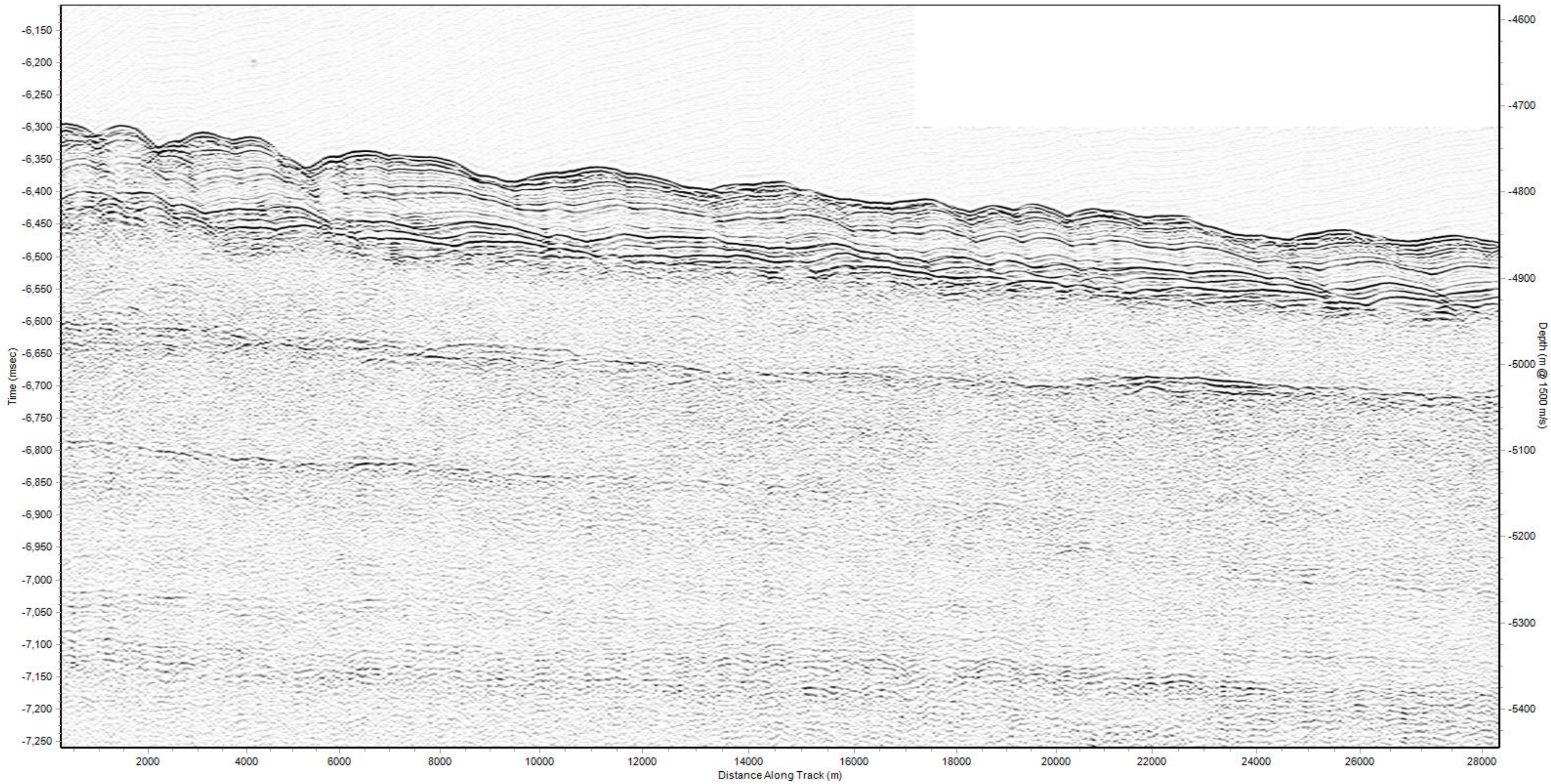

Figure 17: GI gun line 11

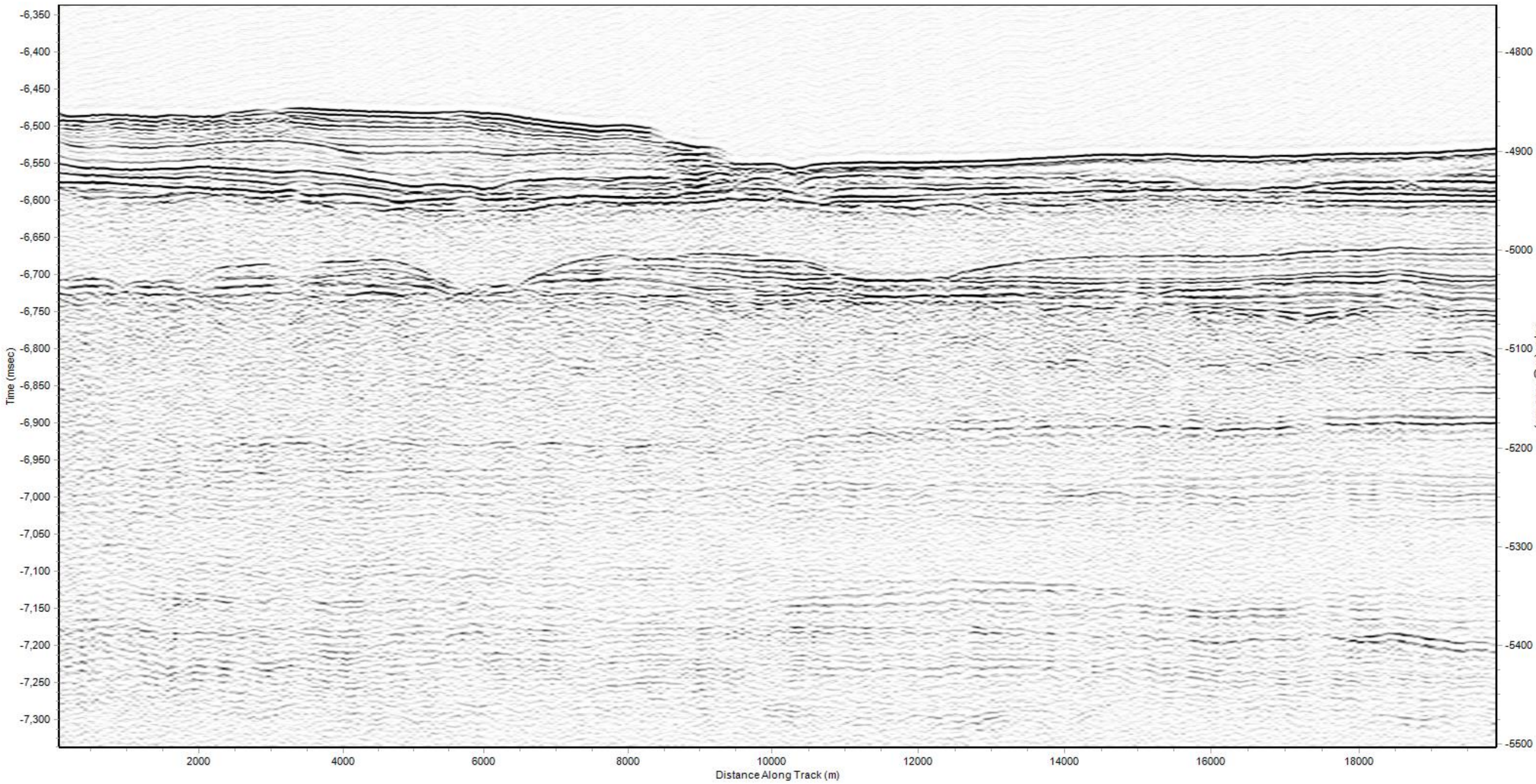

Figure 18: GI gun line 12

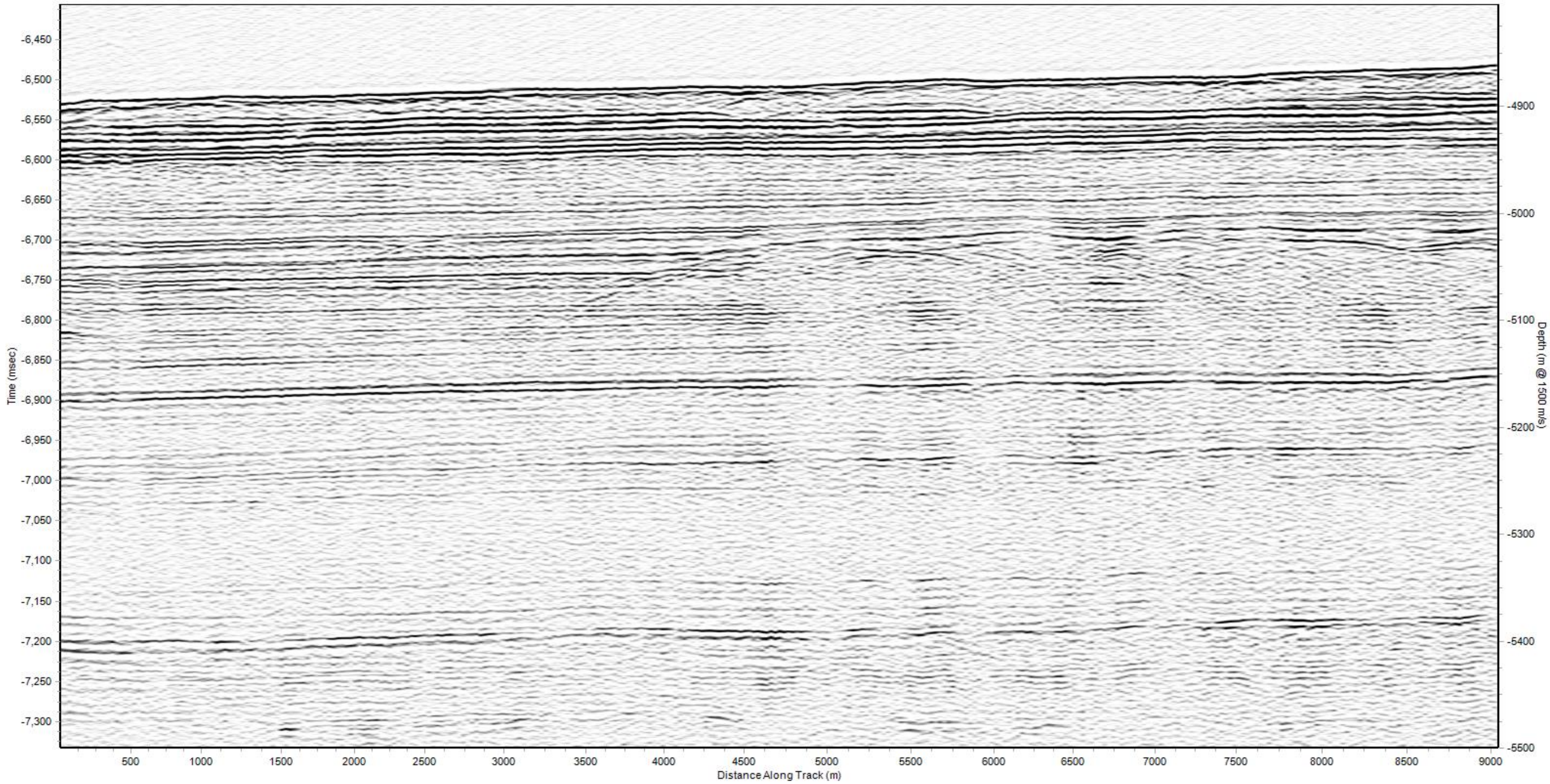

Figure 19: GI gun line 13

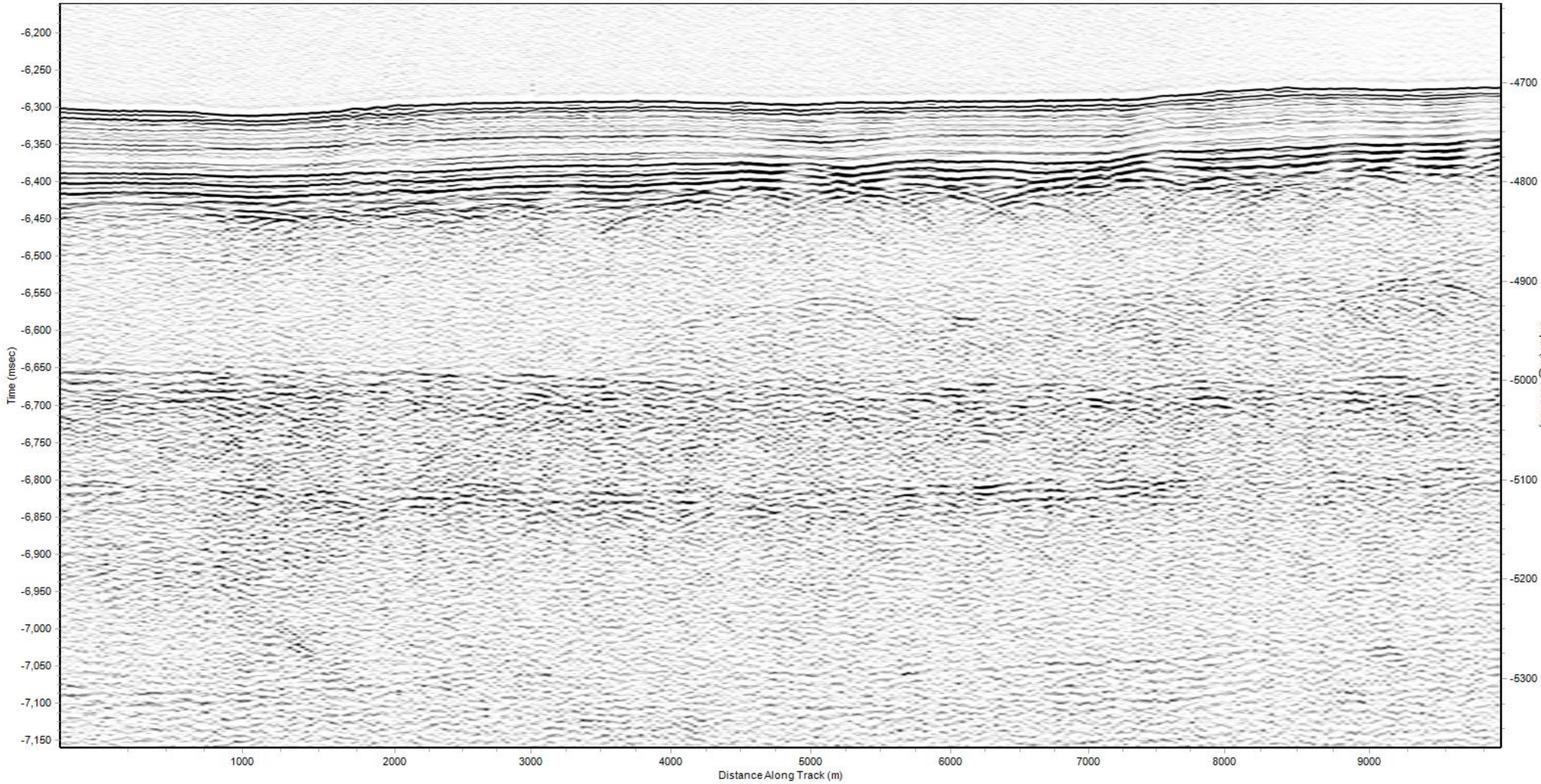

Figure 20: GI gun line 14

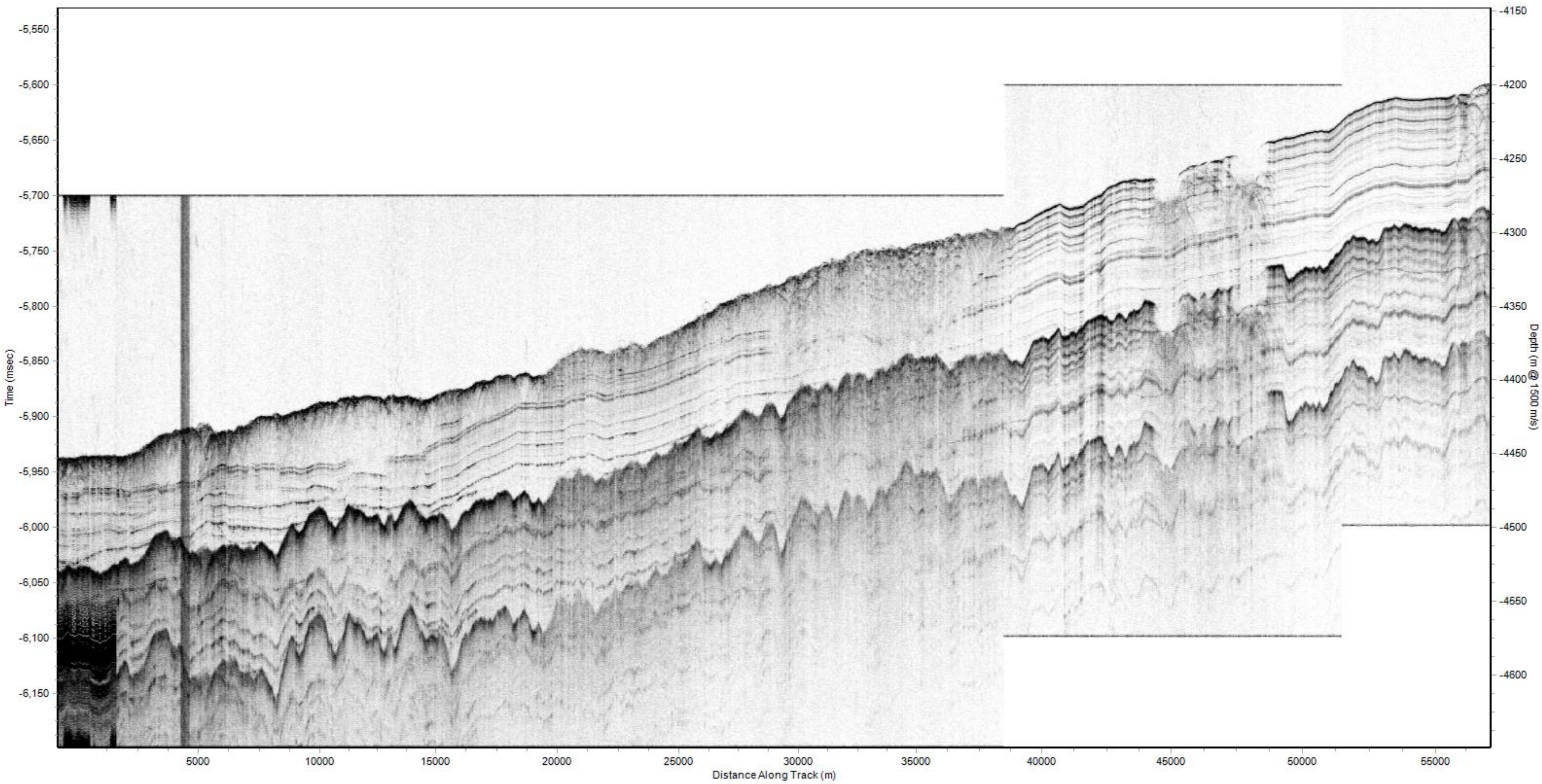

Figure 21: Huntec DTS line1

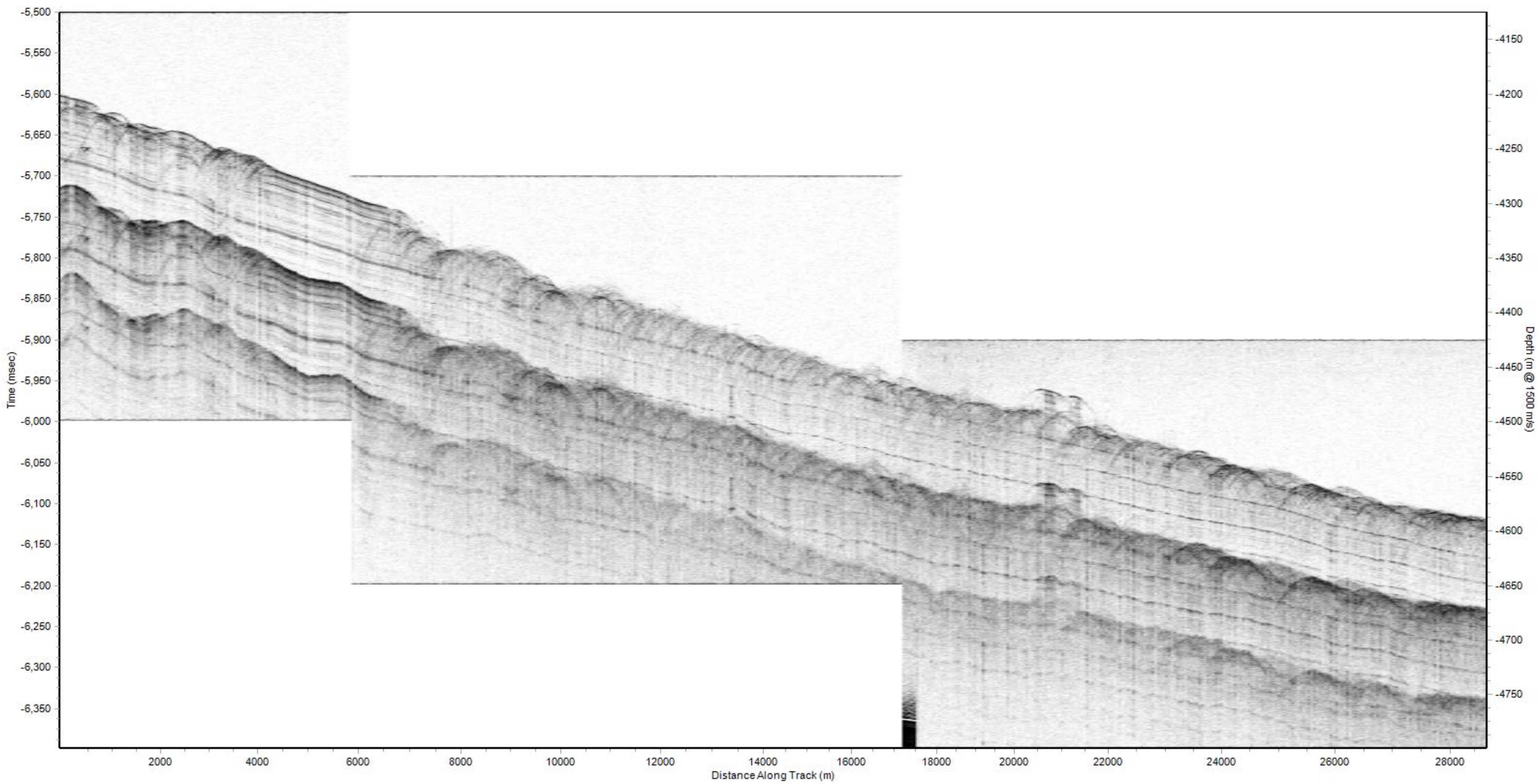

Figure 22: Huntec DTS line 2

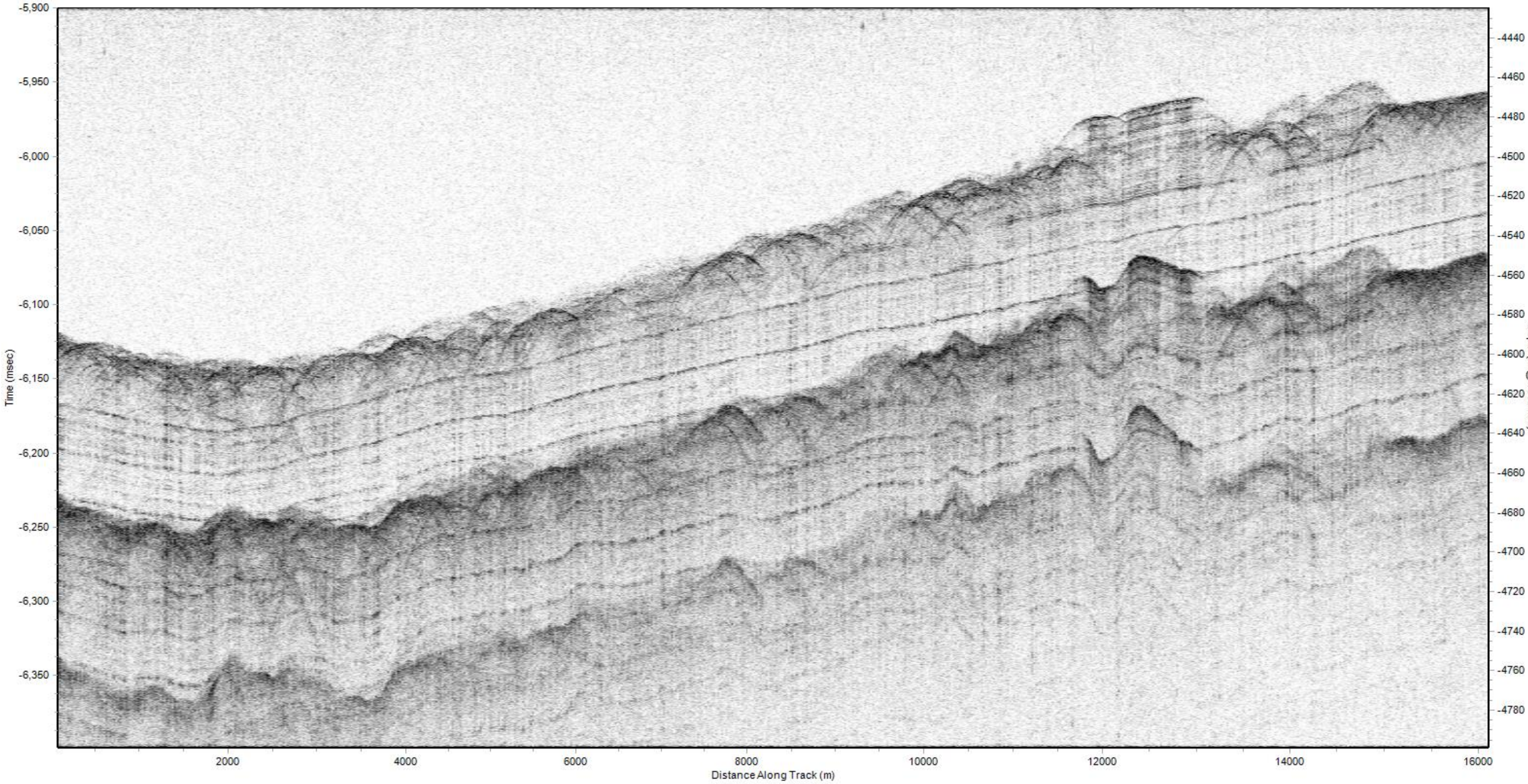

Figure 23: Huntec DTS line 3

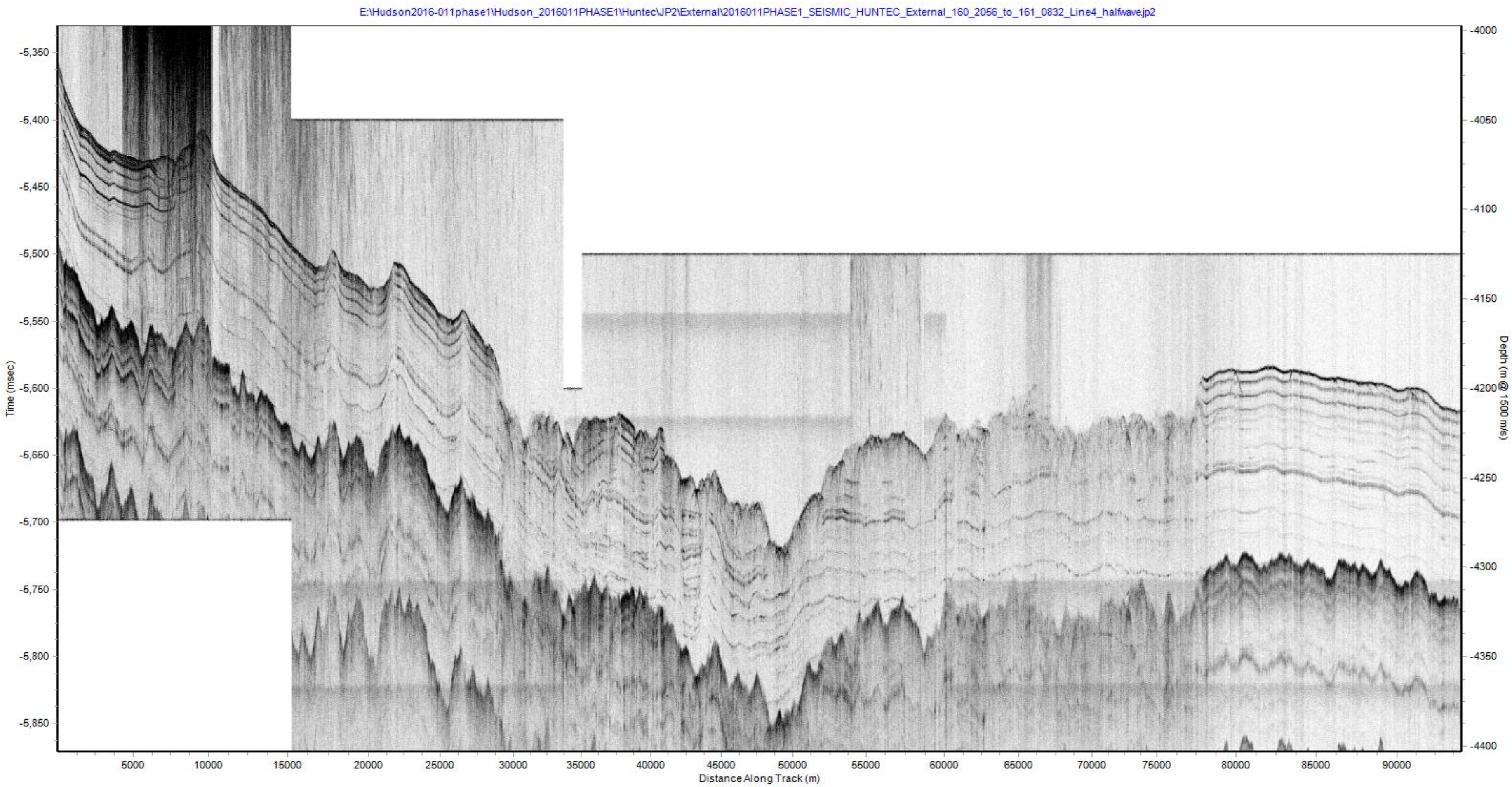

Figure 24: Huntec DTS line 4

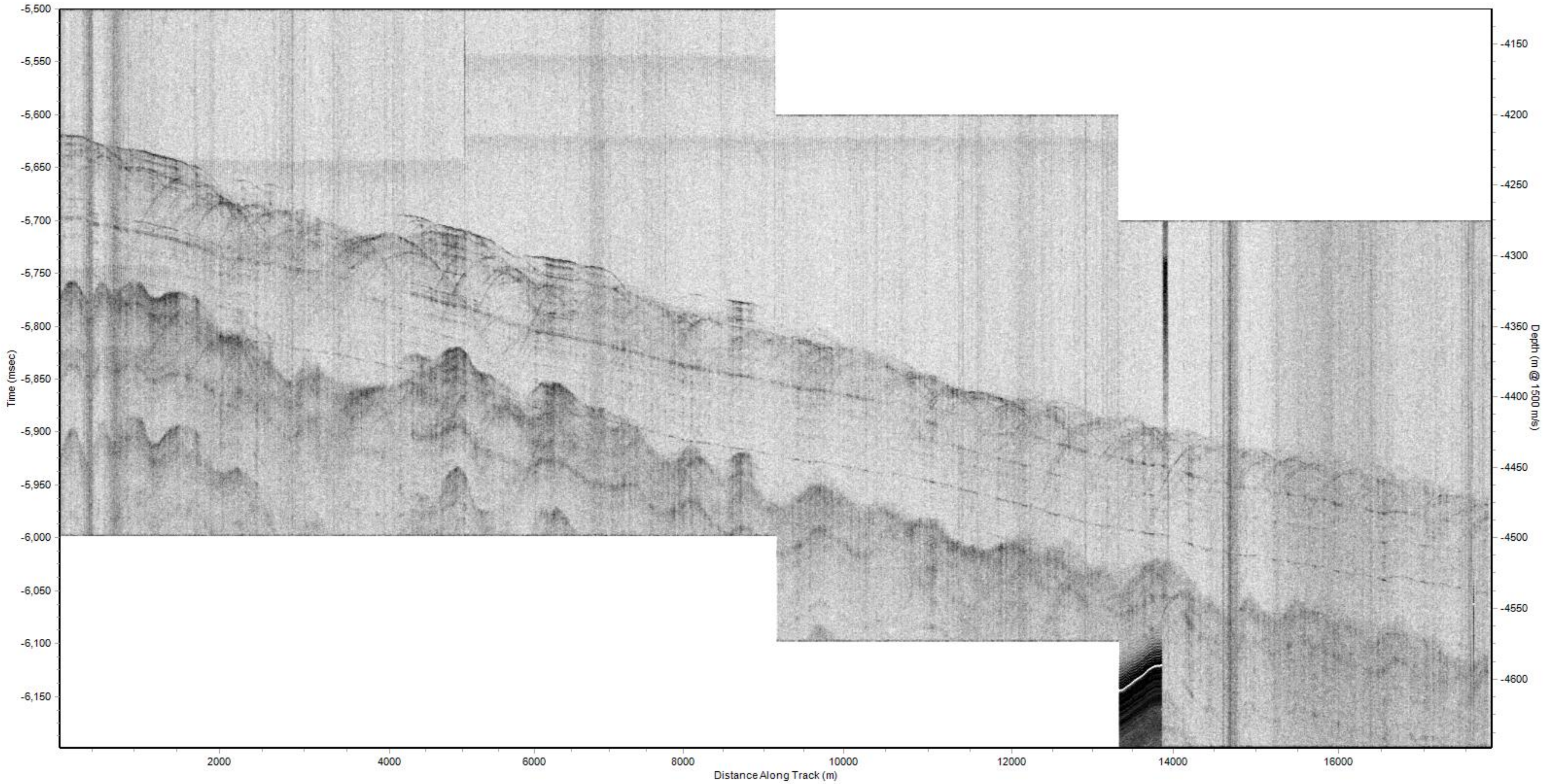

Figure 25: Huntec DTS line 5

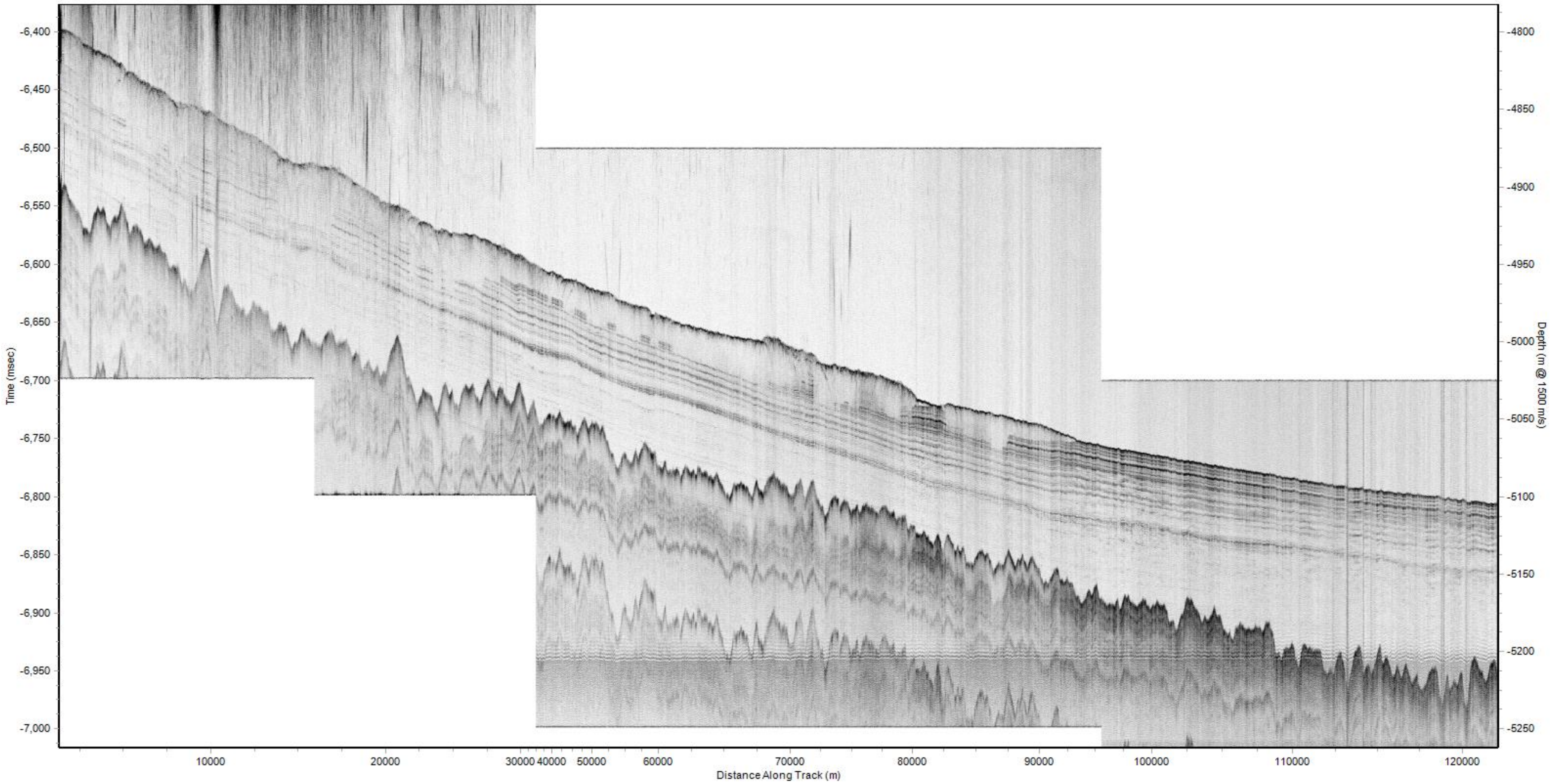

Figure 26: Huntec DTS line 5 continued

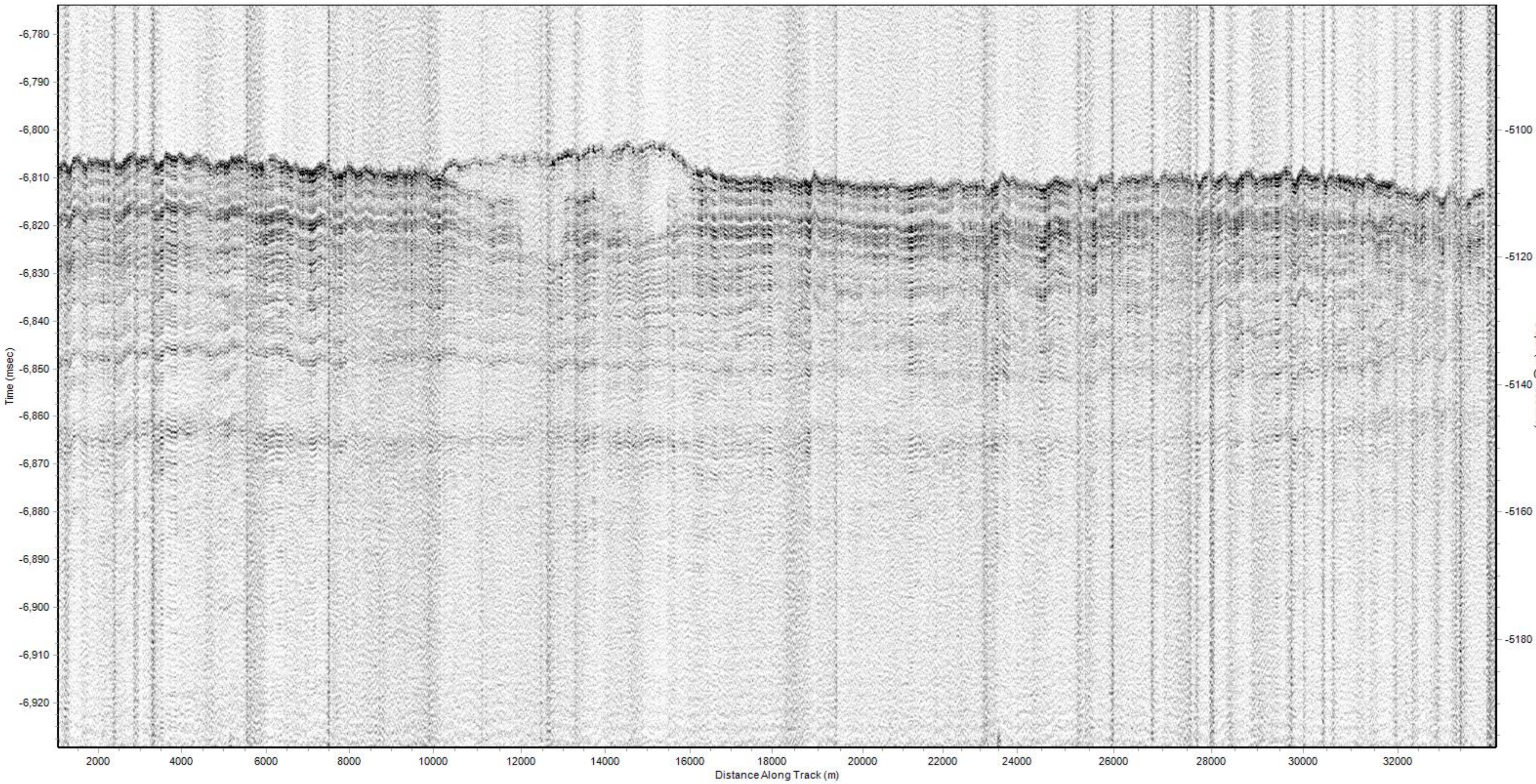

Figure 27: Huntec DTS line 6

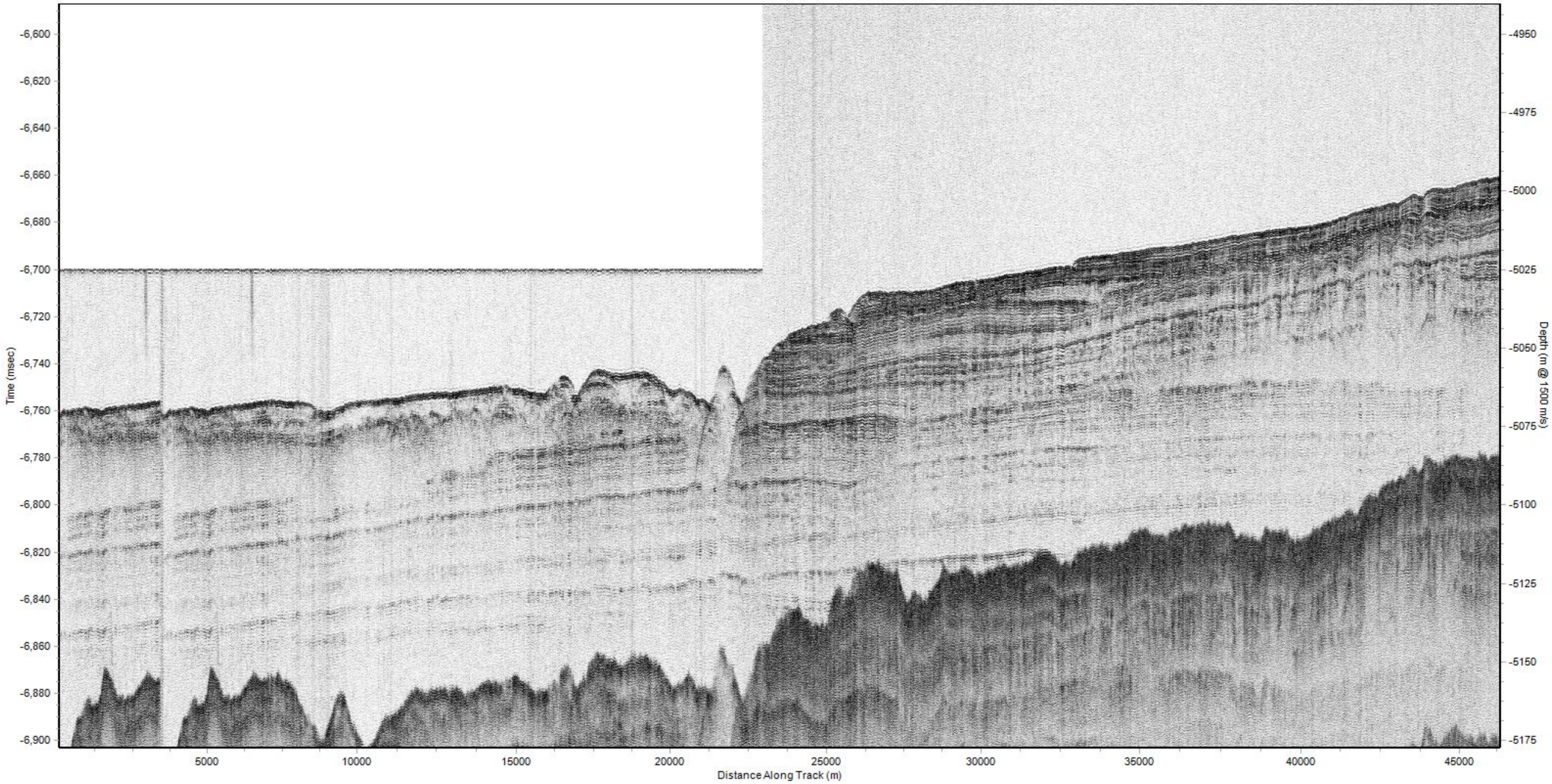

Figure 28 : Huntec DTS line 7

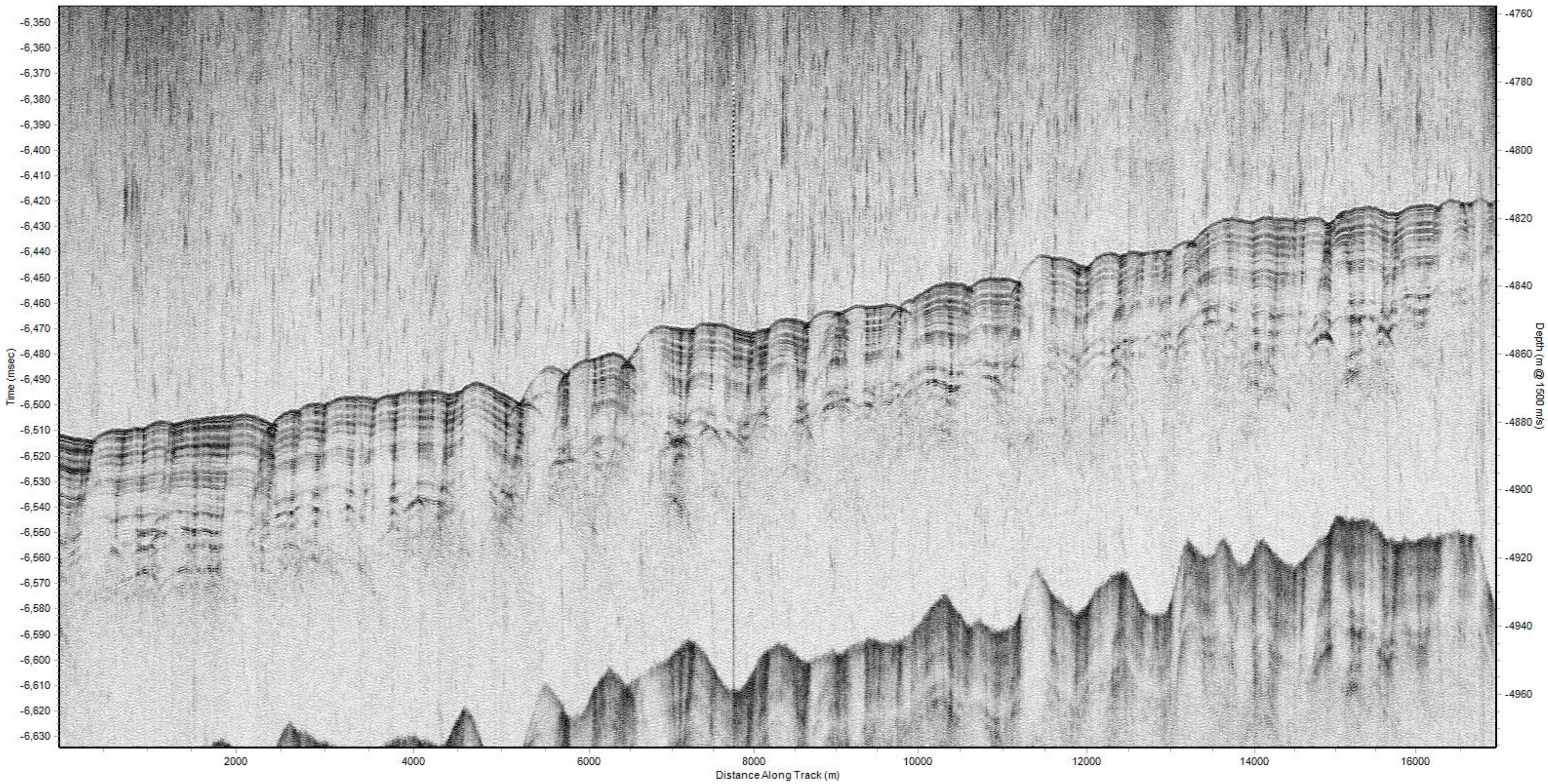

Figure 29: Huntec DTS line 8

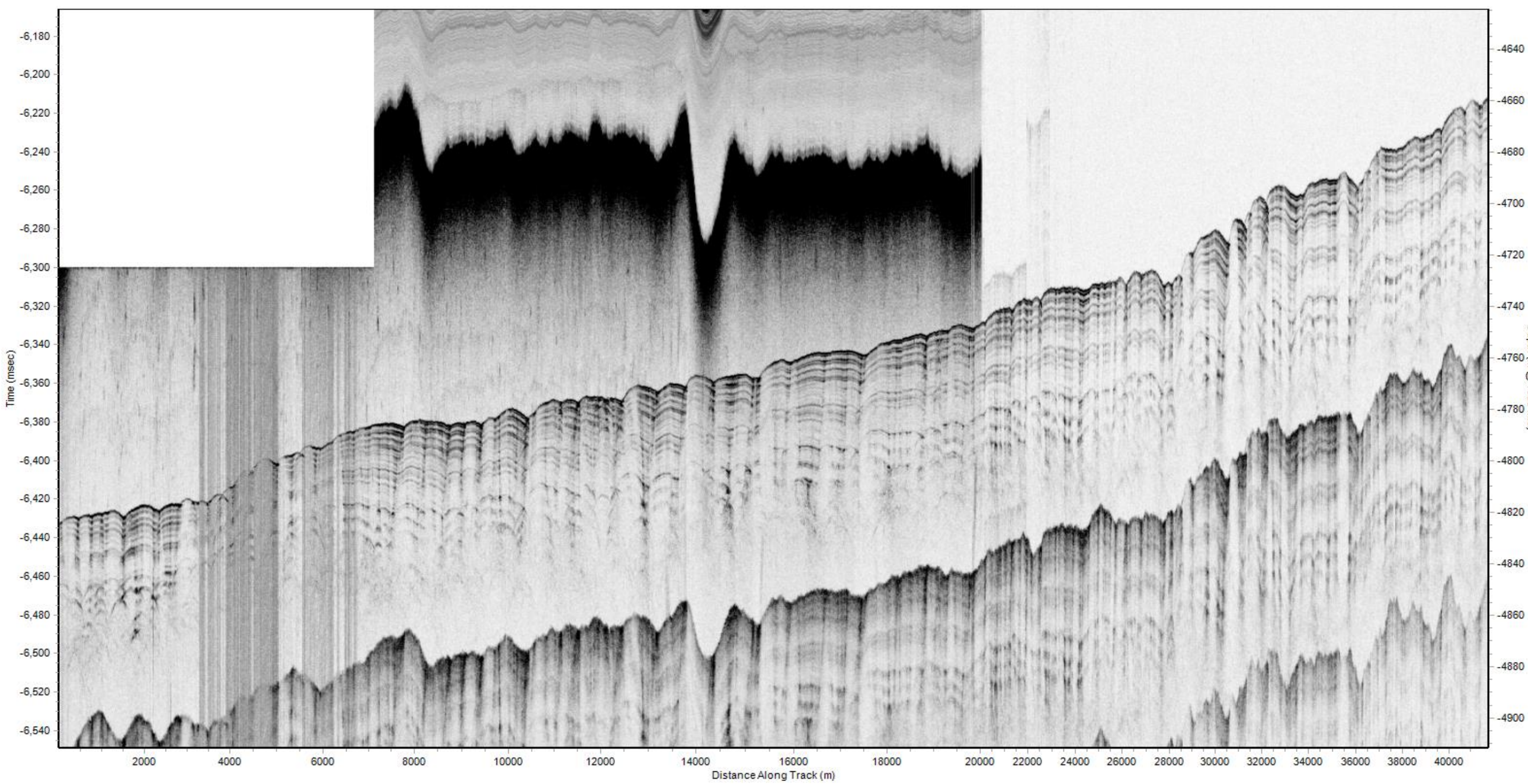

Figure 30: Huntec DTS line 9

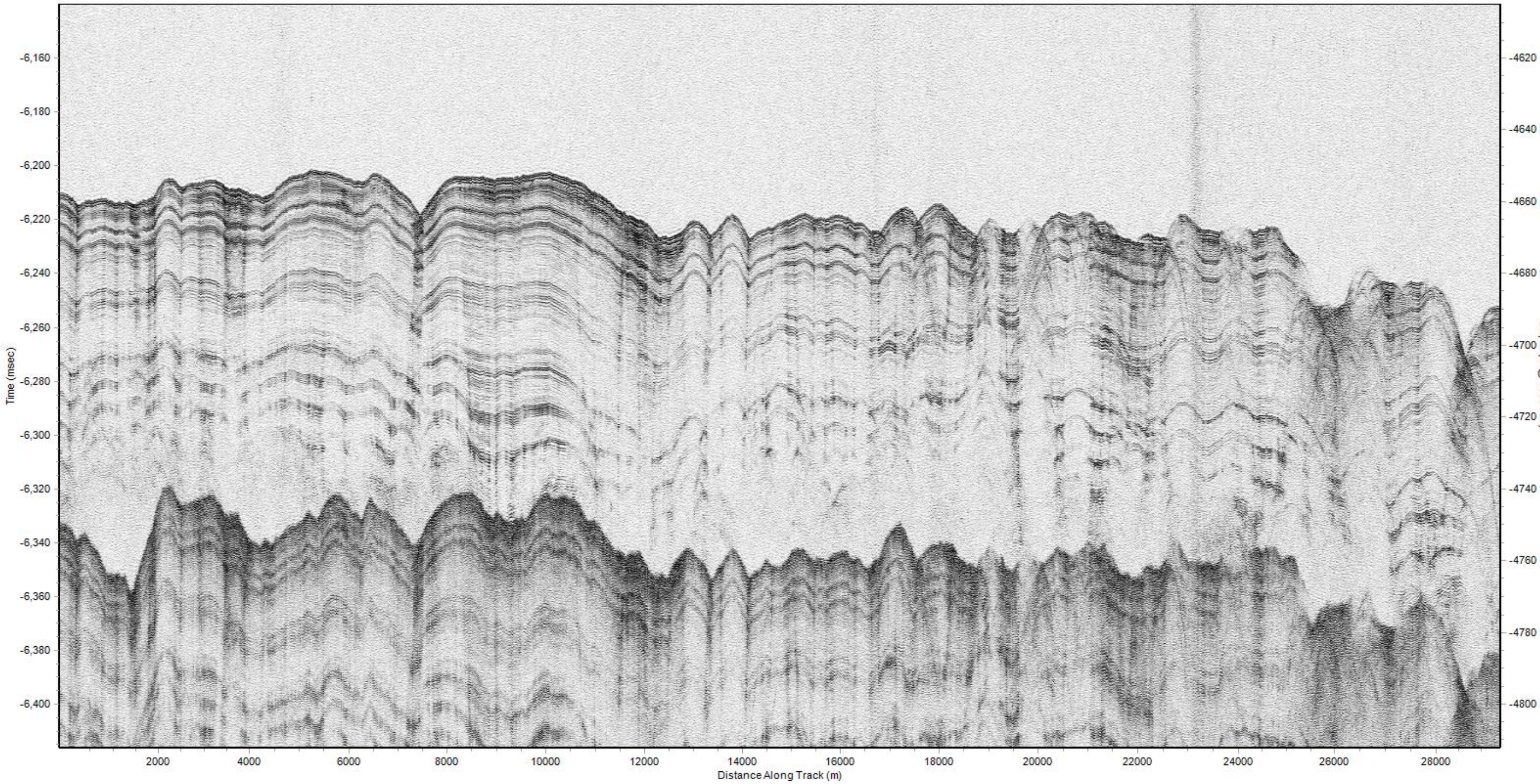

Figure 31: Huntec DTS line 10

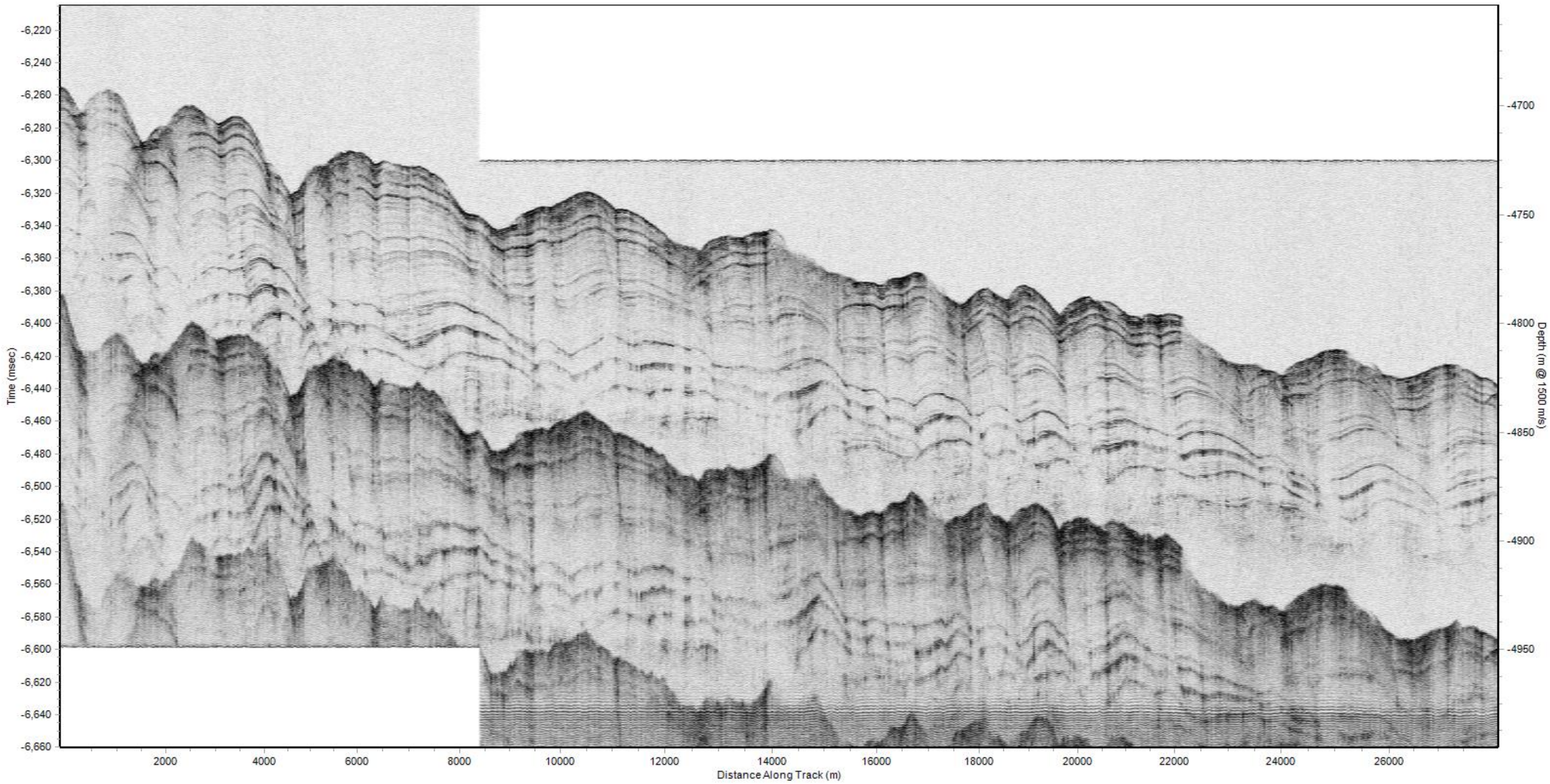

Figure 32: Huntec DTS line 11

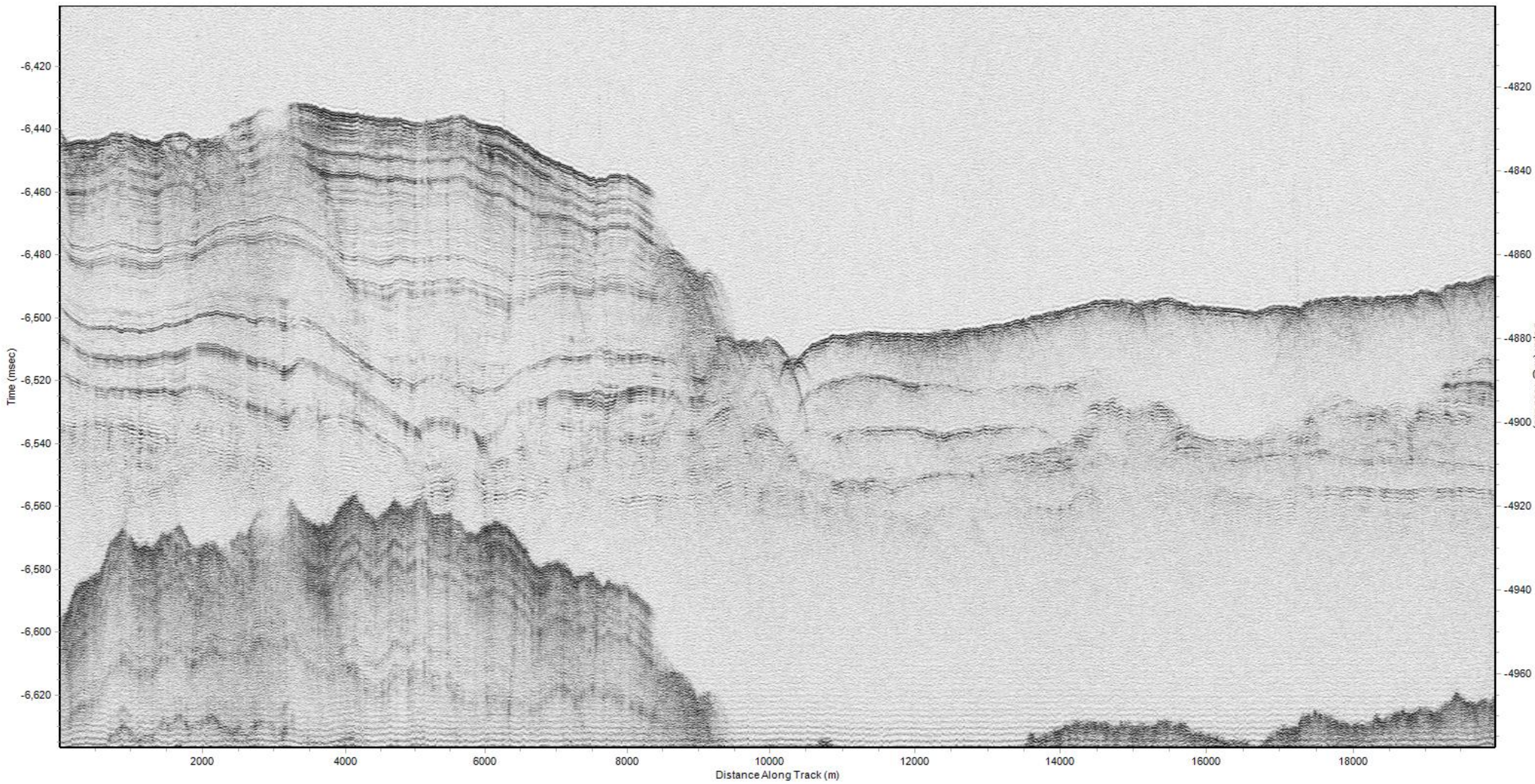

Figure 33: Huntec DTS line 12

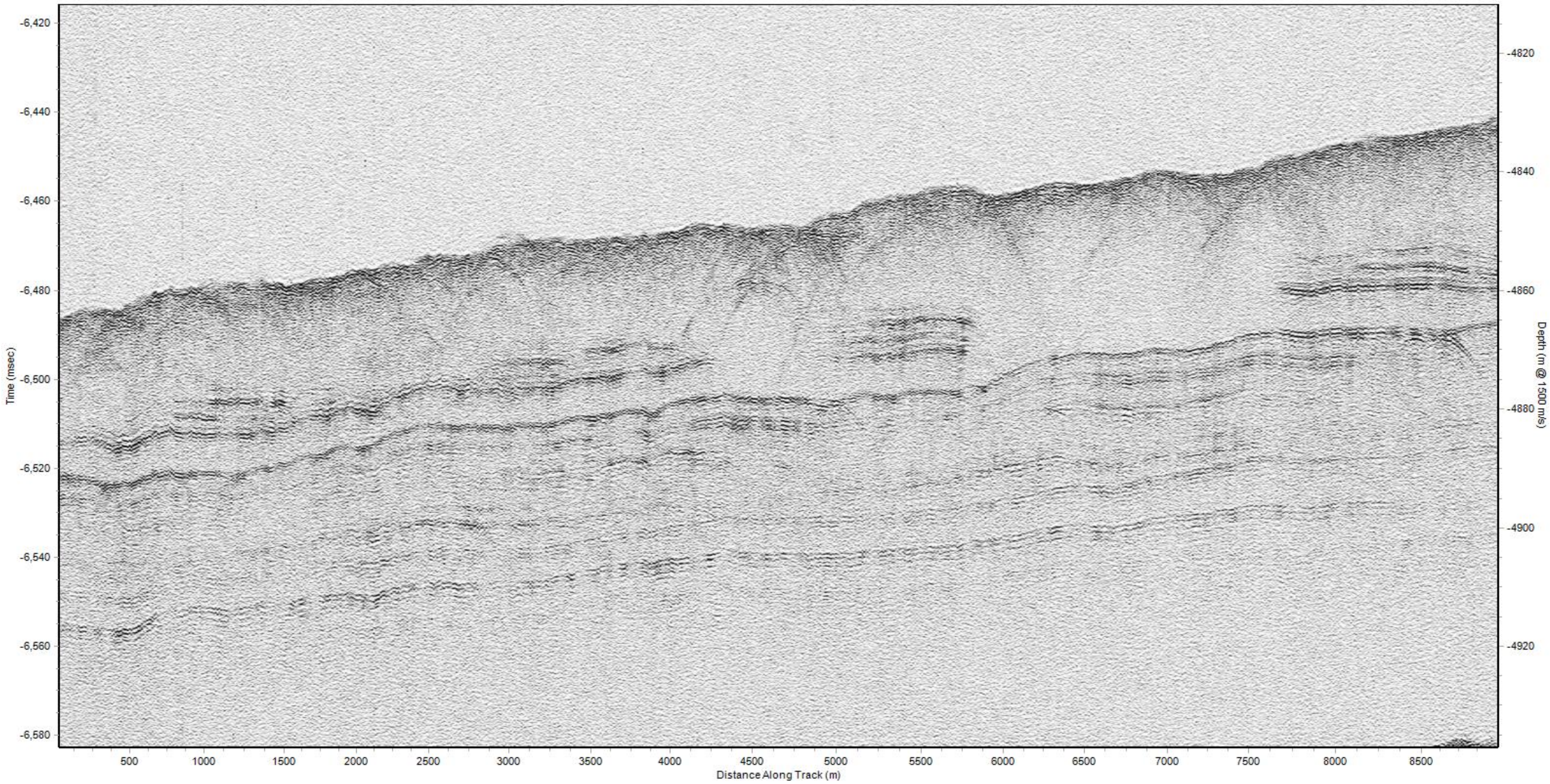

Figure 34: Huntec DTS line 13

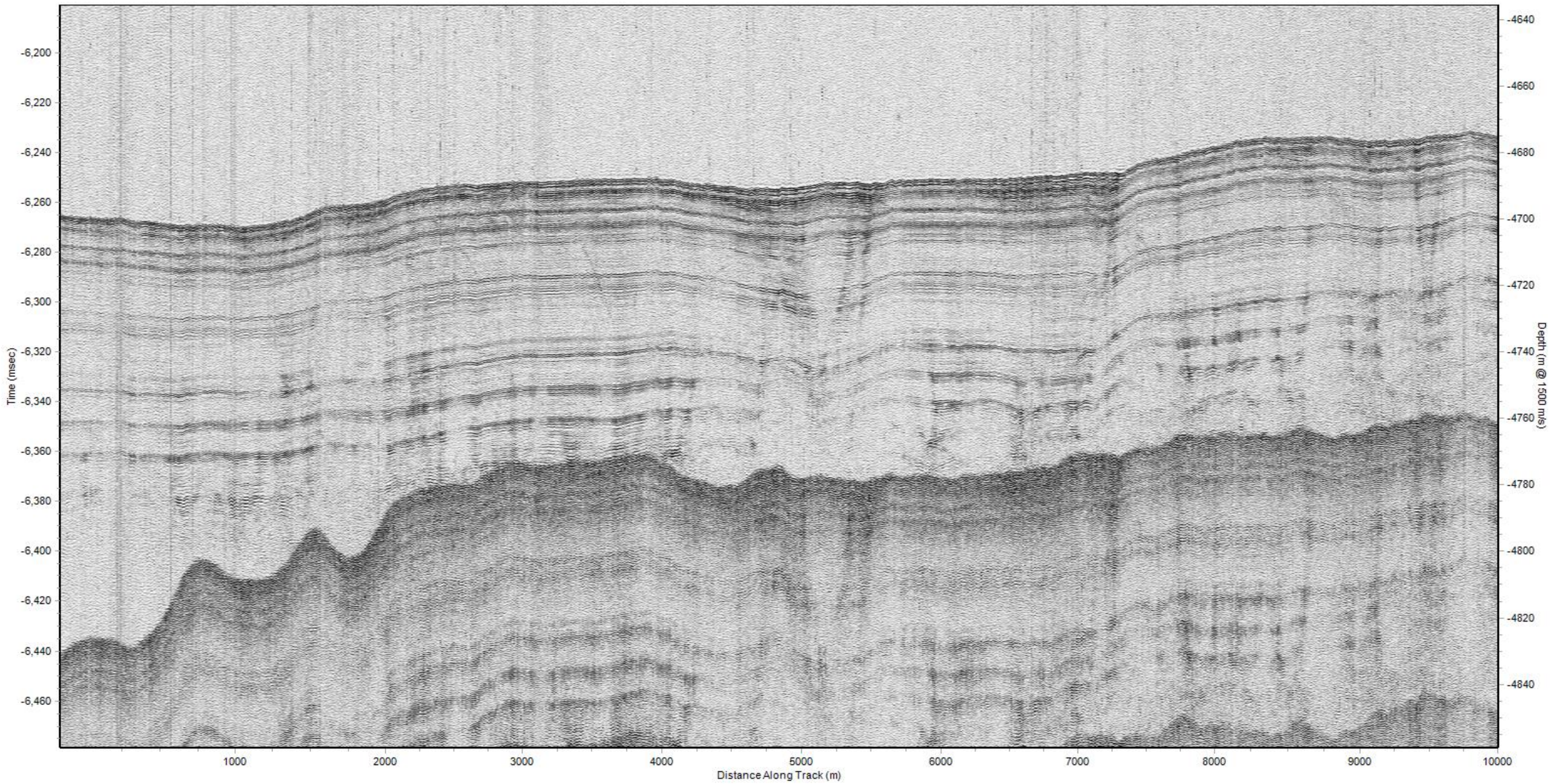

Figure 35: Huntec DTS line 14