
Environmental
Studies
Research
Fund

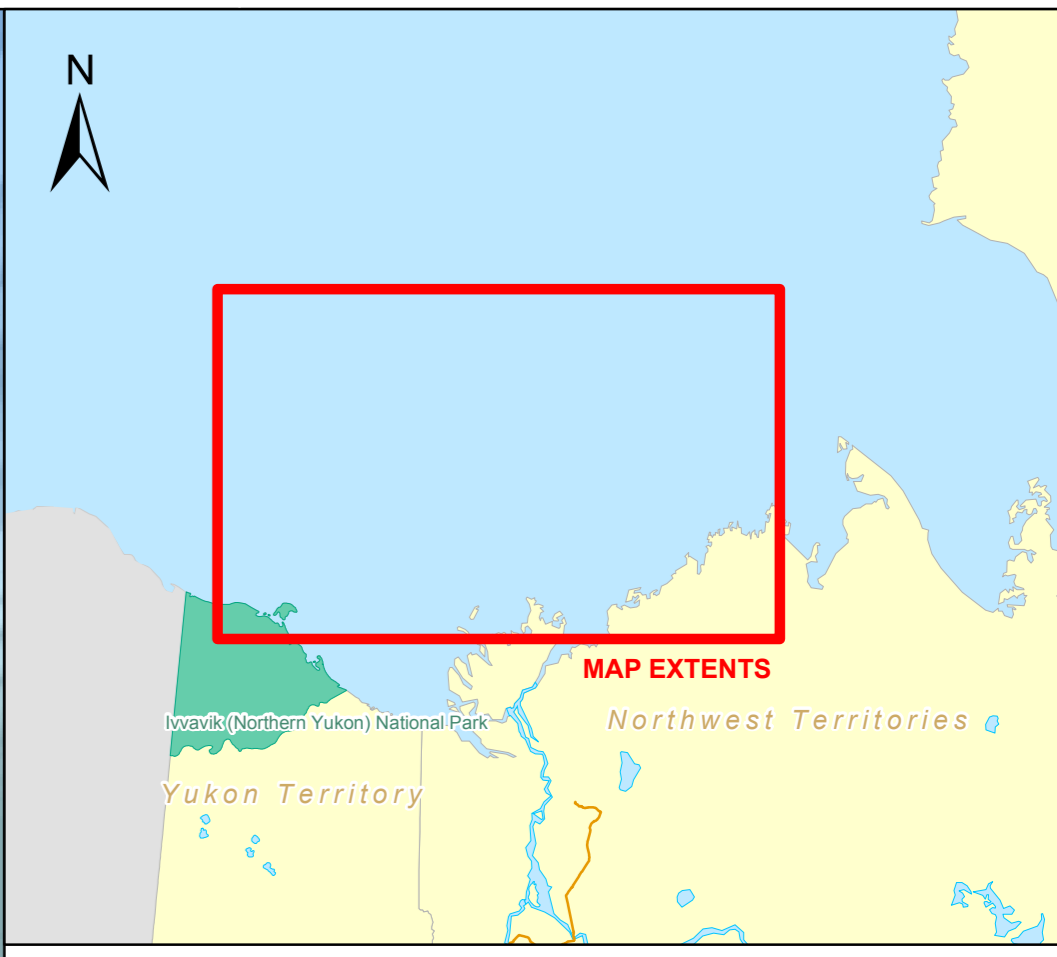
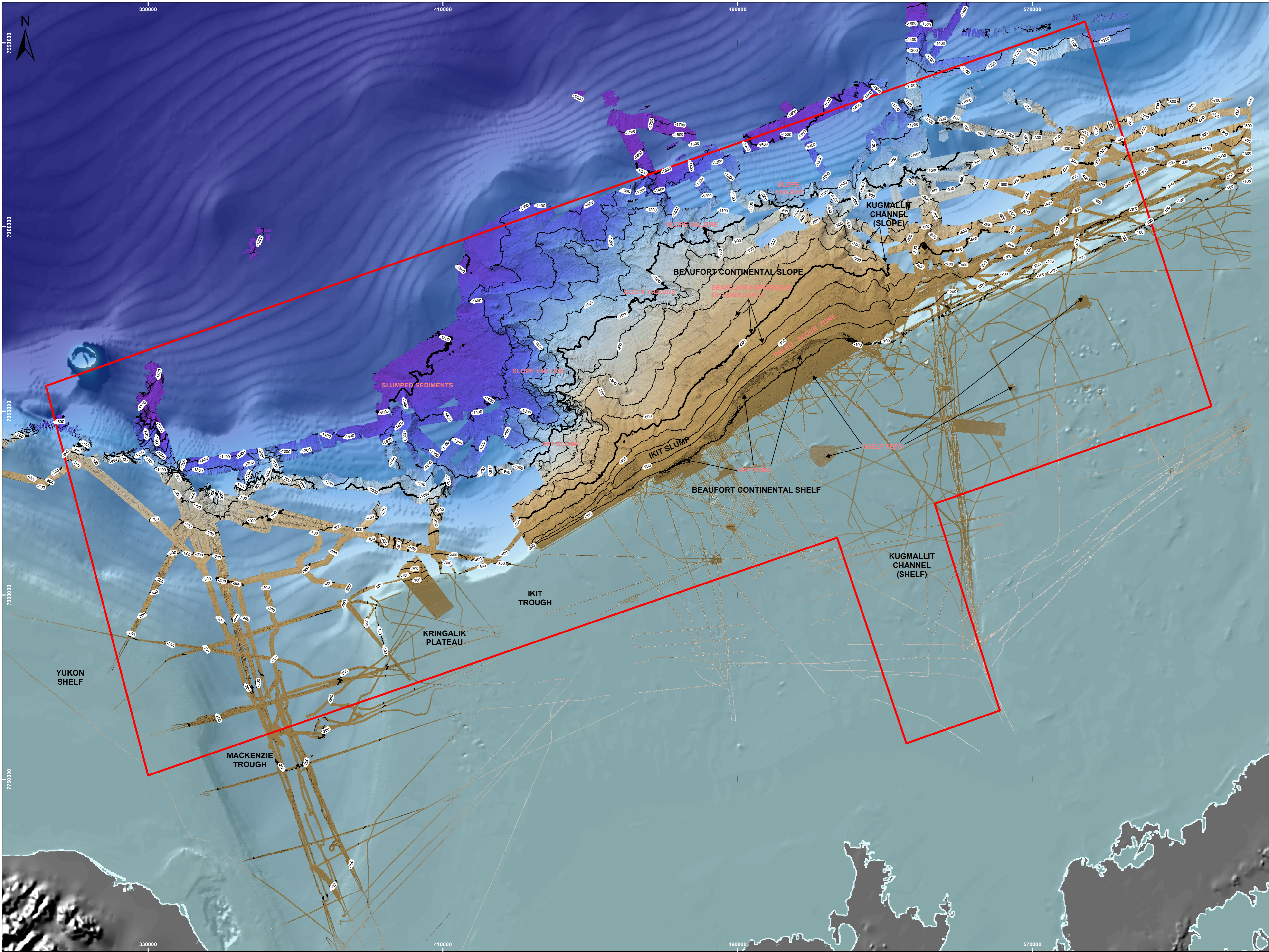
208-2-Enclosures

**Regional Assessment of Seabed Geohazard Conditions
Canadian Beaufort Outer Shelf and Upper Slope:
Legacy Data Synthesis**

**Évaluation régionale des géorisques du fond marin,
plate-forme continentale externe et talus supérieur de la
portion canadienne de la mer de Beaufort :
synthèse des données existantes**

Canada

August 2016



LEGEND AND NOTES

- Study Area
- Major Contours (500m interval)
- Minor Contours (100m interval)

MULTIBEAM BATHYMETRY COMPILED FROM DATASETS COLLECTED BY THE GSC AND UNIVERSITY OF NEW BRUNSWICK

IMAGE SHADING PARAMETERS: AZIMUTH 315°, ELEVATION 45°, VERTICAL EXAGGERATION 10X.

DIGITAL TERRAIN MODEL (DTM) RESOLUTION = 25M

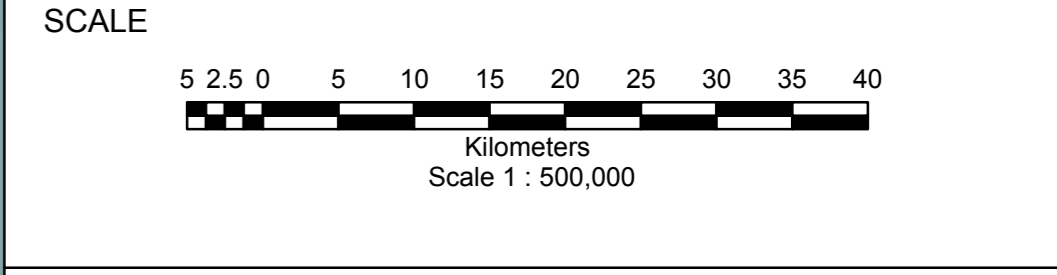
DEPTH (m)

1935

14

MAP PROJECTION DETAILS

ASSUMED NAD83 UTM ZONE 8
 GRS80 ELLIPSOID
 SEMI-MAJOR AXIS 6378137.00
 INVERSE FLATTENING 298.257222101
 6° UNIVERSAL TRANSVERSE MERCATOR
 ZONE 8 CENTRAL MERIDIAN: 135° W
 SCALE FACTOR AT C.M.: 0.9996
 FALSE EASTING: 500,000M
 FALSE NORTHING: 0M

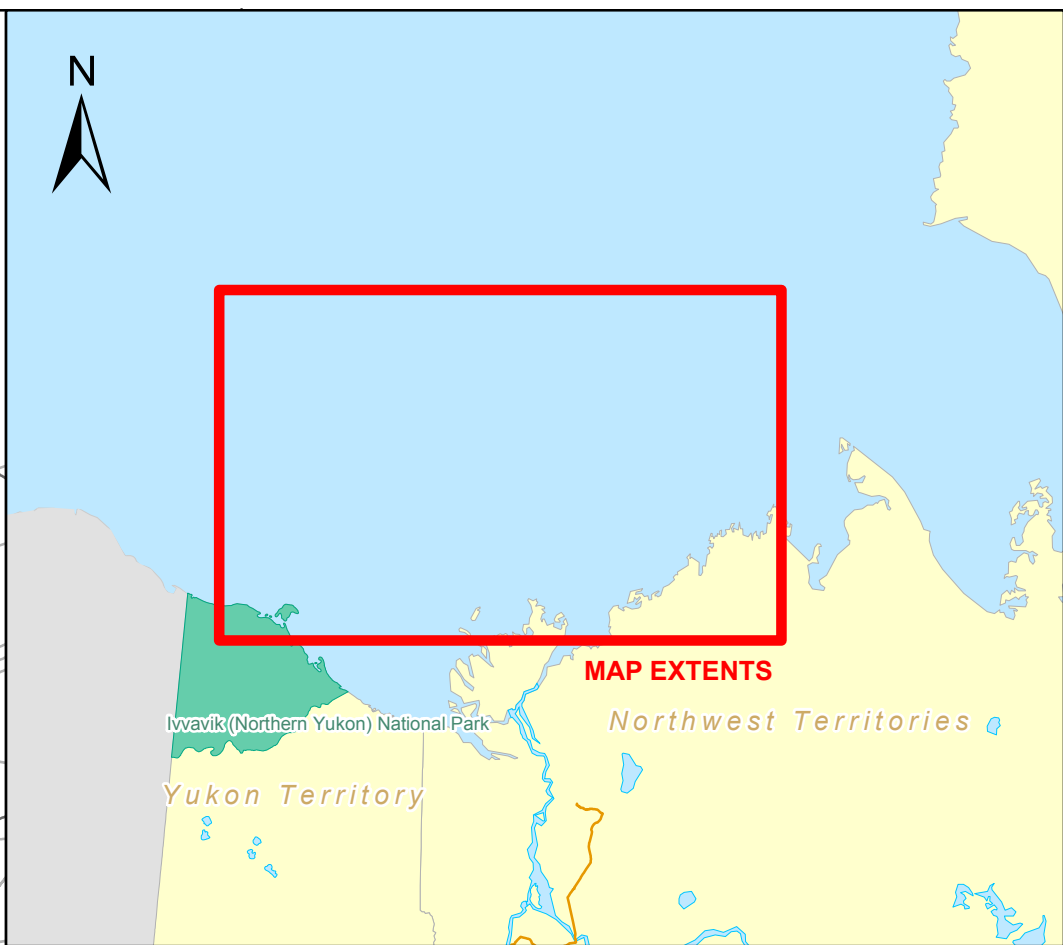
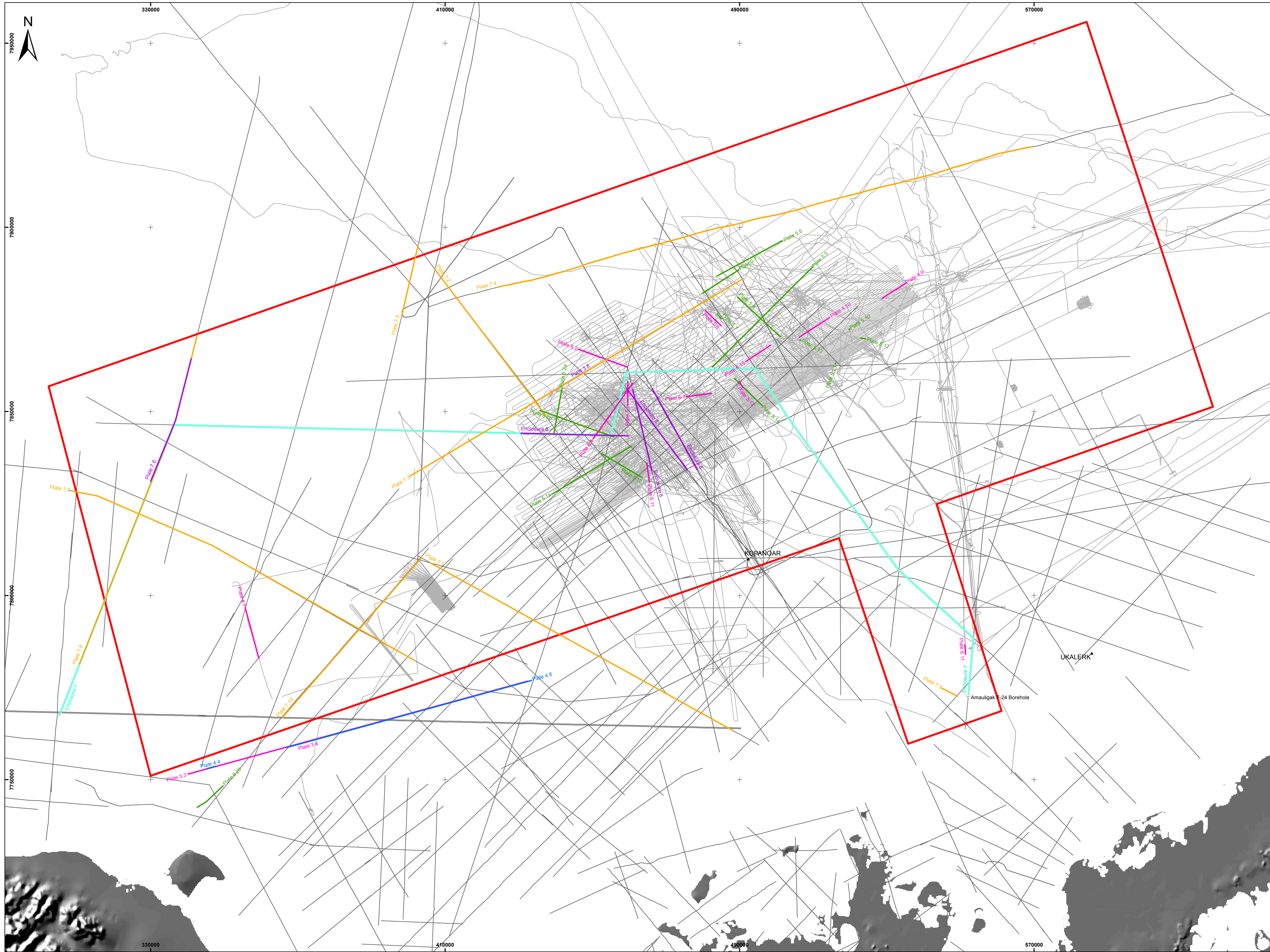


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FUGRO GEOSURVEYS
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**MULTIBEAM BATHYMETRY MAP
SOUTHERN BEAUFORT SEA**

0	Aug.26/15	ISSUED FOR FINAL REPORT	CS	CWL	EC
C	Mar. 16/15	DRAFT C FOR SUBMISSION	AC	CWL	EC
REV	DATE	DESIGNATION	DRAWN	CHECK'D	APPR'D
JOB NUMBER: 20110068			DWG No: 20110068-MBB-REG-E01-0		
DATE: AUGUST 26, 2015			ENCLOSURE: 1		



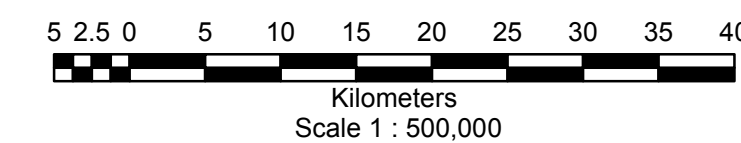
LEGEND AND NOTES

- ▲ Existing Wells
- Core Locations
- ▭ Study Area
- ▭ Lease Blocks
- Illustrated Sub-Bottom Profile Lines
- Illustrated 2DHR Profile Lines
- Illustrated Multibeam Profile Lines
- Sub-Bottom Survey Tracklines
- 2DHR Survey Tracklines

MAP PROJECTION DETAILS

ASSUMED NAD83 UTM ZONE 8
 GRS80 ELLIPSOID
 SEMI-MAJOR AXIS 6378137.00
 INVERSE FLATTENING 298.257222101
 6° UNIVERSAL TRANSVERSE MERCATOR
 ZONE 8 CENTRAL MERIDIAN: 135° W
 SCALE FACTOR AT C.M.: 0.9996
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 FALSE NORTHING: 0M

SCALE



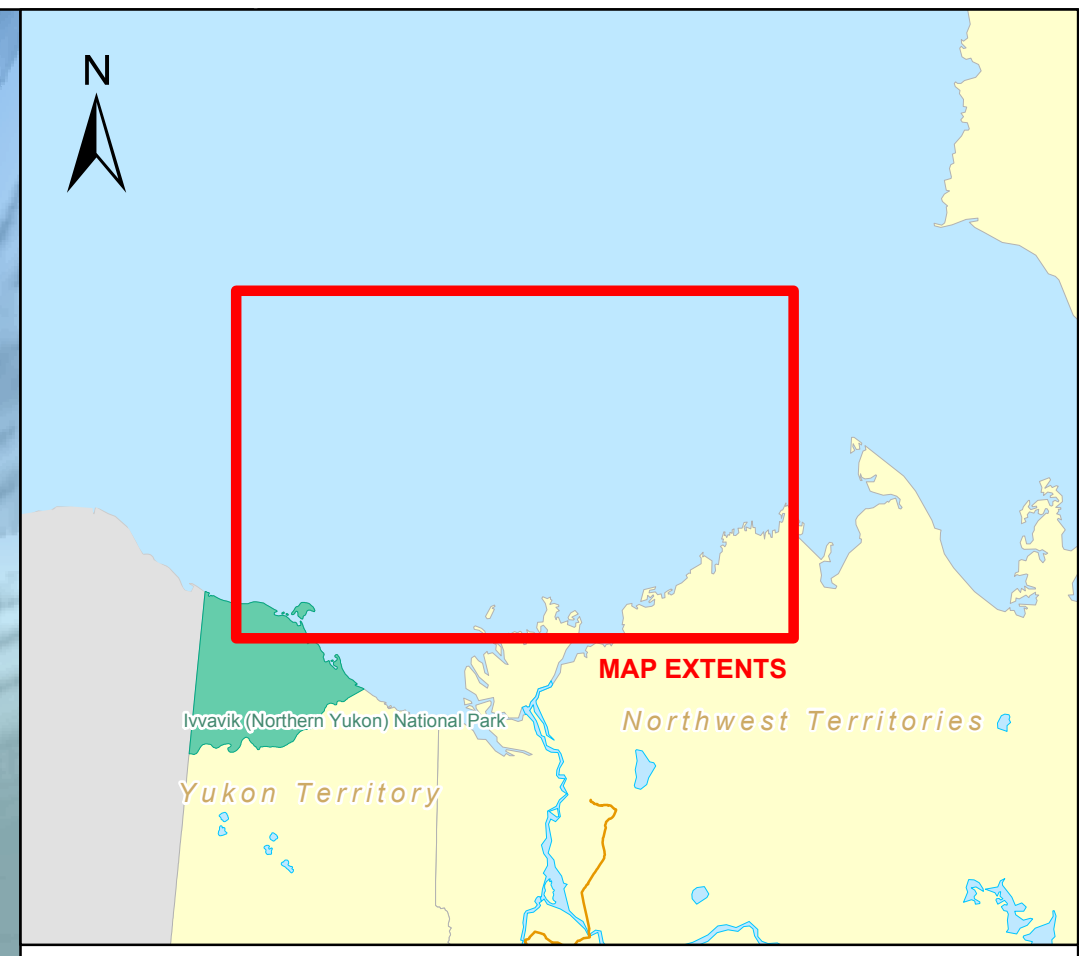
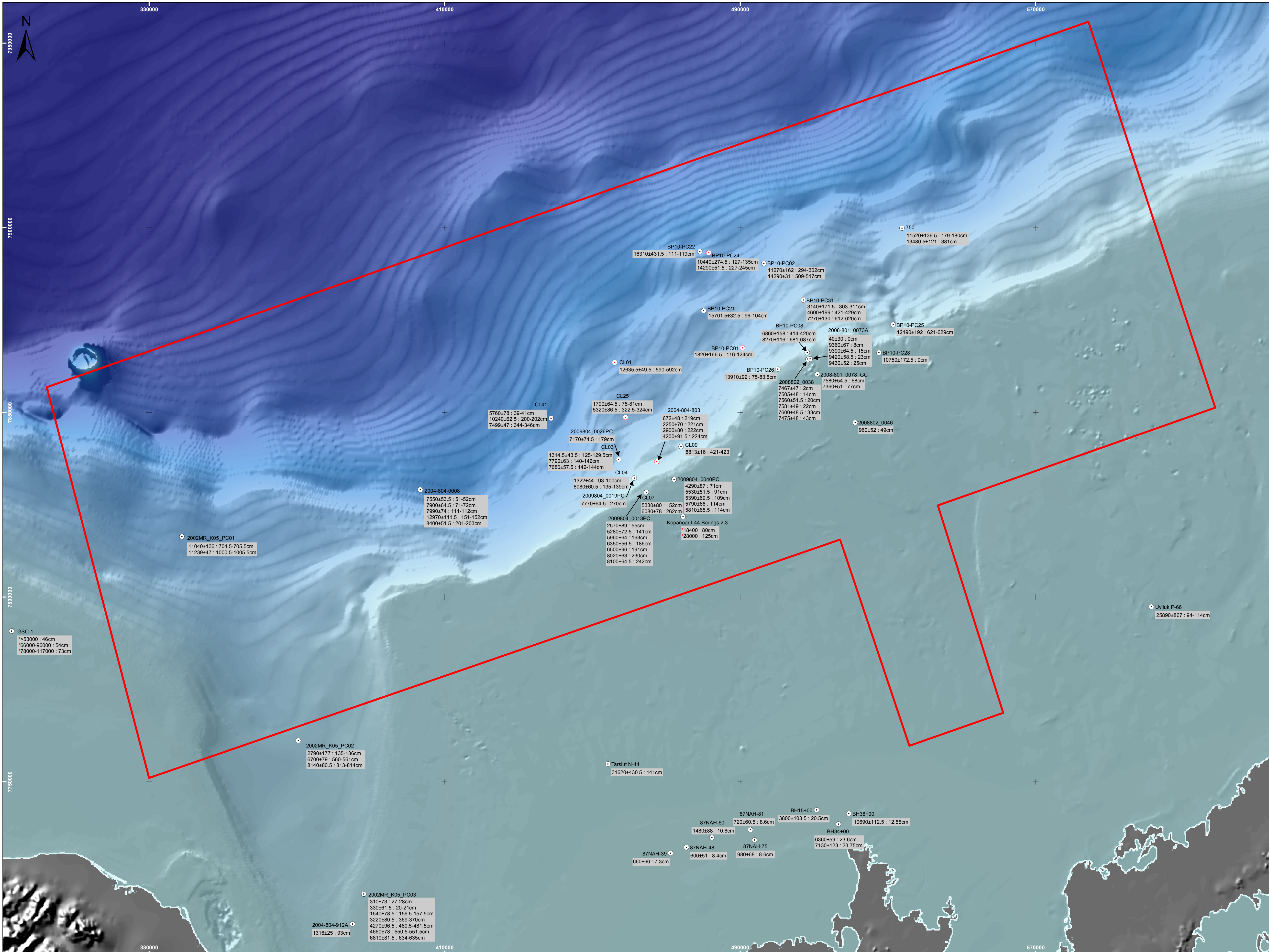
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**SURVEY TRACKPLOT MAP
 SOUTHERN BEAUFORT SEA**

2	Jul. 20/16	SEE CRN 969 FOR REVISION	CS	JF	EC
1	Dec. 03/15	SEE CRN 918 FOR REVISION	AC	CWL	EC
0	Aug. 26/15	ISSUED FOR FINAL REPORT	CS	CWL	EC
C	Mar 16/15	DRAFT C SUBMISSION	AC	CWL	EC
REV	DATE	DESIGNATION	DRAWN	CHECK'D	APPR'D

JOB NUMBER: 20110068	DWG No: 20110068-TRK-REG-E02-2
DATE: JULY 20, 2016	ENCLOSURE: 2



LEGEND AND NOTES

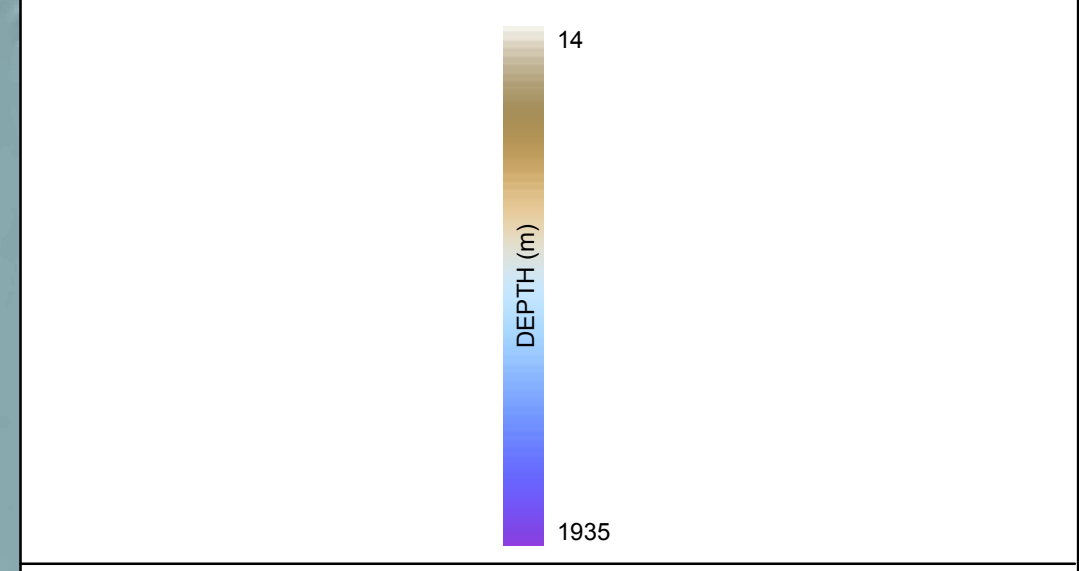
- Core Locations
- Core Locations on the Continental Slope where Units 1 & 2 are stratigraphically undisturbed. Dates from these cores were used for calculation of post-glacial slope sedimentation rates.
- ▭ Study Area

10260 ± 110 : 0cm C₁₄ Date : Sample Depth Below Seafloor

○ Uncalibrated C₁₄ Date

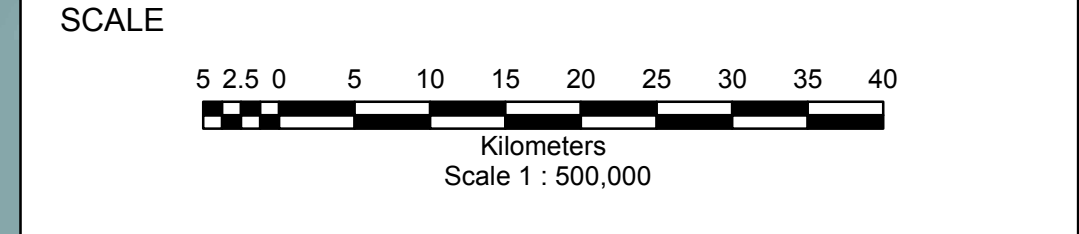
CORE LOCATIONS ARE ASSUMED TO BE IN NAD83 DATUM

MULTIBEAM BATHYMETRY COMPILED FROM DATASETS COLLECTED BY THE GSC AND UNIVERSITY OF NEW BRUNSWICK



MAP PROJECTION DETAILS

ASSUMED NAD83 UTM ZONE 8
 GRS80 ELLIPSOID
 SEMI-MAJOR AXIS 6378137.00
 INVERSE FLATTENING 298.257222101
 6° UNIVERSAL TRANSVERSE MERCATOR
 ZONE 8 CENTRAL MERIDIAN: 135° W
 SCALE FACTOR AT C.M.: 0.9996
 FALSE EASTING: 500,000M
 FALSE NORTHING: 0M



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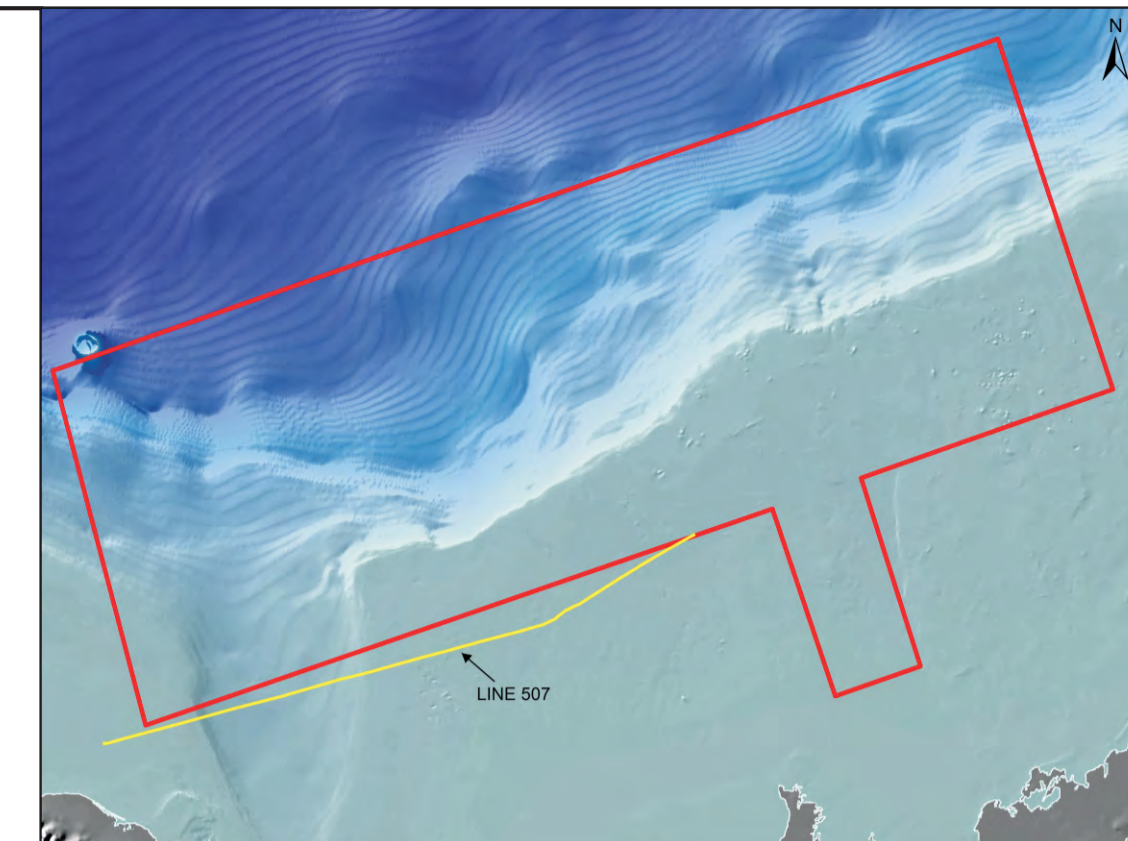
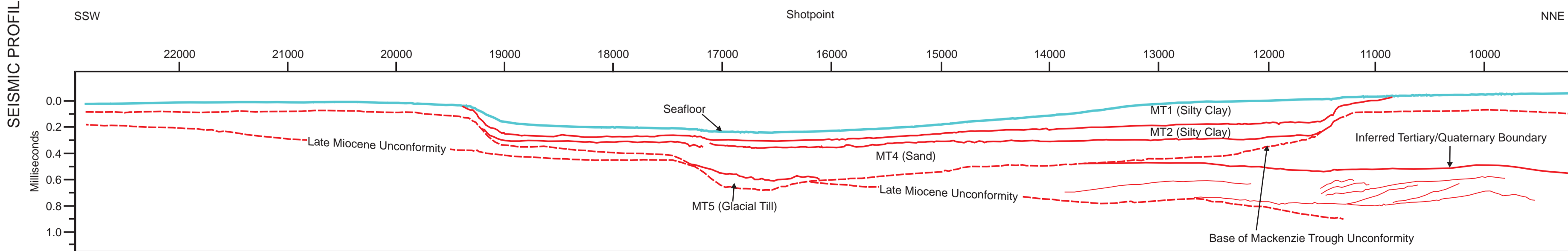
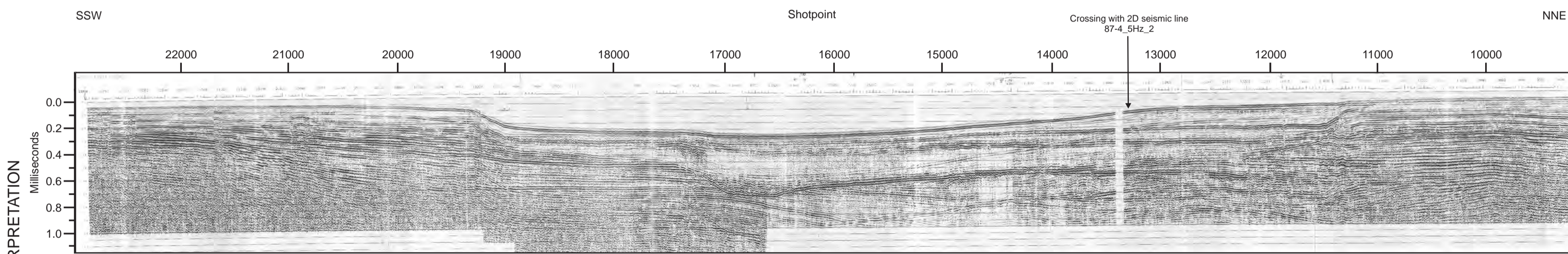
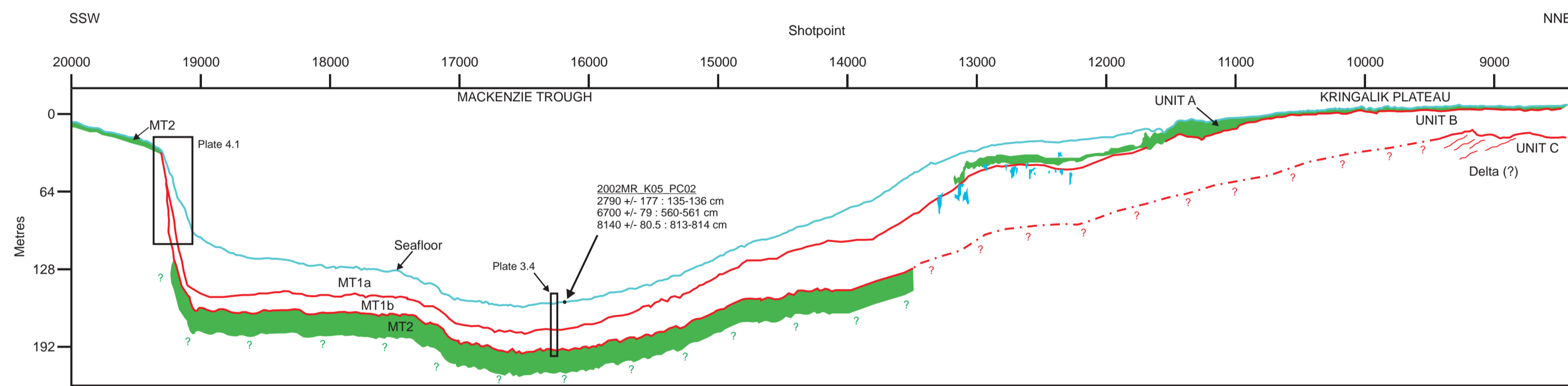
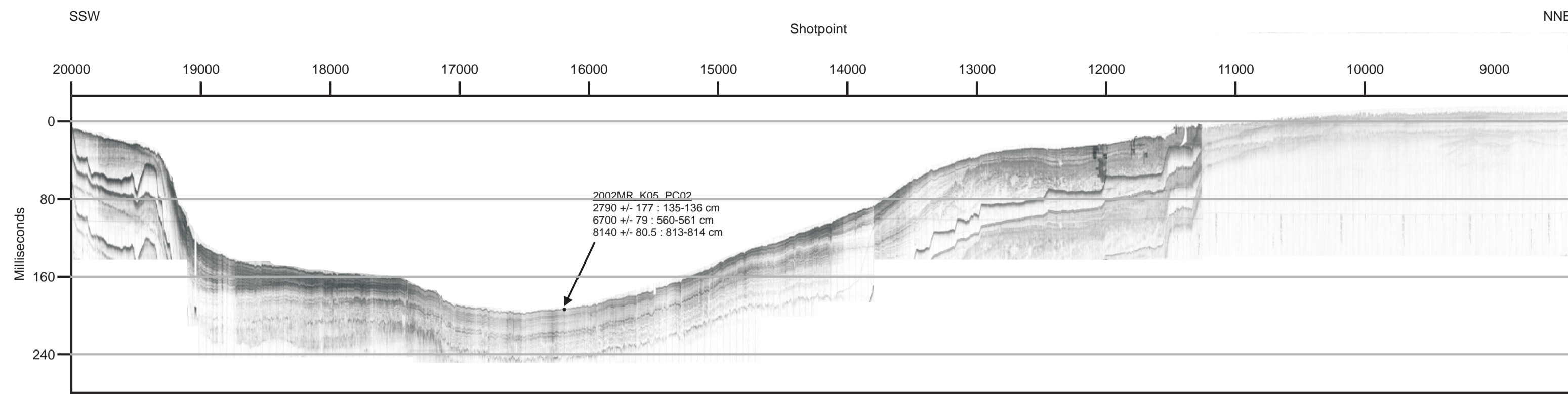
**MULTIBEAM BATHYMETRY
 CORE AND BOREHOLE C₁₄ DATES
 SOUTHERN BEAUFORT SEA**

REV	DATE	DESIGNATION	DRAWN	CHECKD	APPRD
0	Aug. 26/15	ISSUED FOR FINAL REPORT	CS	CWL	EC
C	Mar. 16/15	DRAFT C FOR SUBMISSION	AC	CWL	EC

JOB NUMBER: 20110068 DWG No: 20110068-MBB-C14-E03-0

DATE: AUGUST 26, 2015 ENCLOSURE: 3

SUB-BOTTOM SPARKER PROFILE AND INTERPRETATION



LEGEND AND NOTES

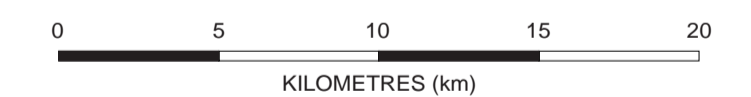
- Ice Keel Turbate
- Possible Gas
- Seafloor
- - - Acoustic/Seismic Unit Boundary (defined/tentative)
- - - Unconformity
- Acoustic/Seismic Horizon

DEPTH SCALE ON SUB-BOTTOM PROFILE INTERPRETATION BASED ON AN ASSUMED SOUND VELOCITY OF 1500m/s.

FUGRO REVISION REFERENCE

REV.	DATE	DESIGNATION	DRAWN	CHECK'D	APPR'D
0	Aug. 26/15	ISSUED FOR FINAL REPORT	CS	CWL	EC
C	Mar. 16/15	DRAFT C SUBMISSION	JF/AC	CWL	EC

SCALE

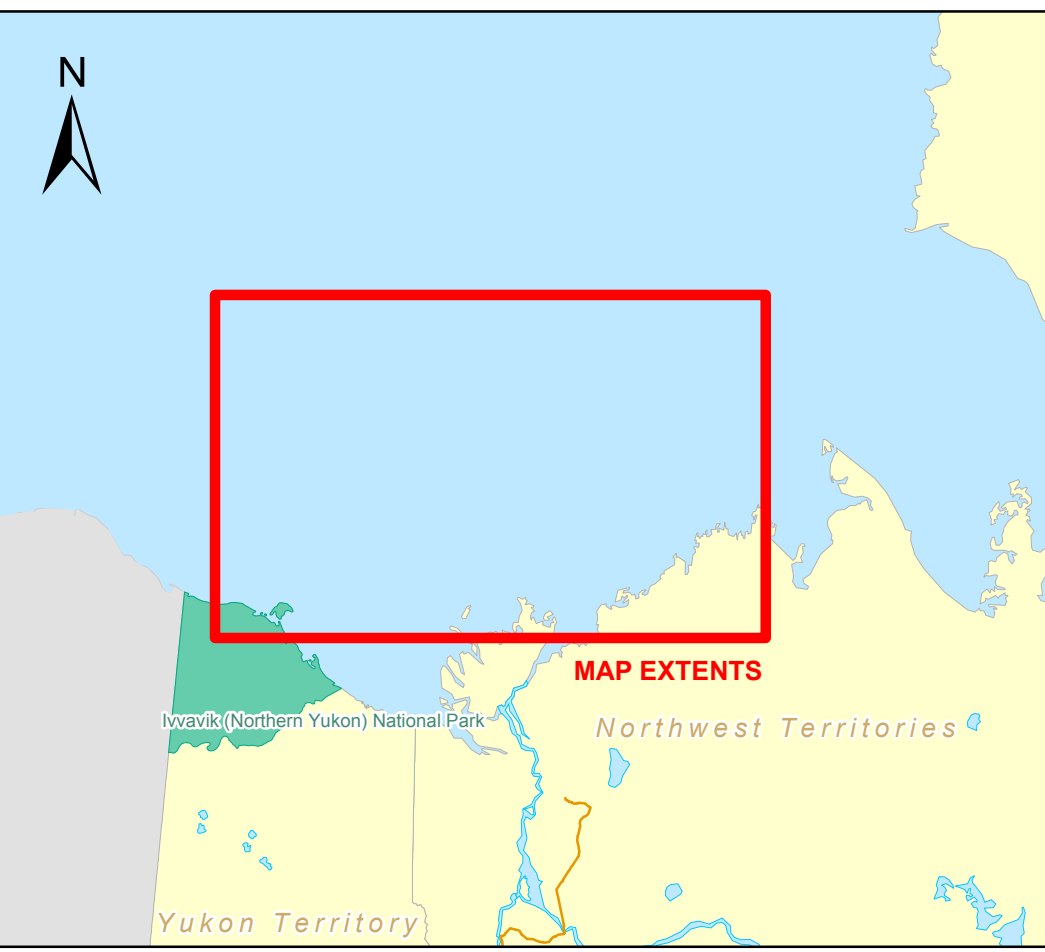
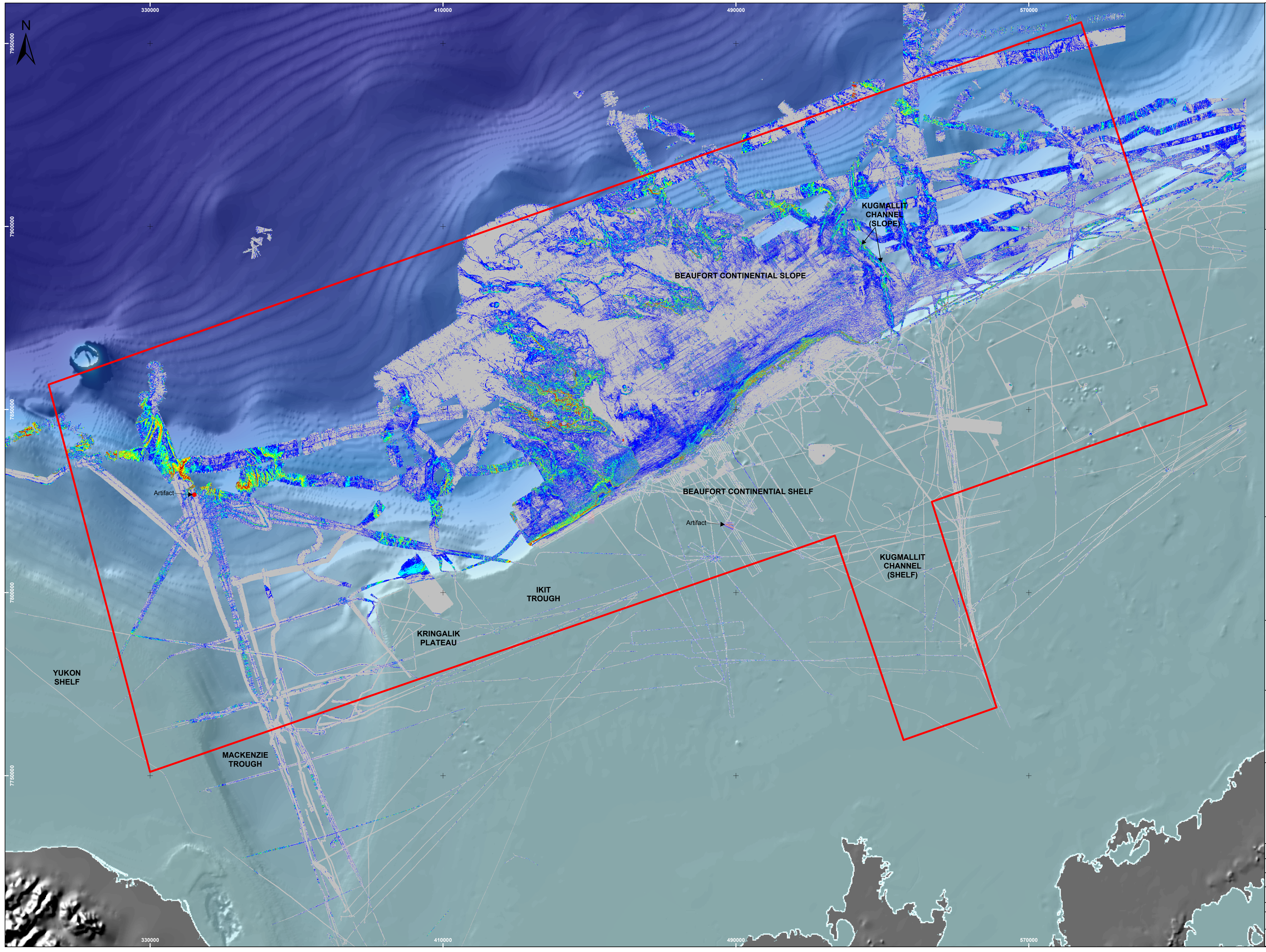


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 St. John's, NL
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SUB-BOTTOM AND 2D SEISMIC PROFILE OF LINE 80-507 SOUTHERN BEAUFORT SEA

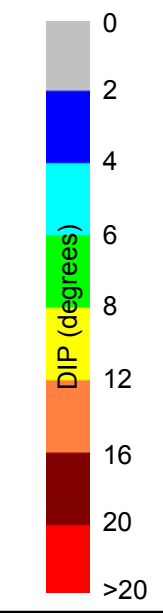
JOB NUMBER: 20110068	DRAWN BY: JF/AC	REV 0
DATE: AUGUST 26, 2015	CHECKED BY: CWL	
DWG NO: 20110068-PRO-L507-E04-0	ENCLOSURE: 4	



LEGEND AND NOTES

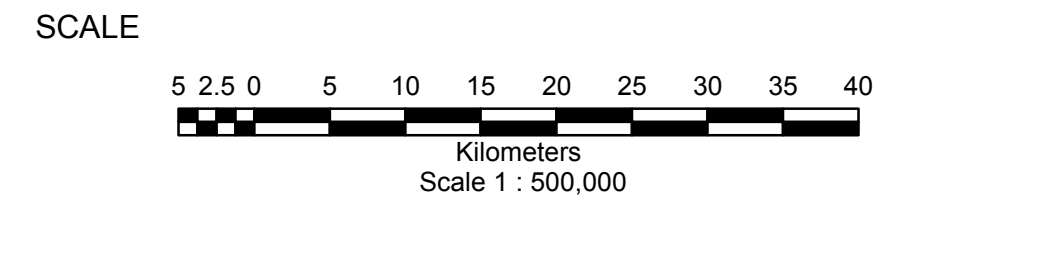
Study Area

MULTIBEAM BATHYMETRY COMPILED FROM DATASETS COLLECTED BY THE GSC AND UNIVERSITY OF NEW BRUNSWICK



MAP PROJECTION DETAILS

ASSUMED NAD83 UTM ZONE 8
 GRS80 ELLIPSOID
 SEMI-MAJOR AXIS 6378137.00
 INVERSE FLATTENING 298.257222101
 6° UNIVERSAL TRANSVERSE MERCATOR
 ZONE 8 CENTRAL MERIDIAN: 135° W
 SCALE FACTOR AT C.M.: 0.9996
 FALSE EASTING: 500,000M
 FALSE NORTHING: 0M

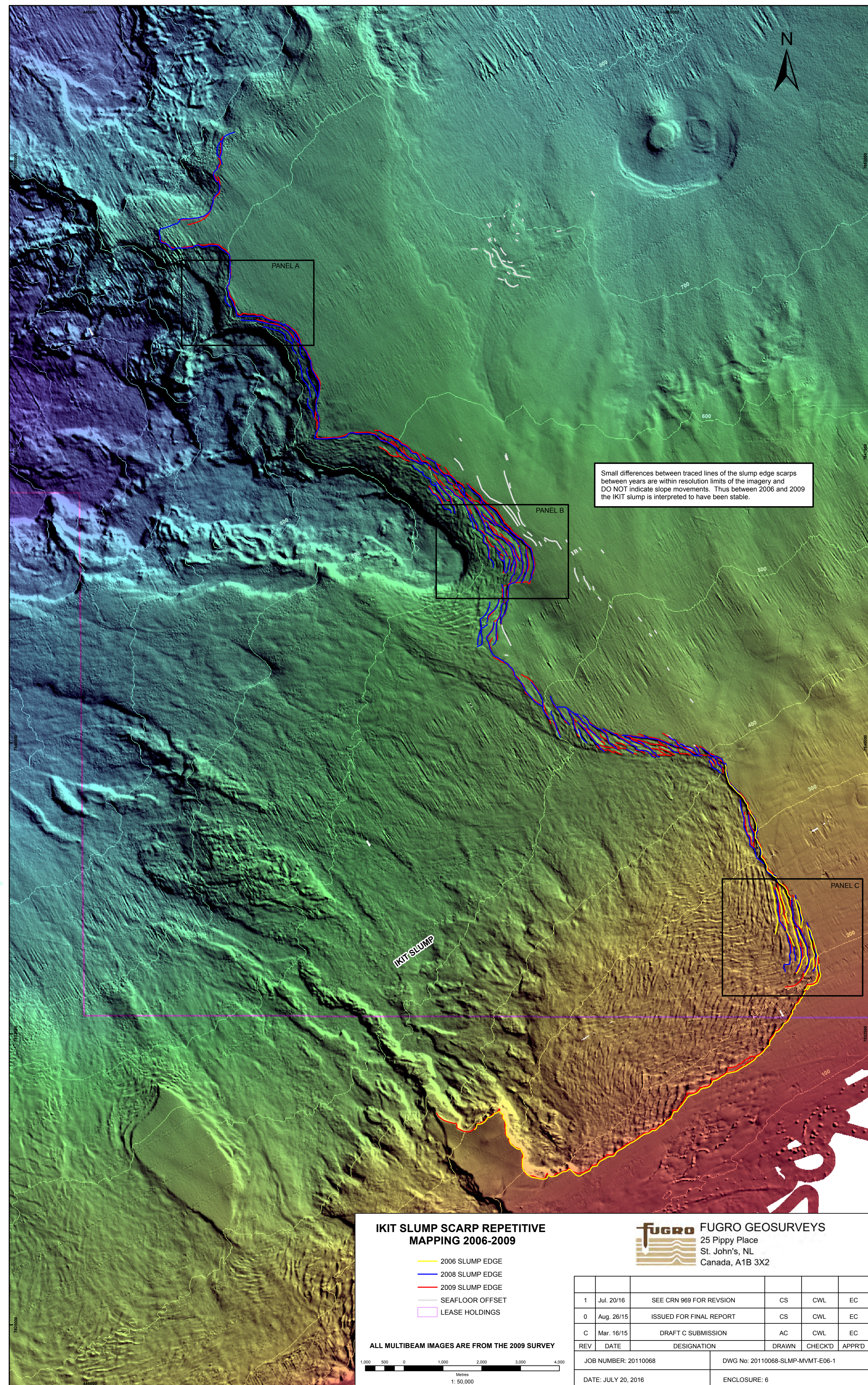
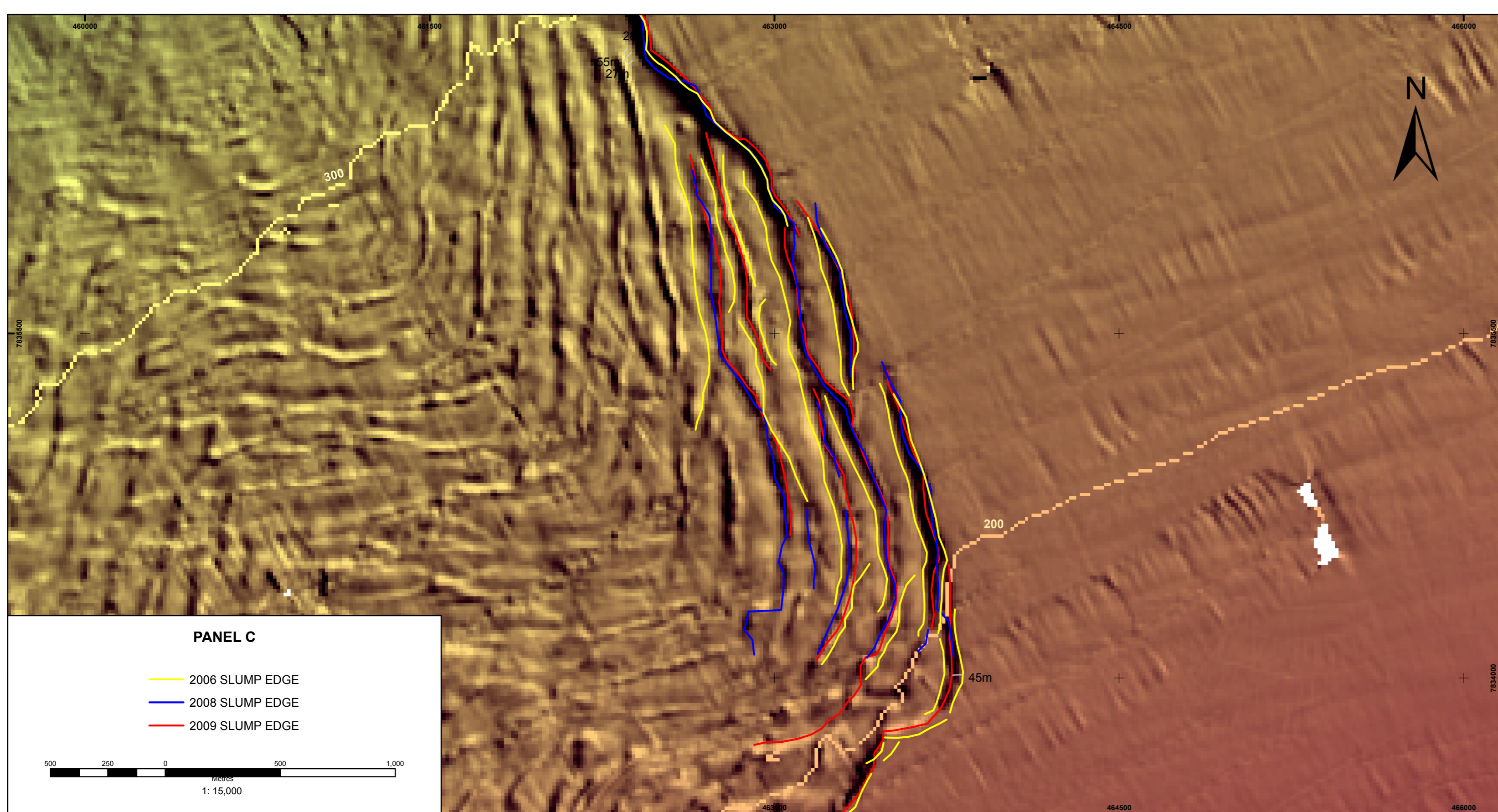
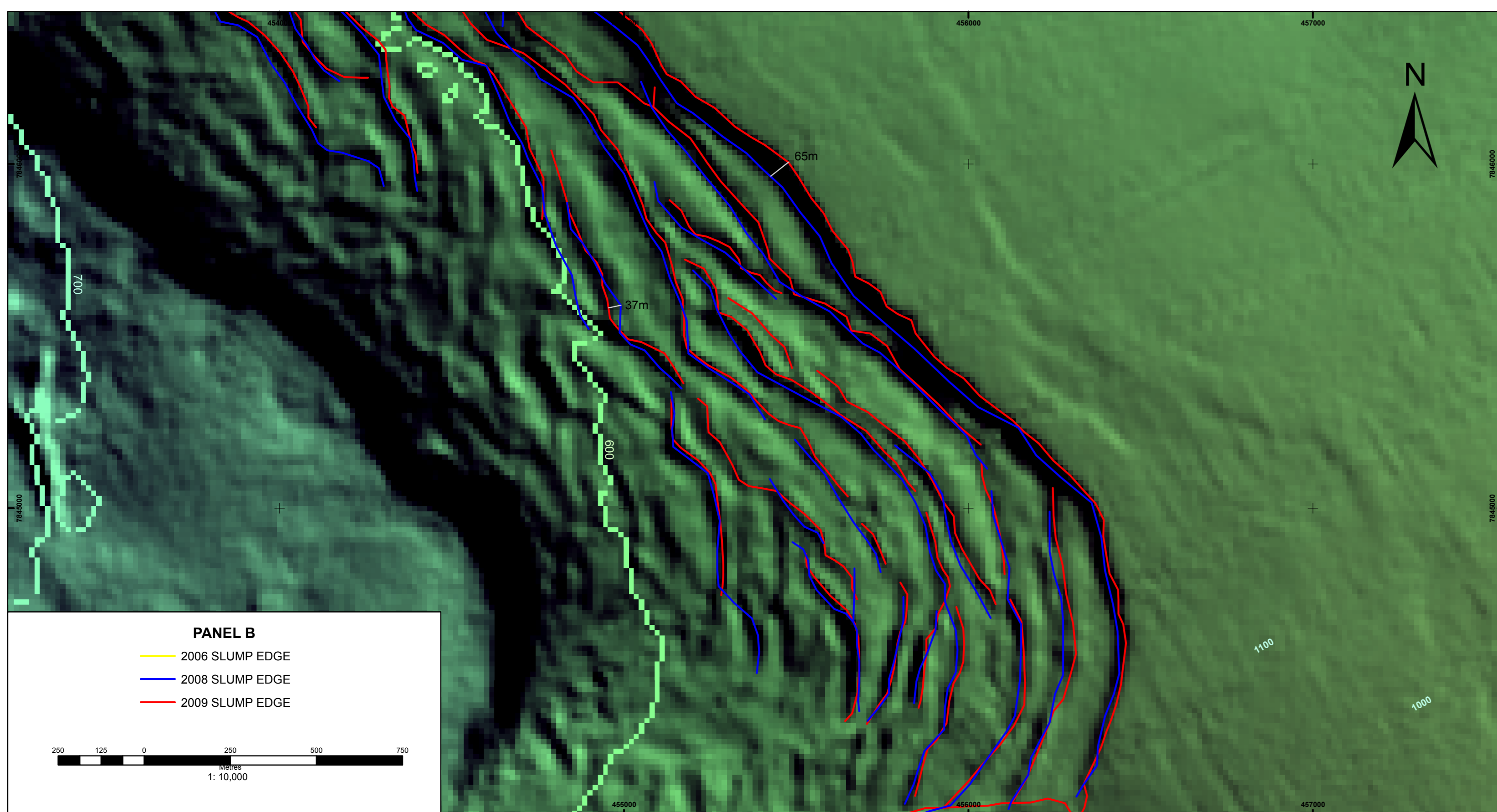
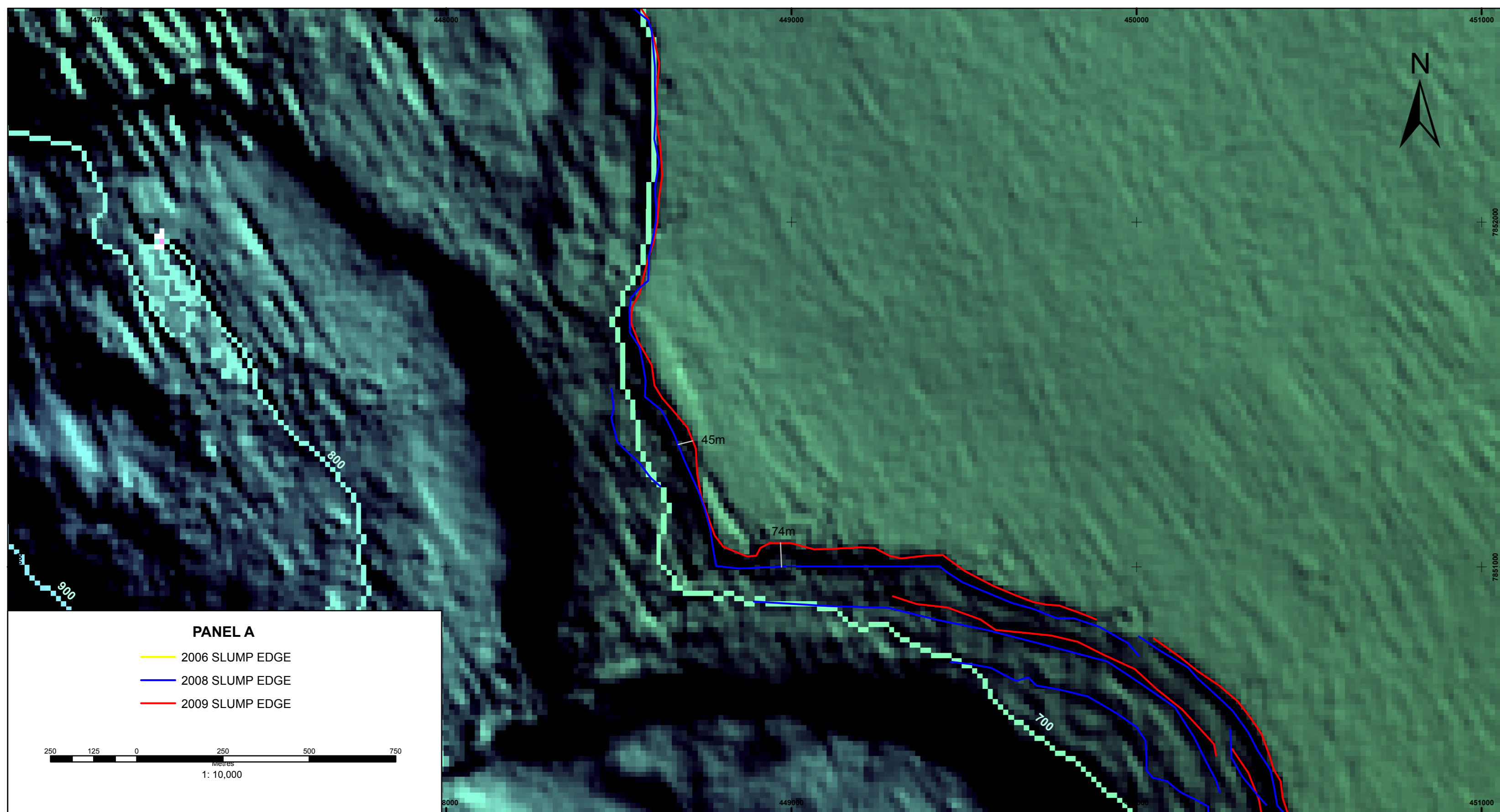


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**SEAFLOOR GRADIENT MAP
 SOUTHERN BEAUFORT SEA**

0	Aug. 26/15	ISSUED FOR FINAL REPORT	CS	CWL	EC
C	Mar. 16/15	DRAFT C SUBMISSION	AC	CWL	EC
REV	DATE	DESIGNATION	DRAWN	CHECKD	APPRD
JOB NUMBER: 20110068			DWG No: 20110068-SLP-REG-E05-0		
DATE: AUGUST 26, 2015			ENCLOSURE: 5		



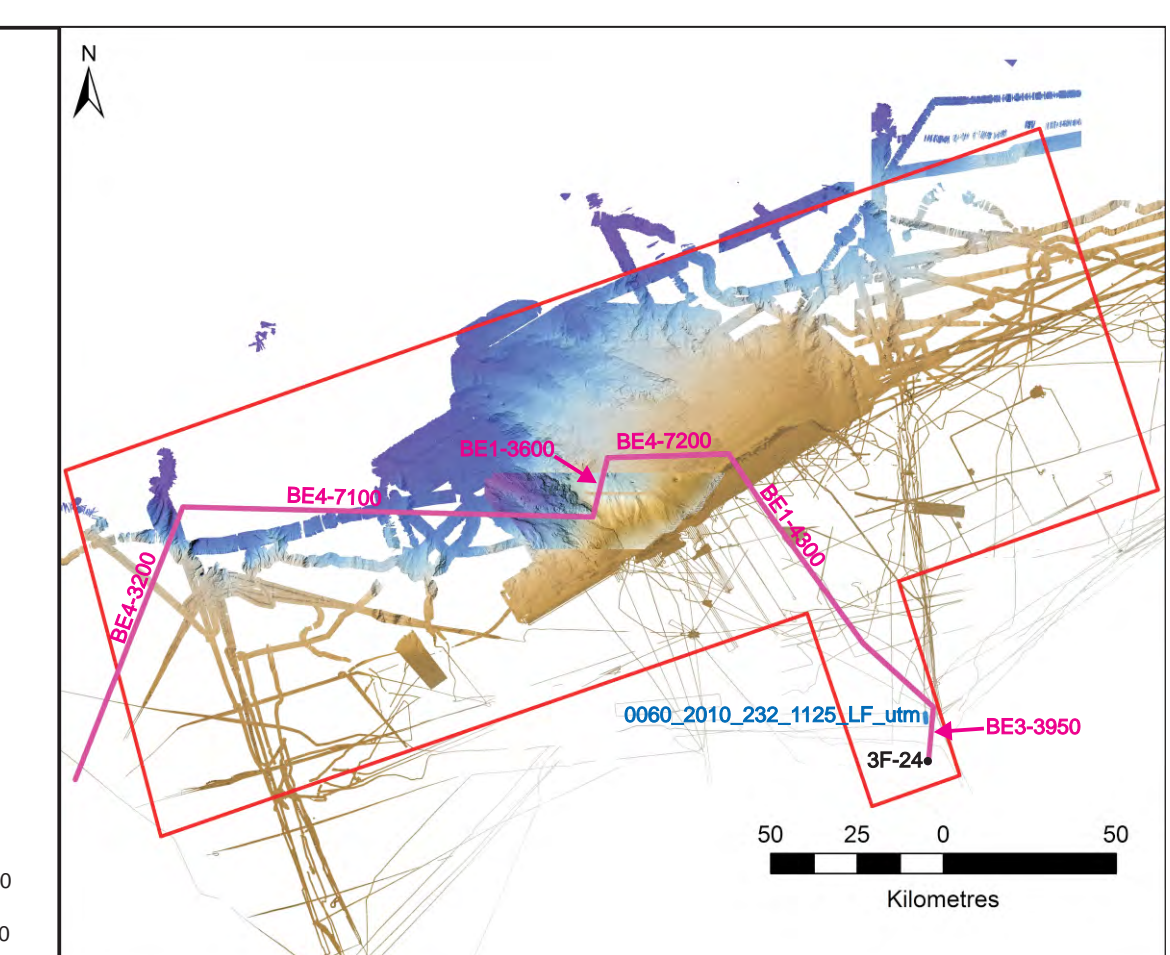
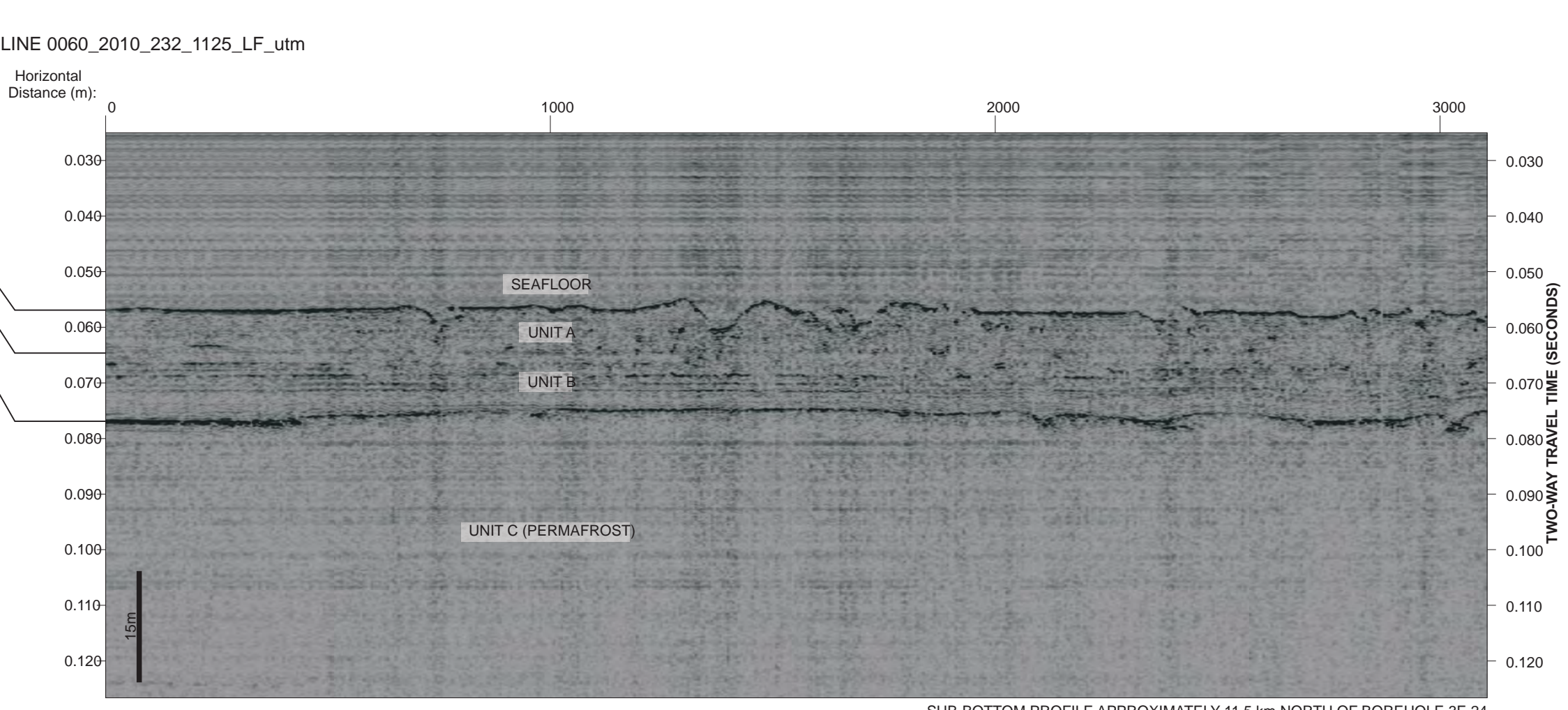
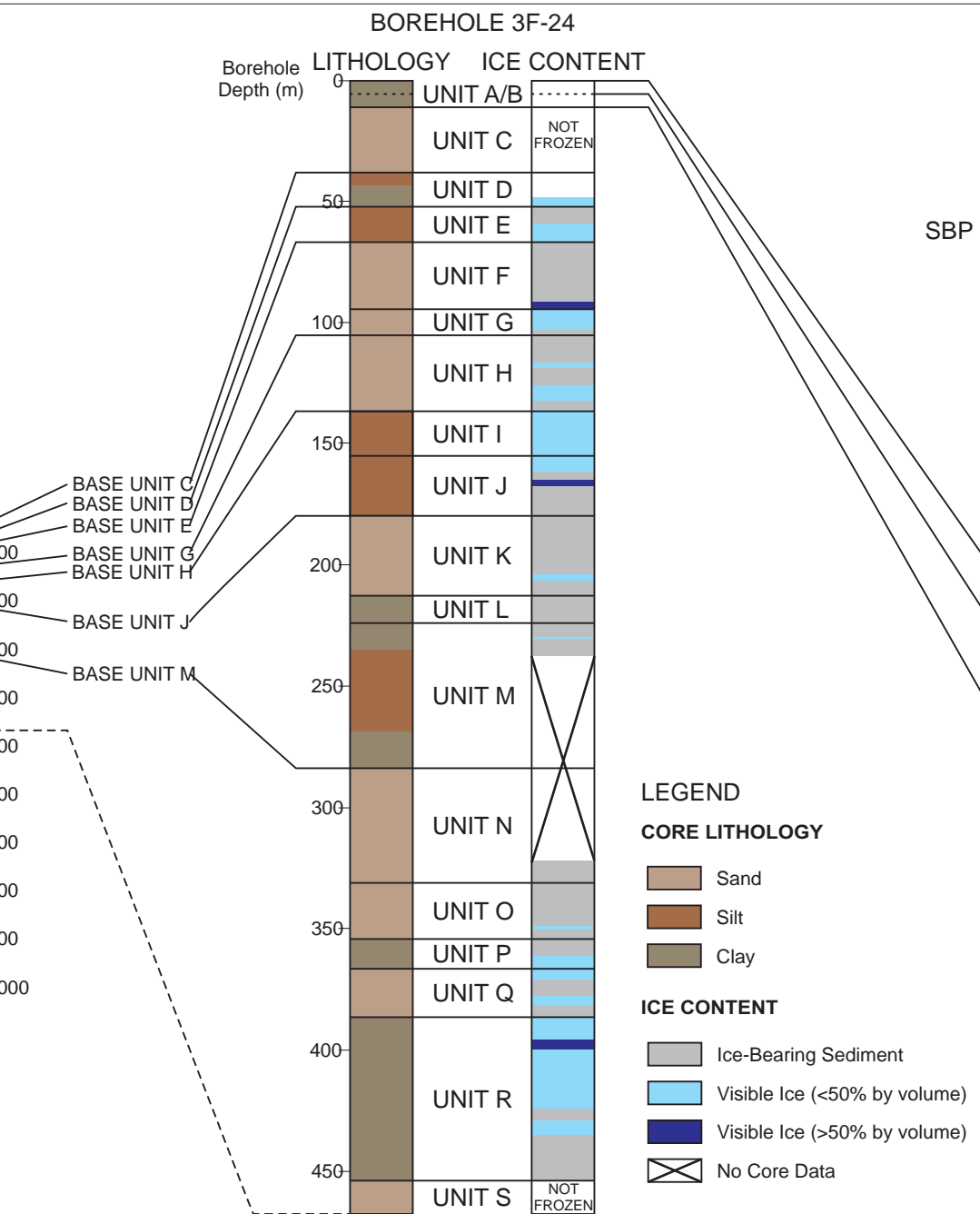
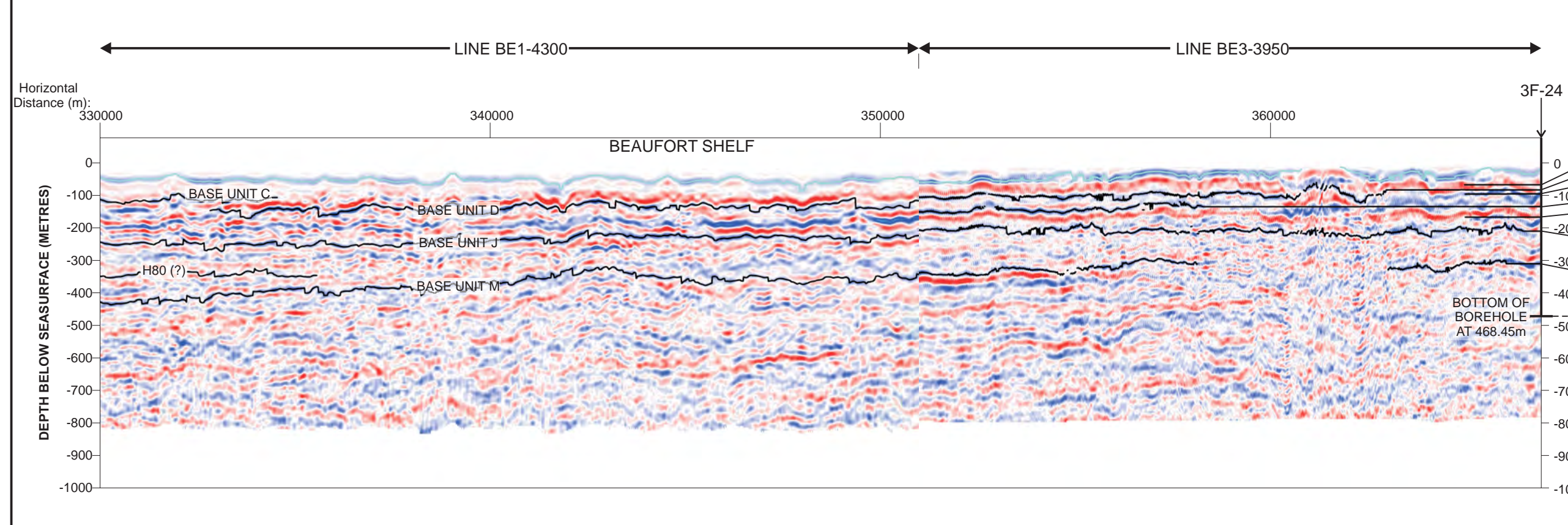
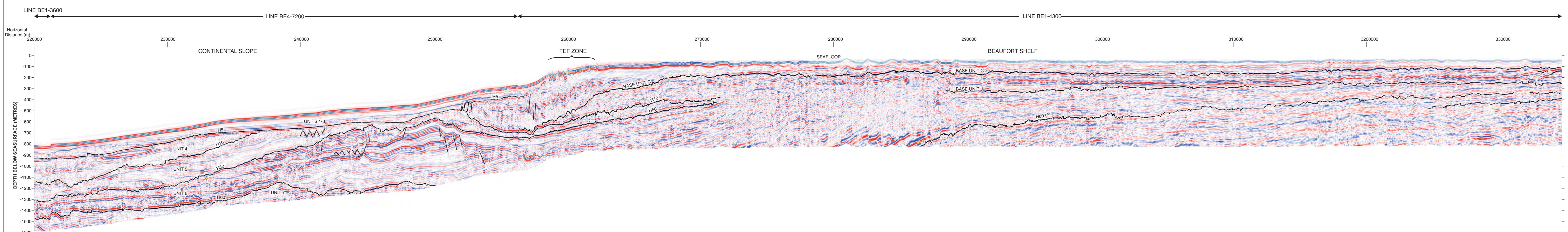
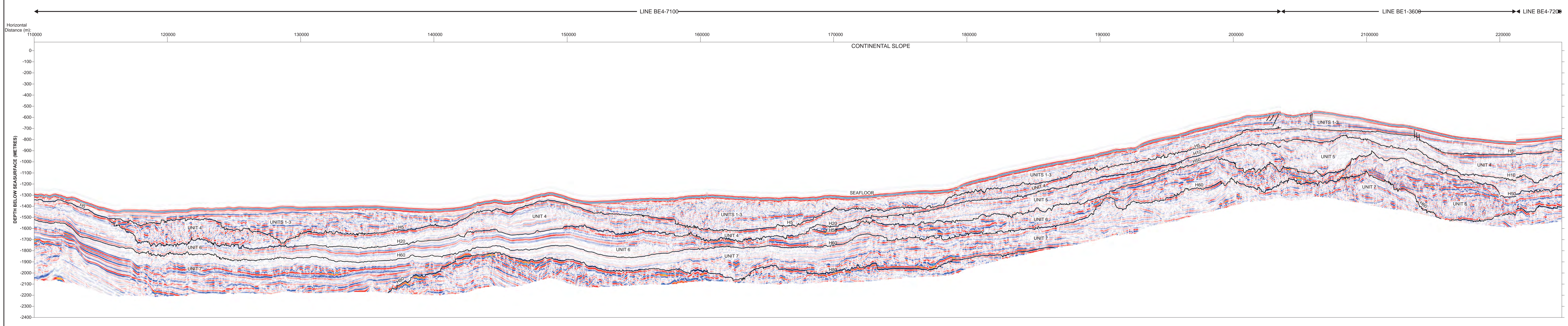
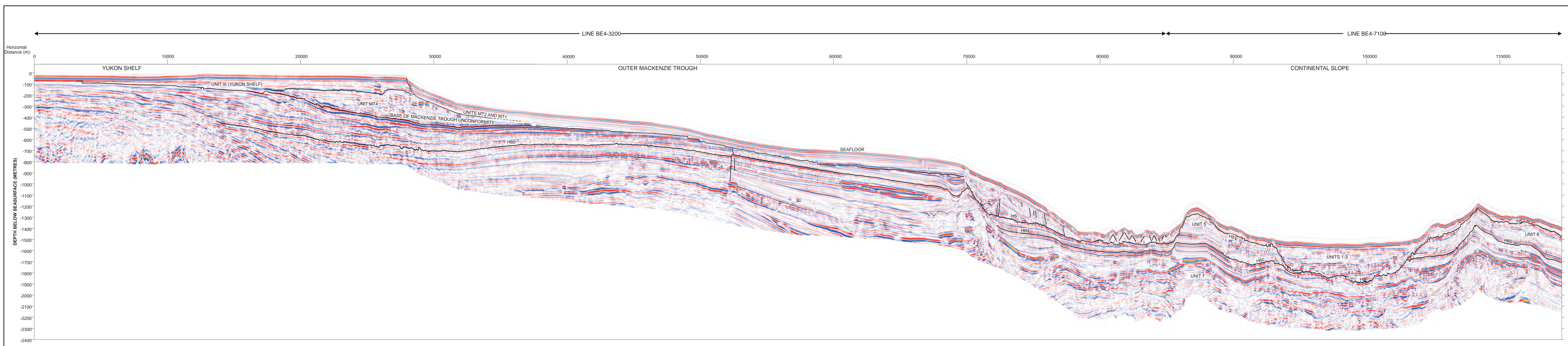
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St. John's, NL
Canada, A1B 3X2

REV	DATE	DESIGNATION	DRAWN	CHECKD	APPRD
1	Jul. 20/16	SEE CRN 969 FOR REVISION	CS	CWL	EC
0	Aug. 26/15	ISSUED FOR FINAL REPORT	CS	CWL	EC
C	Mar. 16/15	DRAFT C SUBMISSION	AC	CWL	EC

ALL MULTIBEAM IMAGES ARE FROM THE 2009 SURVEY

JOB NUMBER: 20110068 DWG No: 20110068-SLMP-MVMT-E06-1

DATE: JULY 20, 2016 ENCLOSURE: 6

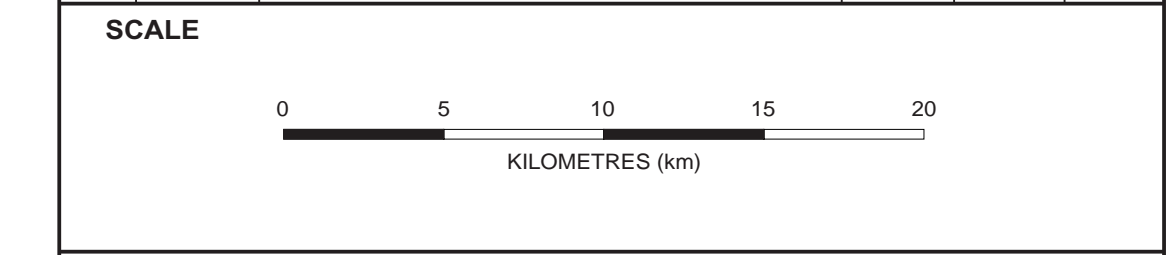


LEGEND AND NOTES

Seafloor
Acoustic Seismic Horizon

DEPTH SCALE ON SUB-BOTTOM PROFILE INTERPRETATION BASED ON AN ASSUMED SOUND VELOCITY OF 1500m/s.

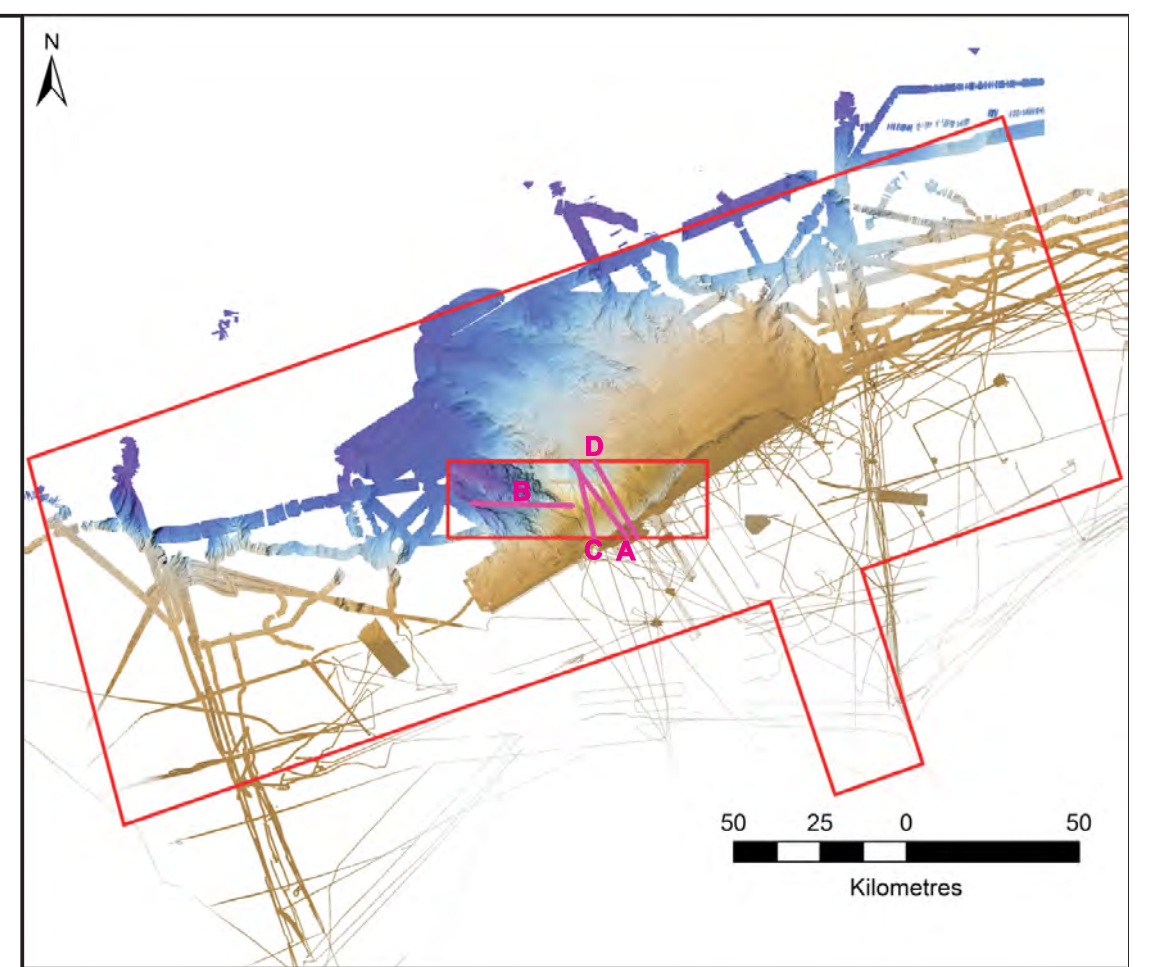
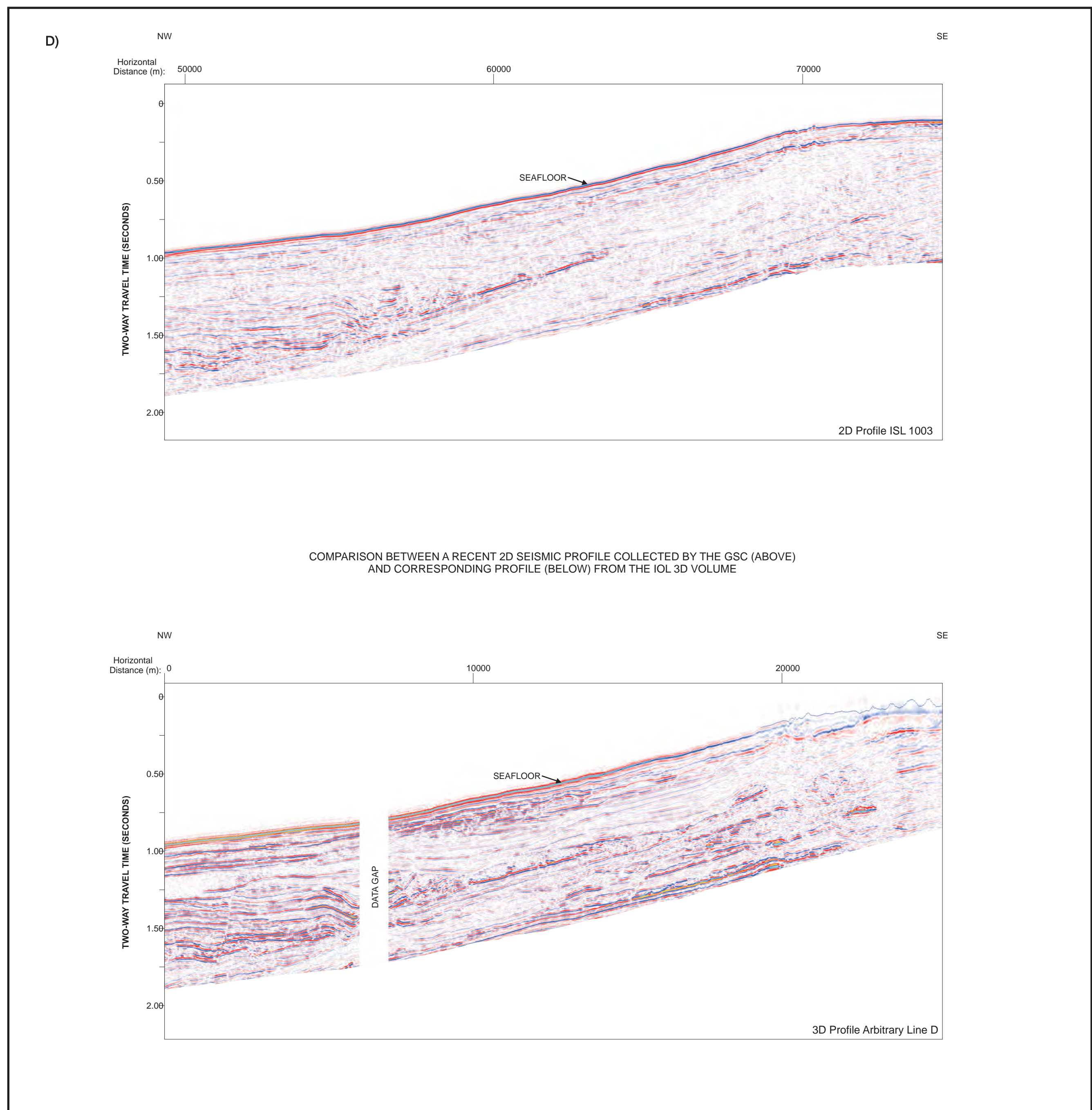
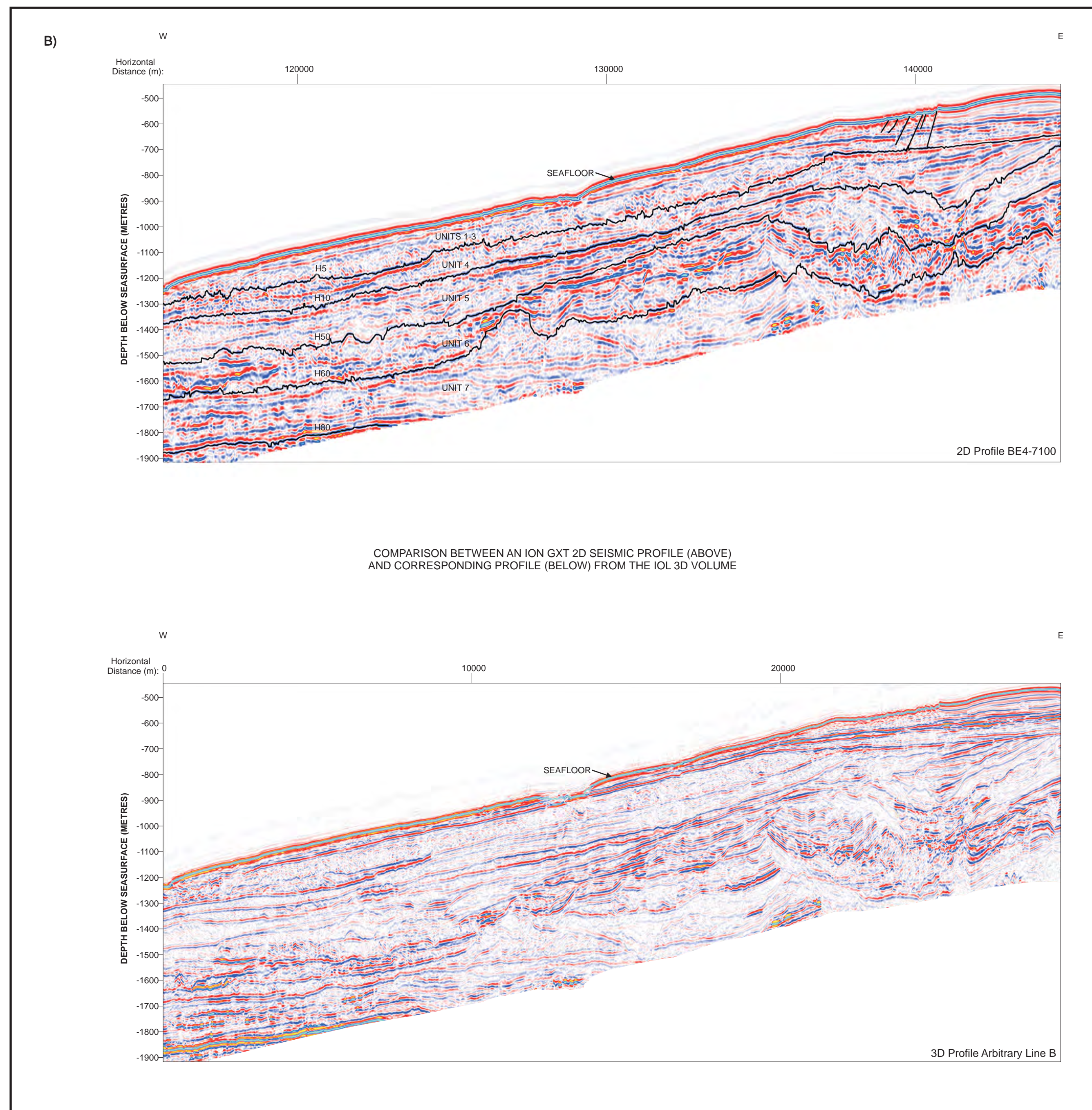
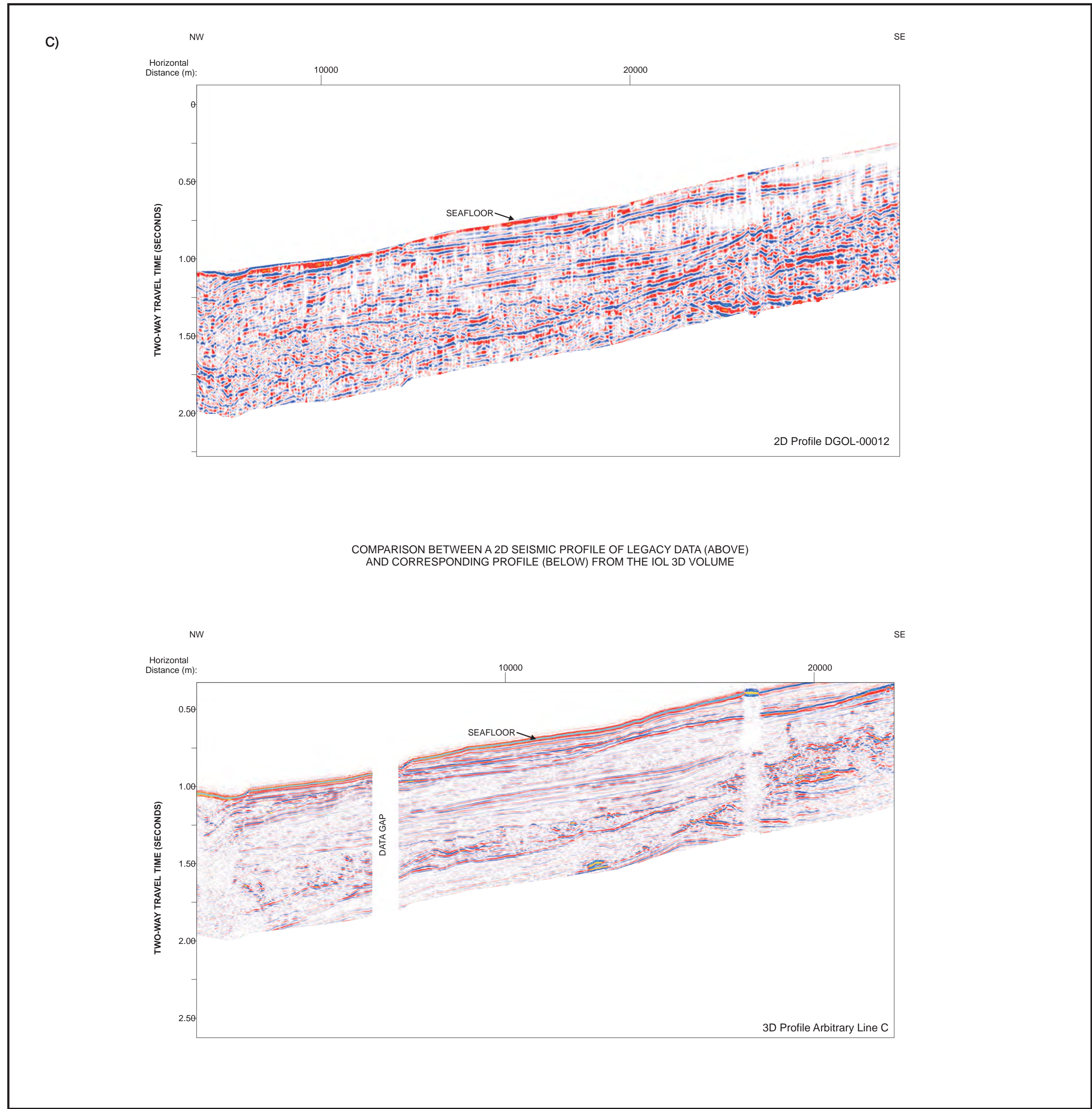
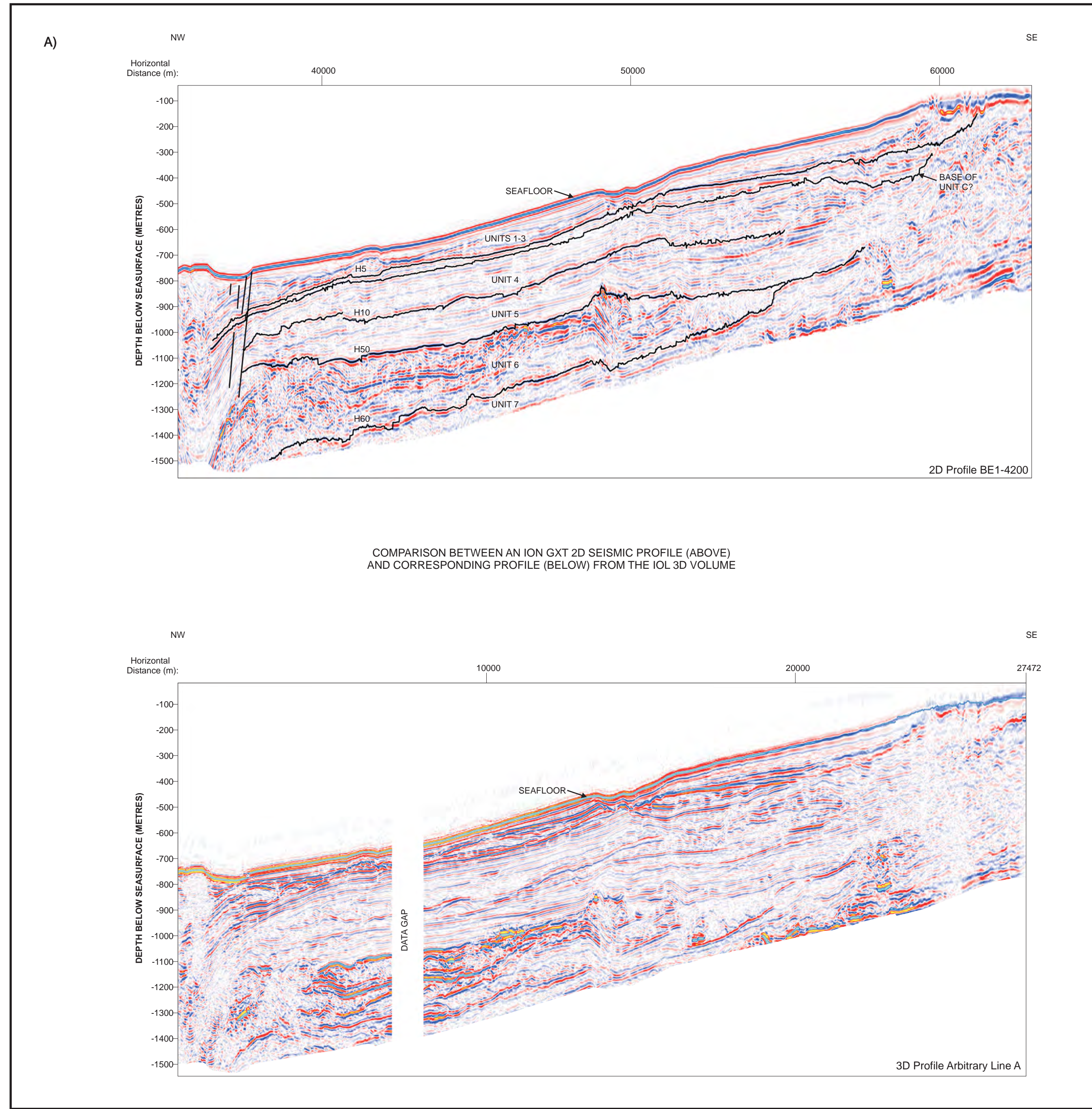
FUGRO REVISION REFERENCE				
REV.	DATE	DESIGNATION	DRAWN	CHECKED/ APPR'D
0	Aug 26/15	ISSUED FOR FINAL REPORT	CS	CWL EC
1	Mar 27/15	DRAFT C SUBMISSION	AC	CWL EC



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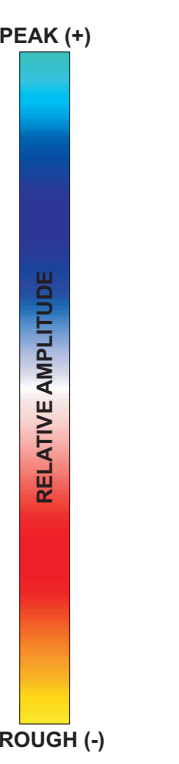
SEISMIC PROFILE ACROSS YUKON SHELF - OUTER MACKENZIE TROUGH - CONTINENTAL SLOPE - BEAUFORT SHELF - AMAULIGAK 3F-24 BOREHOLE SOUTHERN BEAUFORT SEA

JOB NUMBER: 20110060	DRAWN BY: AC	ENCLOSURE: 7	REV 0
DATE: AUGUST 26, 2015	CHECKED BY: CWL		
DWG NO: 20110060-PRC-ARB-607-0			



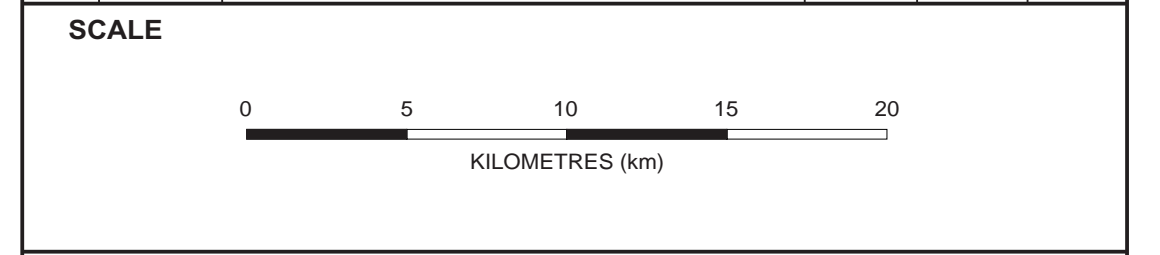
LEGEND AND NOTES

Seafloor
Acoustic Seismic Horizon



FUGRO REVISION REFERENCE

REV.	DATE	DESIGNATION	DRAWN	CHECKED	APPROV.
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1	Mar 1615	DRAFT C FOR SUBMISSION	AC	CWL	EC



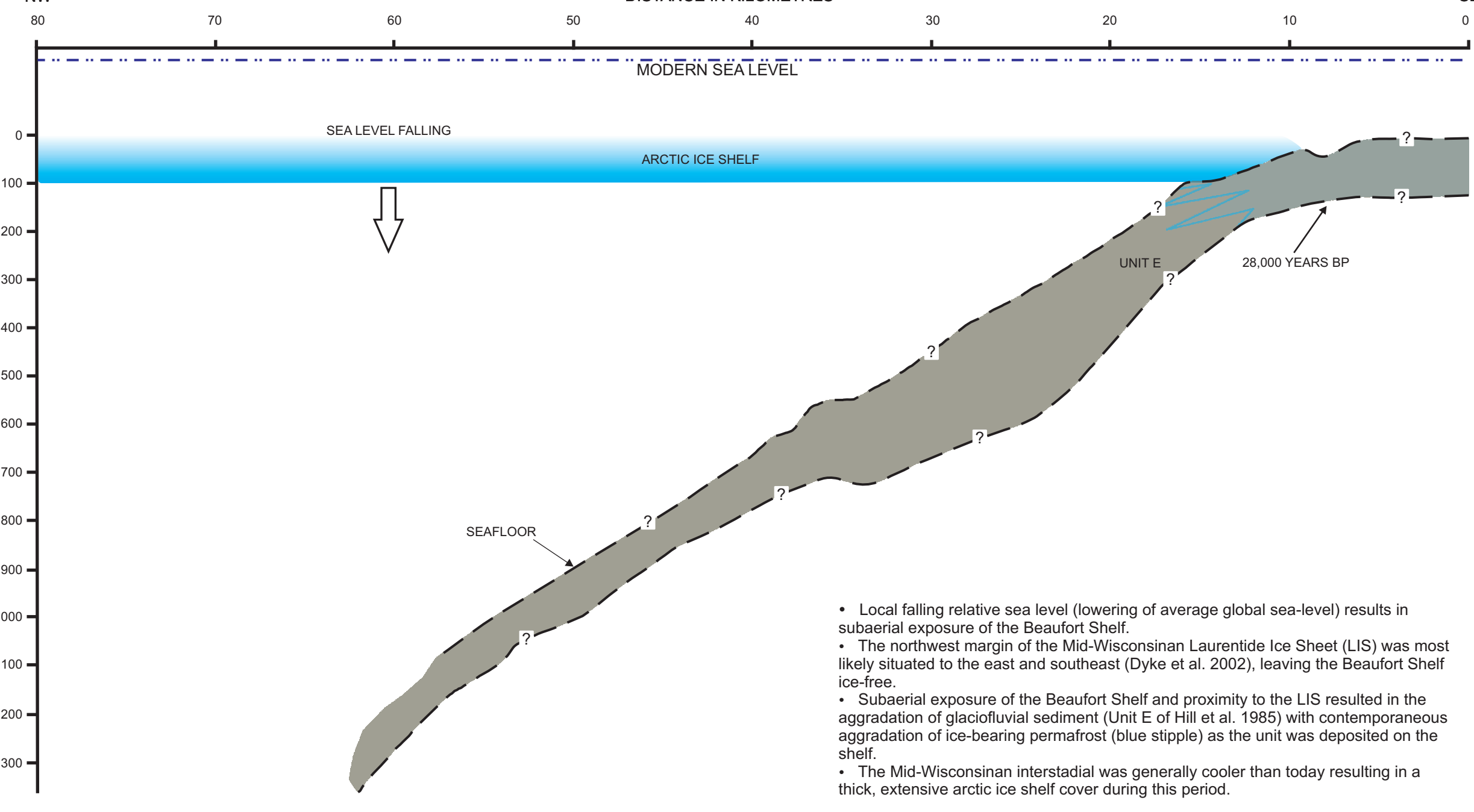
PREPARED BY

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St. John's, NL
Canada, A1B 3X2

**2D AND 3D SEISMIC PROFILE COMPARISONS
SOUTHERN BEAUFORT SEA**

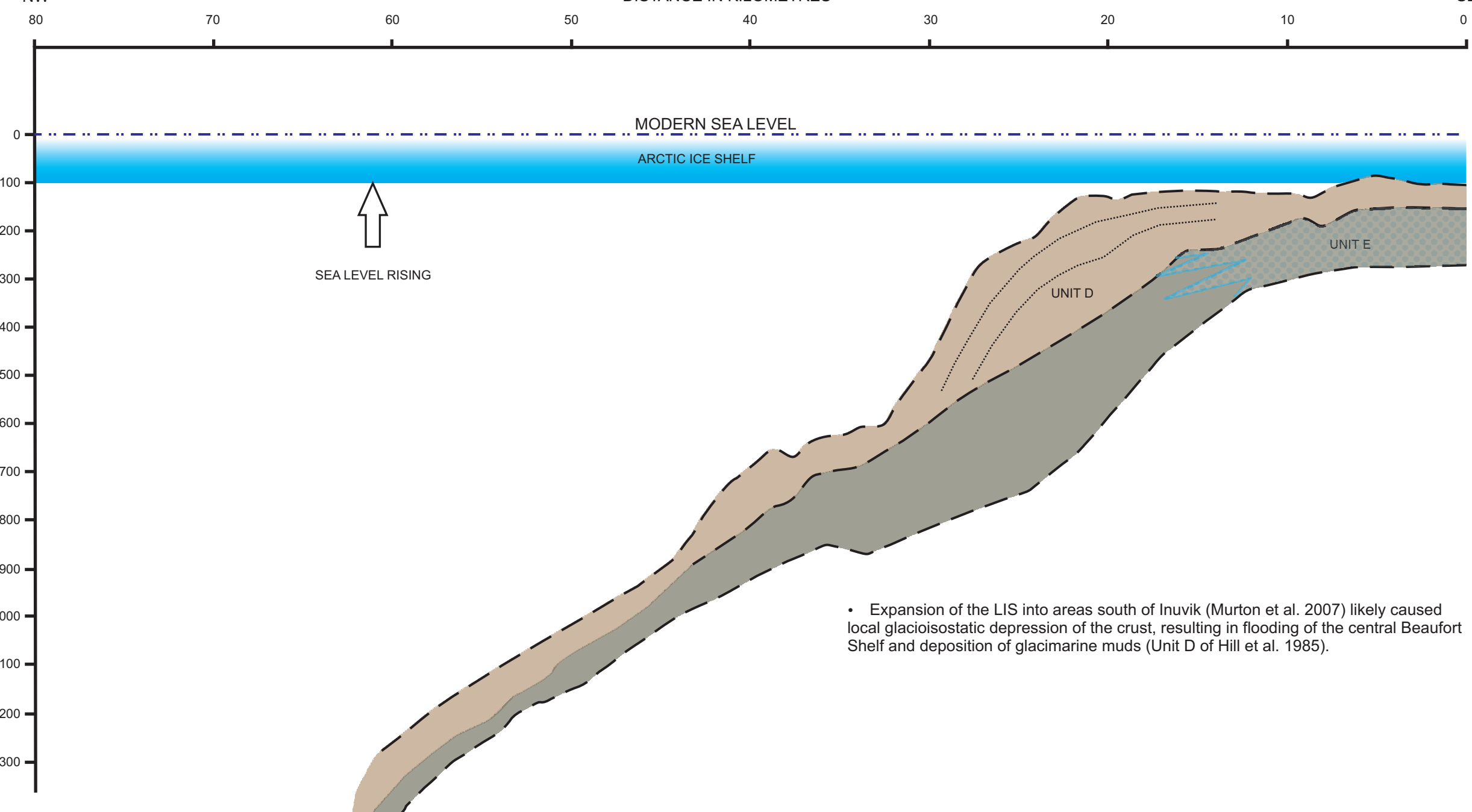
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DATE: AUGUST 26, 2015	CHECKED BY: CWL	
DWG NO: 20110068-PRC-302D-E08-0	ENCLOSURE: 8	

APPROXIMATELY 30,000 - 21,000 YEARS BP



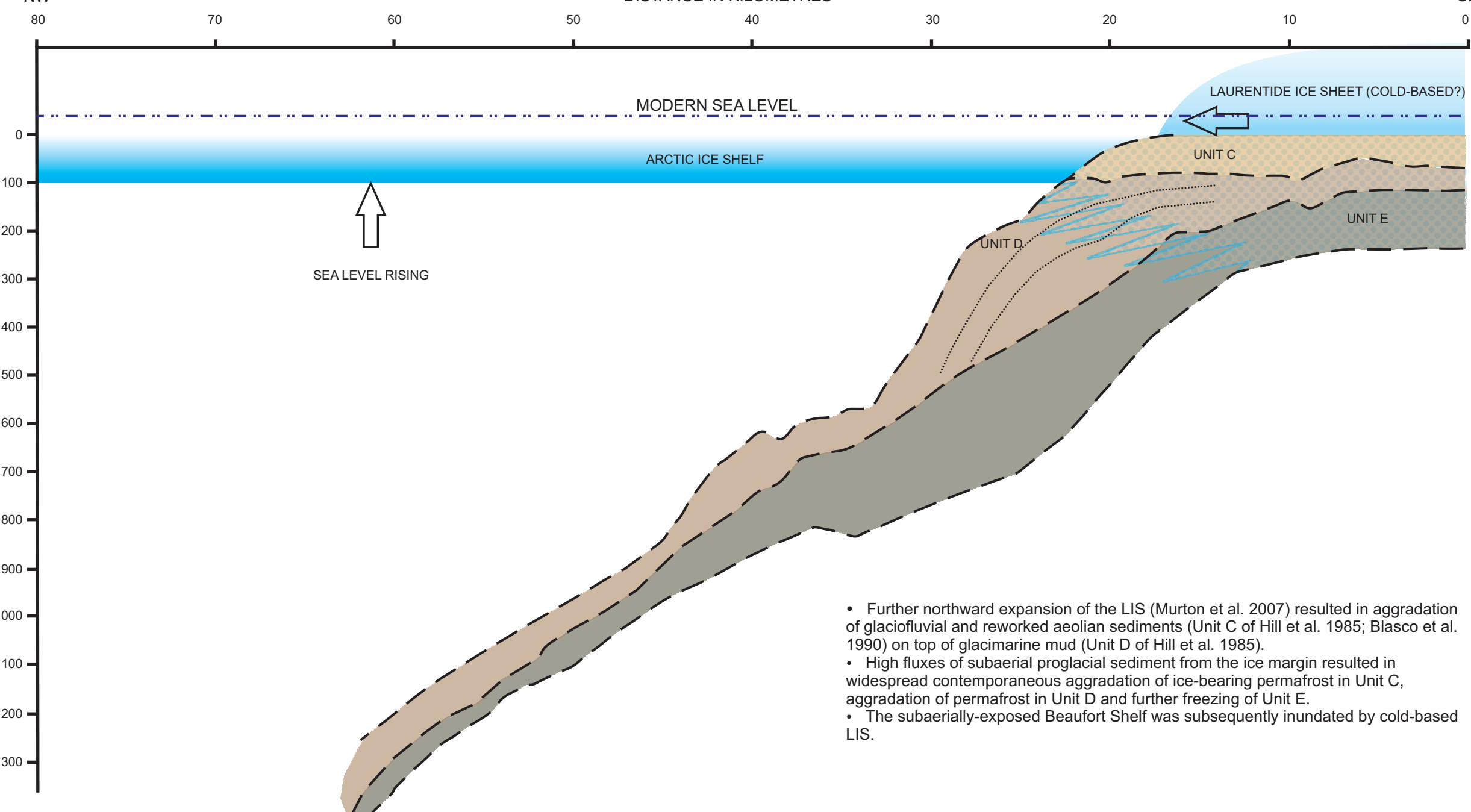
- Local falling relative sea level (lowering of average global sea-level) results in subaerial exposure of the Beaufort Shelf.
- The northwest margin of the Mid-Wisconsinan Laurentide Ice Sheet (LIS) was most likely situated to the east and southeast (Dyke et al. 2002), leaving the Beaufort Shelf ice-free.
- Subaerial exposure of the Beaufort Shelf and proximity to the LIS resulted in the aggradation of glaciofluvial sediment (Unit E of Hill et al. 1985) with contemporaneous aggradation of ice-bearing permafrost (blue stippled) as the unit was deposited on the shelf.
- The Mid-Wisconsinan interstadial was generally cooler than today resulting in a thick, extensive arctic ice shelf cover during this period.

APPROXIMATELY 21,000 YEARS BP



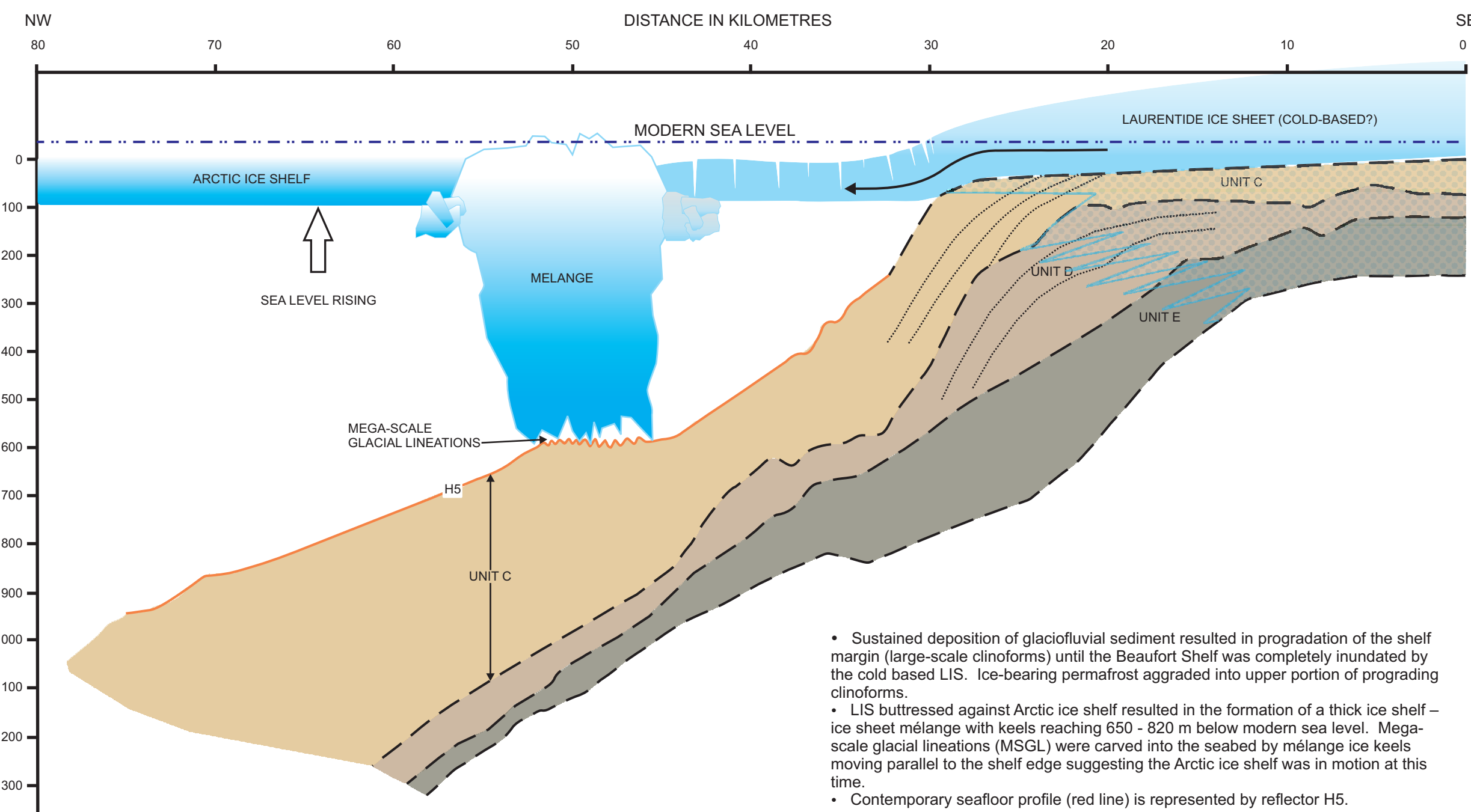
- Expansion of the LIS into areas south of Inuvik (Murton et al. 2007) likely caused local glaciostatic depression of the crust, resulting in flooding of the central Beaufort Shelf and deposition of glaciomarine muds (Unit D of Hill et al. 1985).

APPROXIMATELY 21,000 - 19,000 YEARS BP



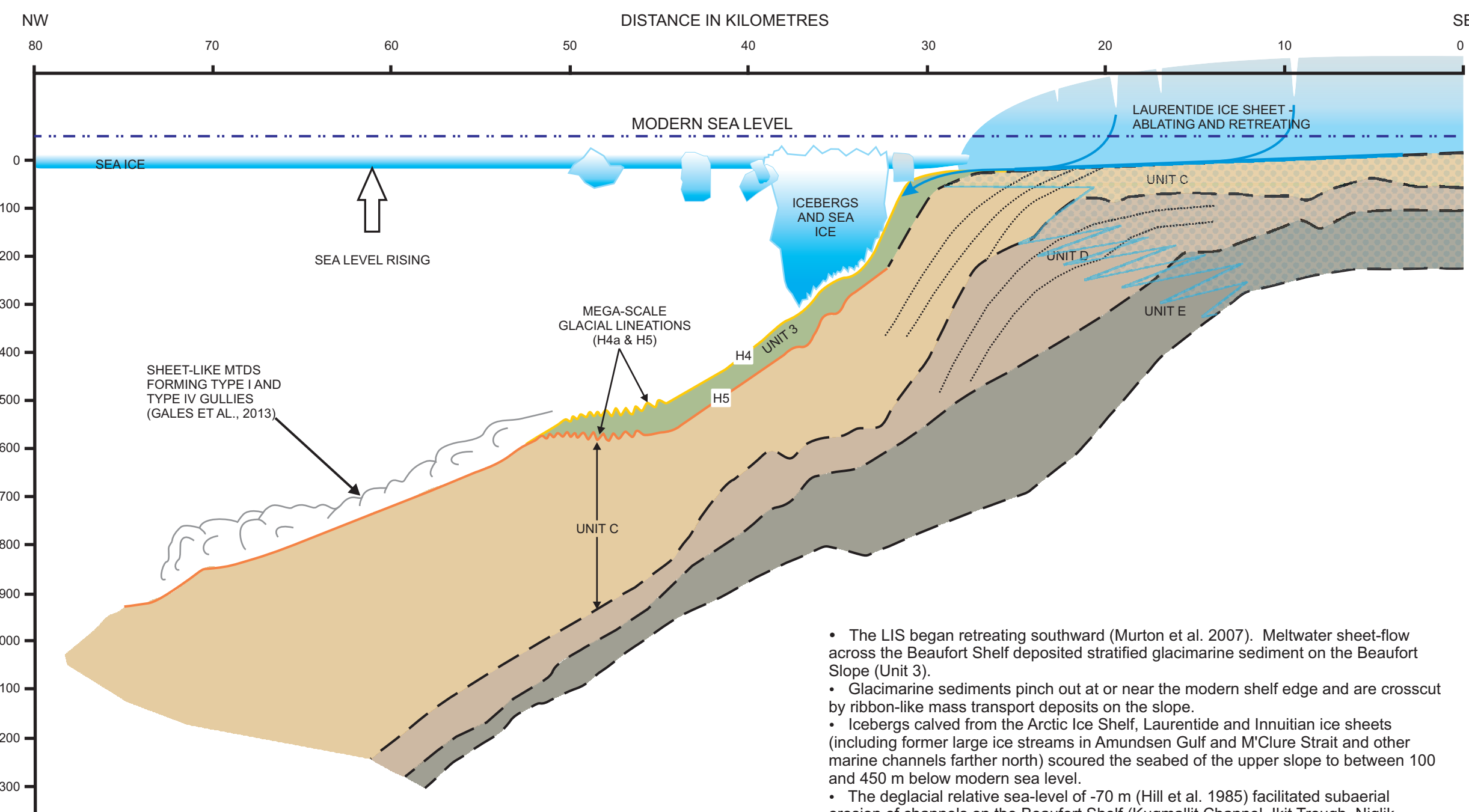
- Further northward expansion of the LIS (Murton et al. 2007) resulted in aggradation of glaciofluvial and reworked aeolian sediments (Unit C of Hill et al. 1985; Blasco et al. 1992) on top of glaciomarine muds (Unit D of Hill et al. 1985).
- High fluxes of subaerial proglacial sediment from the ice margin resulted in widespread contemporaneous aggradation of ice-bearing permafrost in Unit C, aggradation of permafrost in Unit D and further freezing of Unit E.
- The subaerially-exposed Beaufort Shelf was subsequently inundated by cold-based LIS.

APPROXIMATELY 19,000 - 16,000 YEARS BP



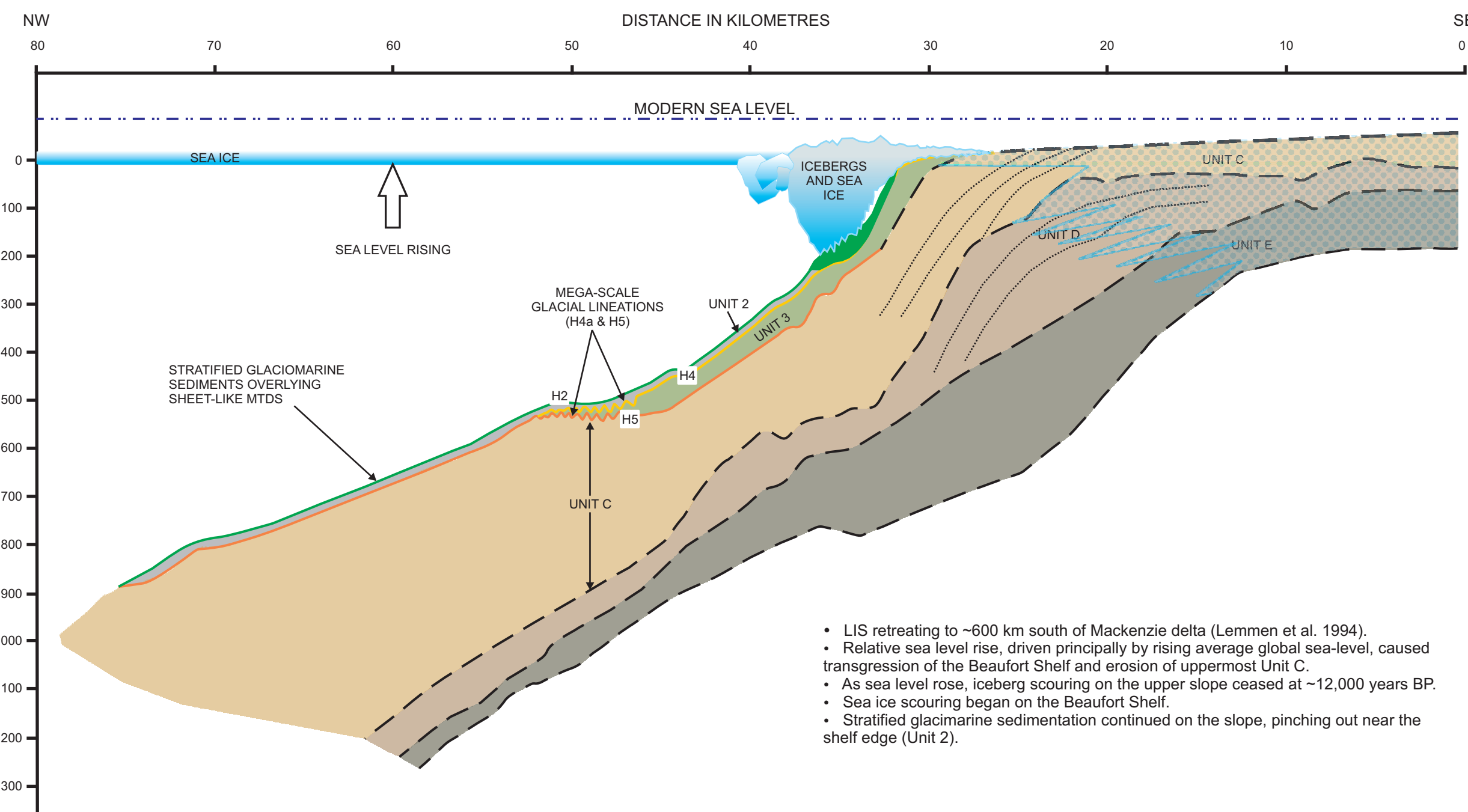
- Sustained deposition of glaciofluvial sediment resulted in progradation of the shelf margin (large-scale clinoforms) until the Beaufort Shelf was completely inundated by the cold based LIS. Ice-bearing permafrost aggraded into upper portion of prograding clinoforms.
- LIS buttressed against Arctic ice shelf resulted in the formation of a thick ice shelf-ice sheet melange with keels reaching 650 - 820 m below modern sea level. Mega-scale glacial lineations (MSG) were carved into the seabed by melange ice keels moving parallel to the shelf edge suggesting the Arctic ice shelf was in motion at this time.
- Contemporary seafloor profile (red line) is represented by reflector H5.

16,000 - 13,000 YEARS BP



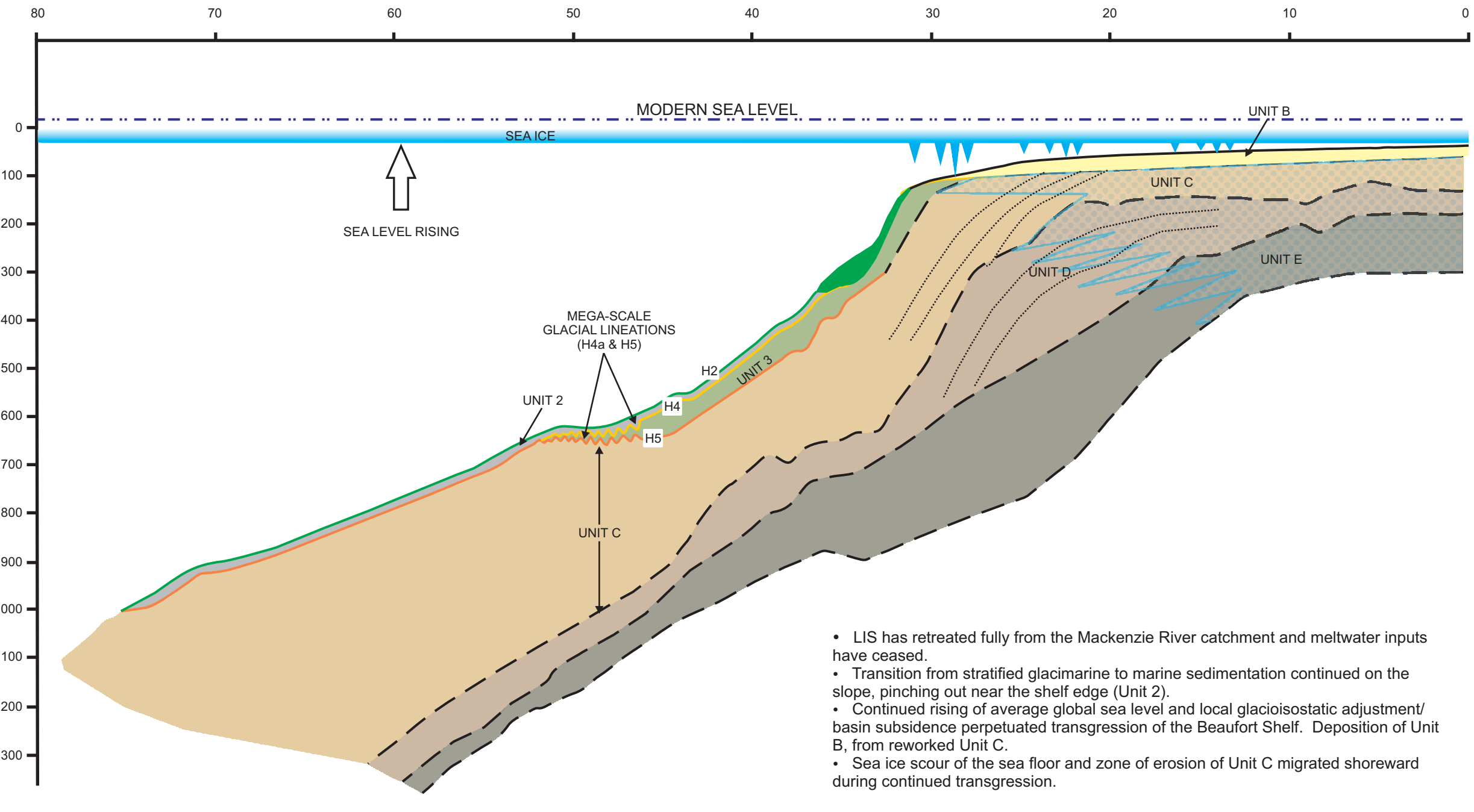
- The LIS began retreating southward (Murton et al. 2007). Meltwater sheet-flow across the Beaufort Shelf deposited stratified glaciomarine sediment on the Beaufort Slope (Unit 3).
- Glaciomarine sediments pinch out at or near the modern shelf edge and are crosscut by ribbon-like mass transport deposits on the slope.
- Icebergs calved from the Arctic Ice Shelf, Laurentide and Innuitian ice sheets (including former large ice streams in Amundson Gulf and McCreary Strait and other marine channels further north) scoured the seabed of the upper slope to between 100 and 450 m below modern sea level.
- The diachronal sea-level of ~70 m (Hill et al. 1985) facilitated subaerial erosion of channels on the Beaufort Shelf (Kugmallit Channel, Ikt Trough, Niglik Channel). Downslope meltwater flow eroded Kugmallit Channel which incised the slope and can be traced on the modern seafloor to present water depths of at least 750 m.

13,000 - 12,000 YEARS BP



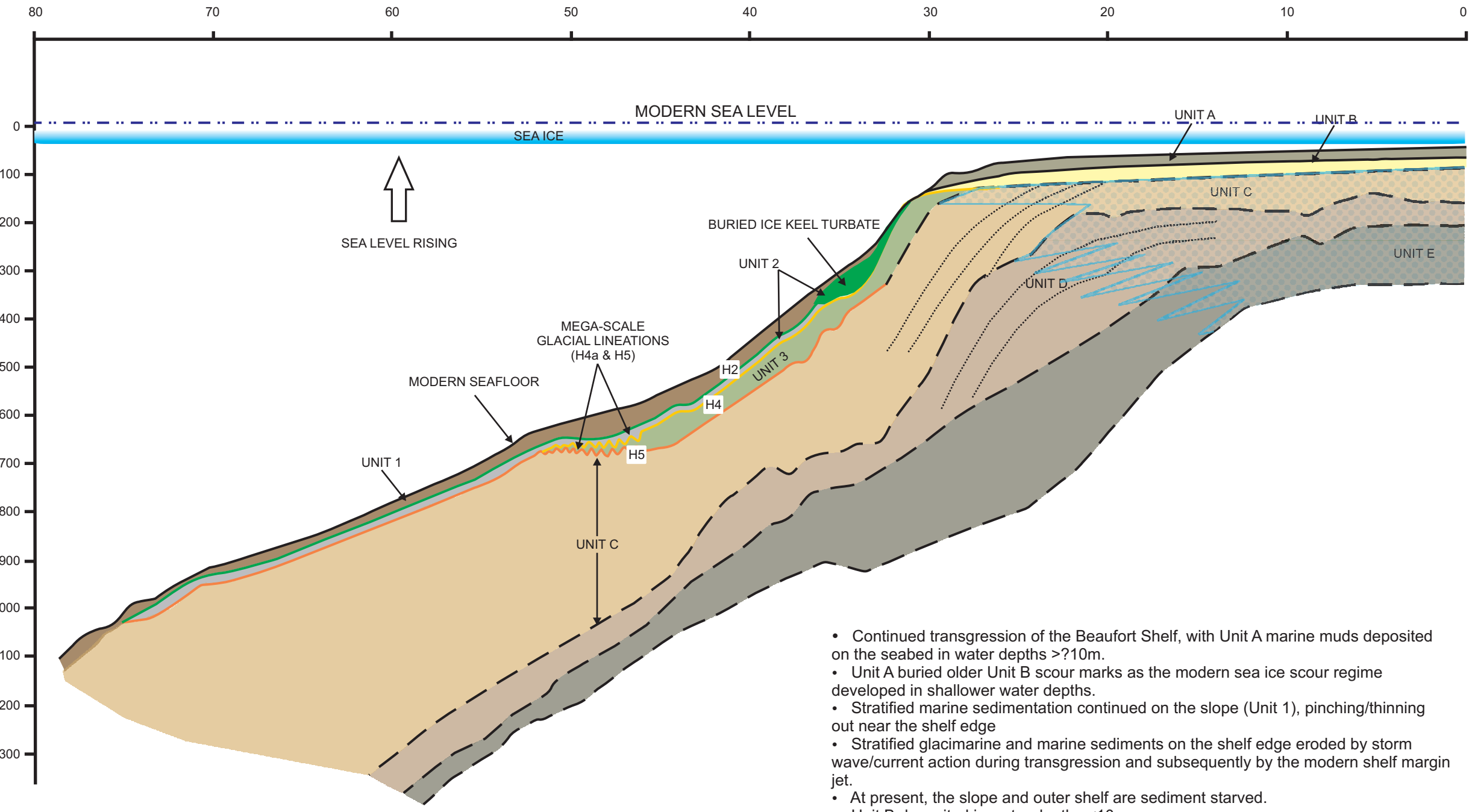
- LIS retreating to ~600 km south of Mackenzie delta (Lemmen et al. 1994).
- Relative sea level rise, driven principally by rising average global sea-level, caused transgression of the Beaufort Shelf and erosion of uppermost Unit C.
- As sea level rose, iceberg scouring on the upper slope ceased at ~12,000 years BP.
- Sea ice scouring began on the Beaufort Shelf.
- Stratified glaciomarine sedimentation continued on the slope, pinching out near the shelf edge (Unit 2).

12,000 - 9,000 YEARS BP



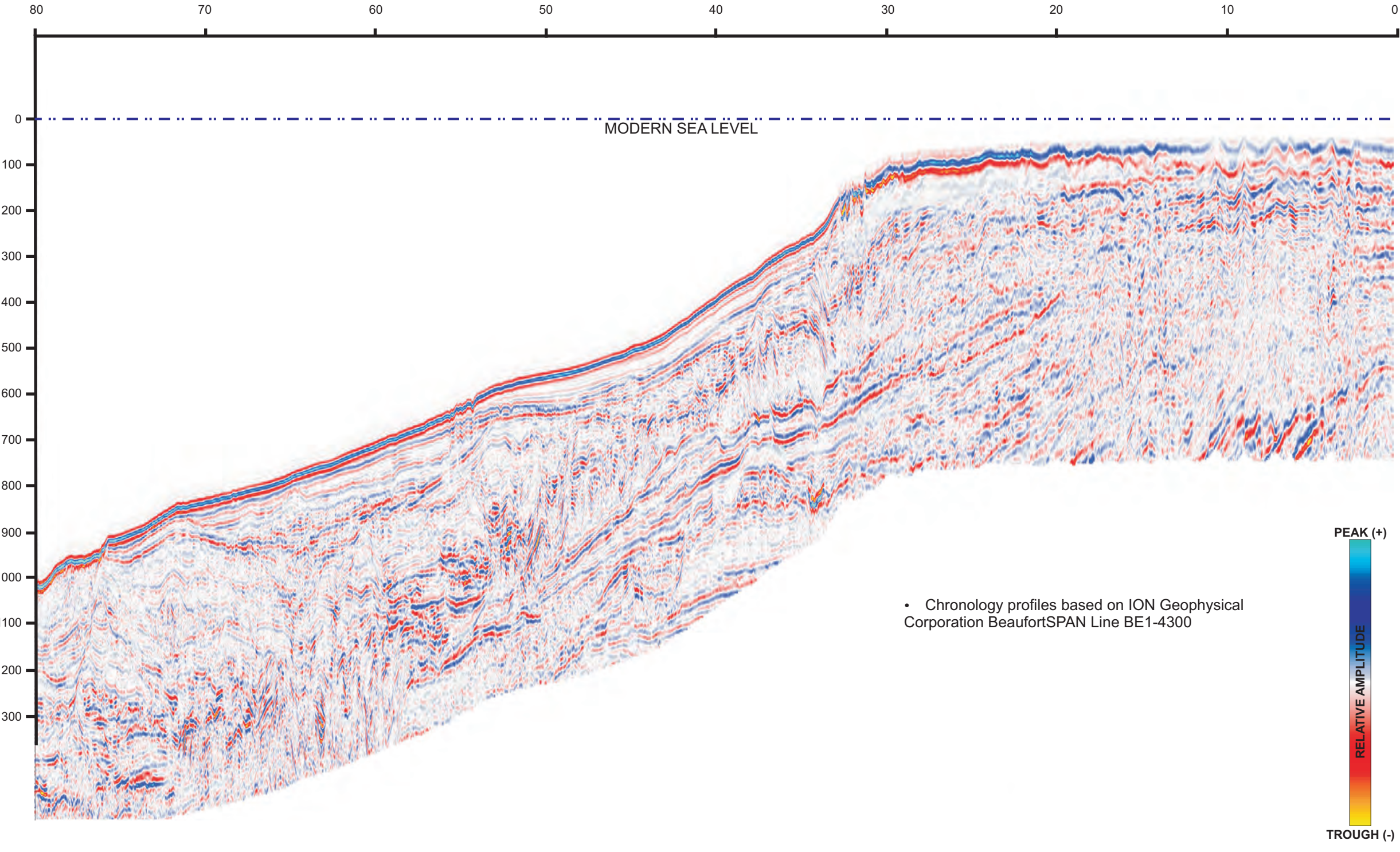
- LIS has retreated fully from the Mackenzie River catchment and meltwater inputs have ceased.
- Transition from stratified glaciomarine to marine sedimentation continued on the slope, pinching out near the shelf edge (Unit 2).
- Continued rising of average global sea level and local glaciostatic adjustment/basin subsidence perpetuated transgression of the Beaufort Shelf. Deposition of Unit B, from reworked Unit C.
- Sea ice scour of the sea floor and zone of erosion of Unit C migrated shoreward during continued transgression.

9,000 YEARS BP TO PRESENT

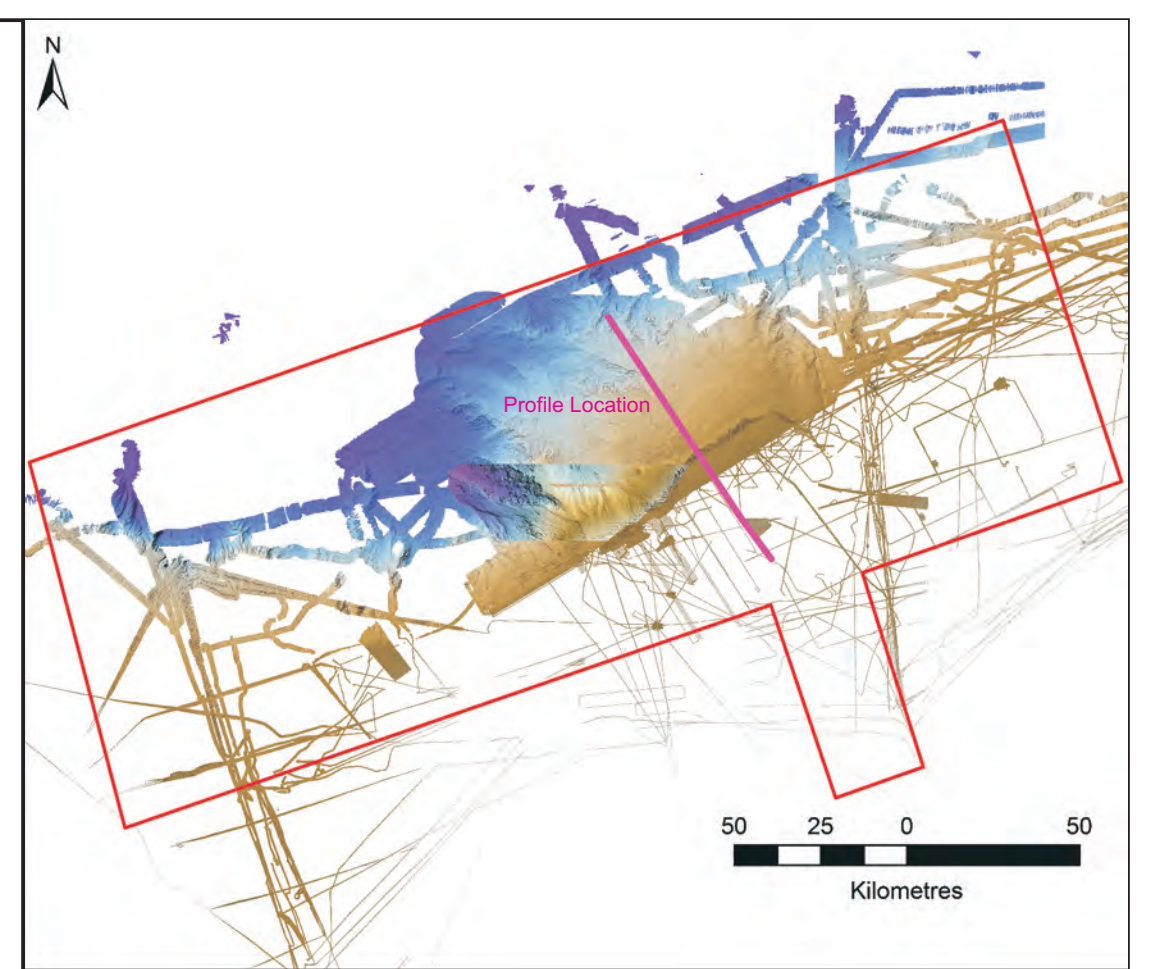


- Continued transgression of the Beaufort Shelf, with Unit A marine muds deposited on the seabed in water depths >110m.
- Unit A buried older Unit B scour marks as the modern sea ice scour regime developed in shallower water depths.
- Stratified marine sedimentation continued on the slope (Unit 1), pinching/thinning out near the shelf edge.
- Stratified glaciomarine and marine sediments on the shelf edge eroded by storm wave/current action during transgression and subsequently by the modern shelf margin jet.
- At present, the slope and outer shelf are sediment starved.
- Unit B deposited in water depths <10m.

ION GXT LINE BE1-4300



- Chronology profiles based on ION Geophysical Corporation BeaufortSPAN Line BE1-4300



LEGEND AND NOTES

- Seafloor
- Horizon H2
- Horizon H4
- Horizon H5
- Clinoform
- Sediment Flow
- Permafrost

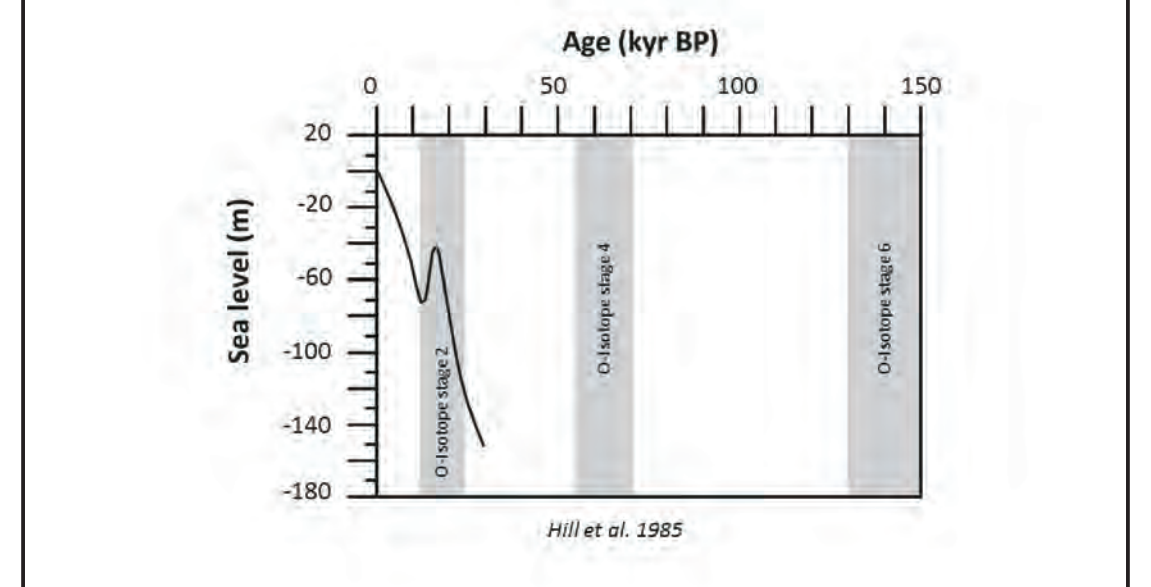
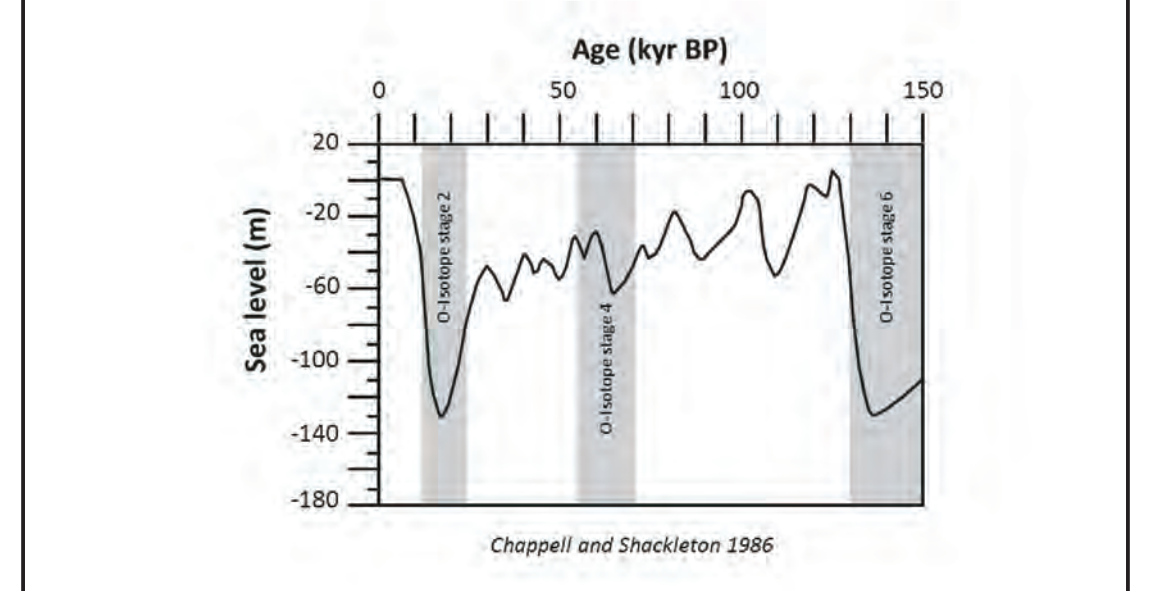
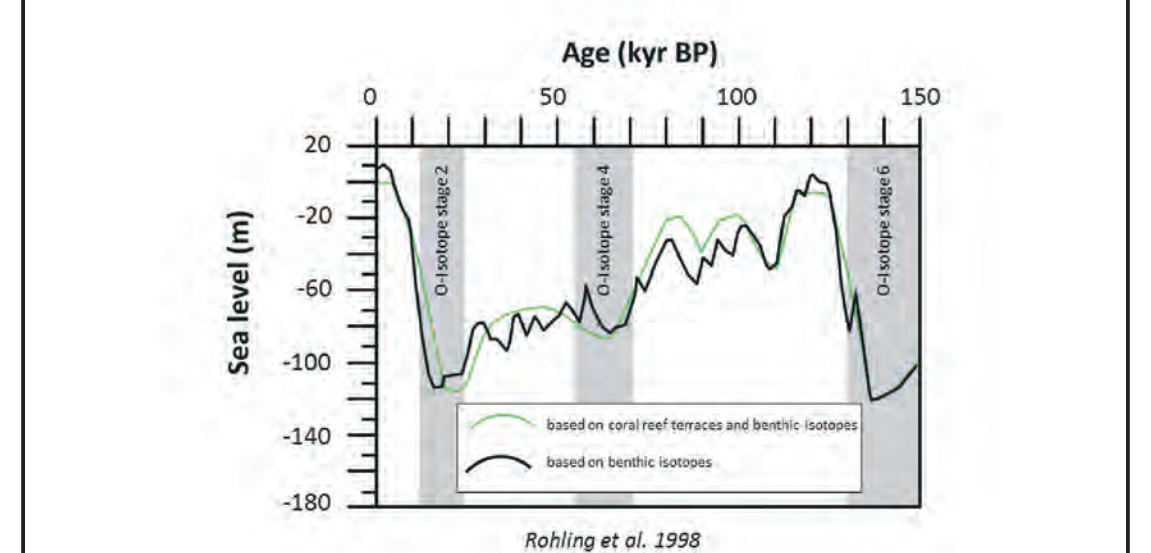
CONTINENTAL SLOPE

- Unit 1
- Unit 2
- Unit 3

BEAUFORT SHELF

- Unit A
- Unit B
- Unit C
- Unit D
- Unit E

Ice Keel Turbate



FUGRO REVISION REFERENCE

REV.	DATE	DESIGNATION	DRAWN	CHECKED	APPROV.
1	Dec 03/15	ISSUED FOR FINAL REPORT - CORN NO. 918 FOR CHANGES	AC	CWL	EC
0	Aug 26/15	ISSUED FOR FINAL REPORT	CS	CWL	EC
C	Mar 16/15	DRAFT SUBMISSION	JFAC	CWL	EC

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LATE QUATERNARY EVOLUTION OF THE SOUTHERN BEAUFORT SEA