Istituto Nazionale di Oceanografia e di Geofisica Sperimentale

Università degli studi di Trieste

LAUREA MAGISTRALE IN GEOSCIENZE

Classe Scienze e Tecnologie Geologiche

Curriculum: Esplorazione Geologica

Anno accademico 2024 - 2025

Analisi di Bacino e Stratigrafia Sequenziale (426SM)

Docente: **Michele Rebesco**

Istituto Nazionale di Oceanografia e di Geofisica Sperimentale

Modulo 3.8
Typical facies of depositional-erosional system in polar environment

Docente: **Laura De Santis**

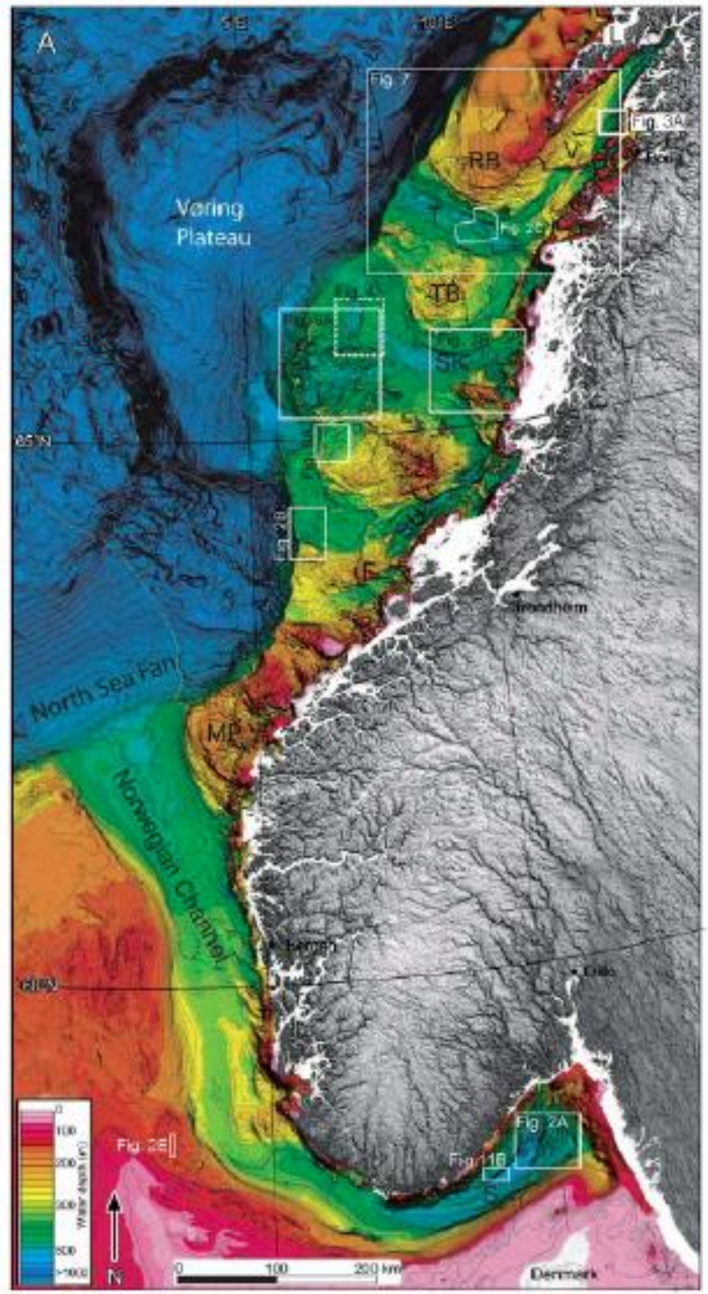
Modulo 3.8 Typical facies of depositional/erosional system in polar environment

Docente: Laura De Santis

OUTLINE

Diagnostic features

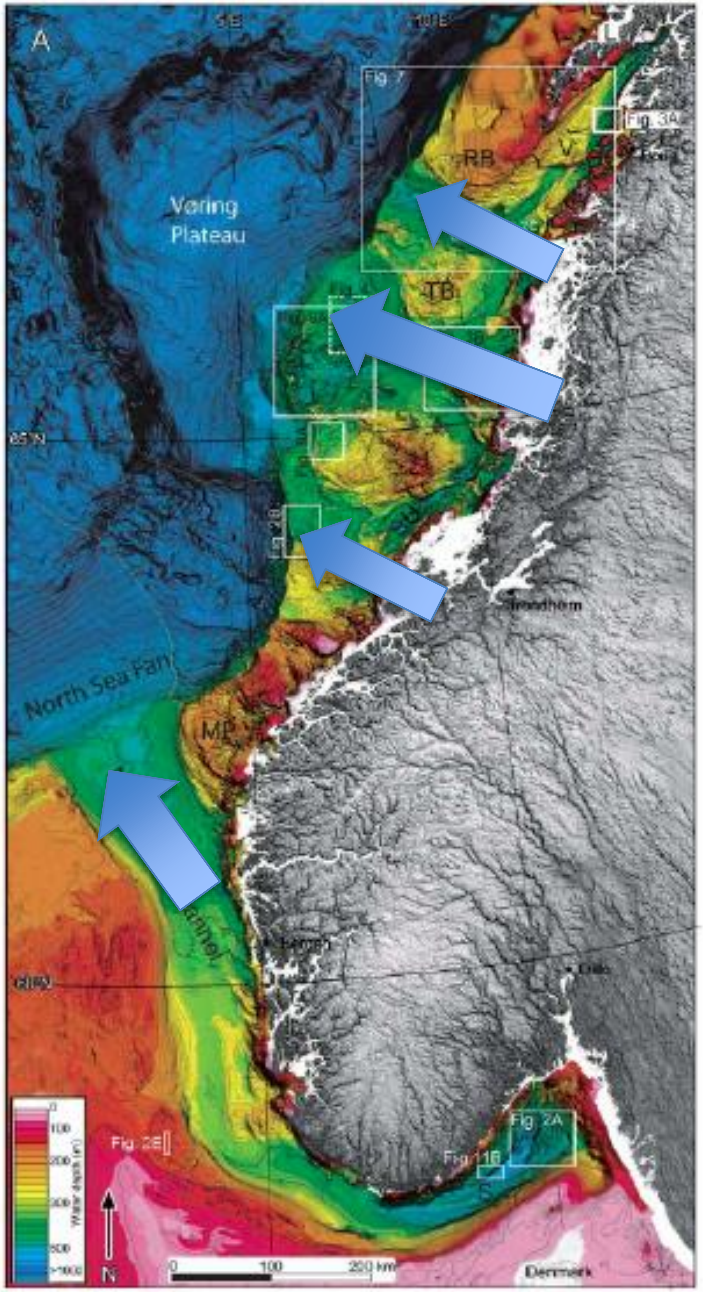
- Glacial valleys and banks topography
- Trough mouth fans
- Landward deepening continental shelf
- Ice grounding zone wedge
- Glacial lineations, outwash channels



Modulo 3.8 Typical facies of depositional/erosional system in polar environment

Docente: Laura De Santis

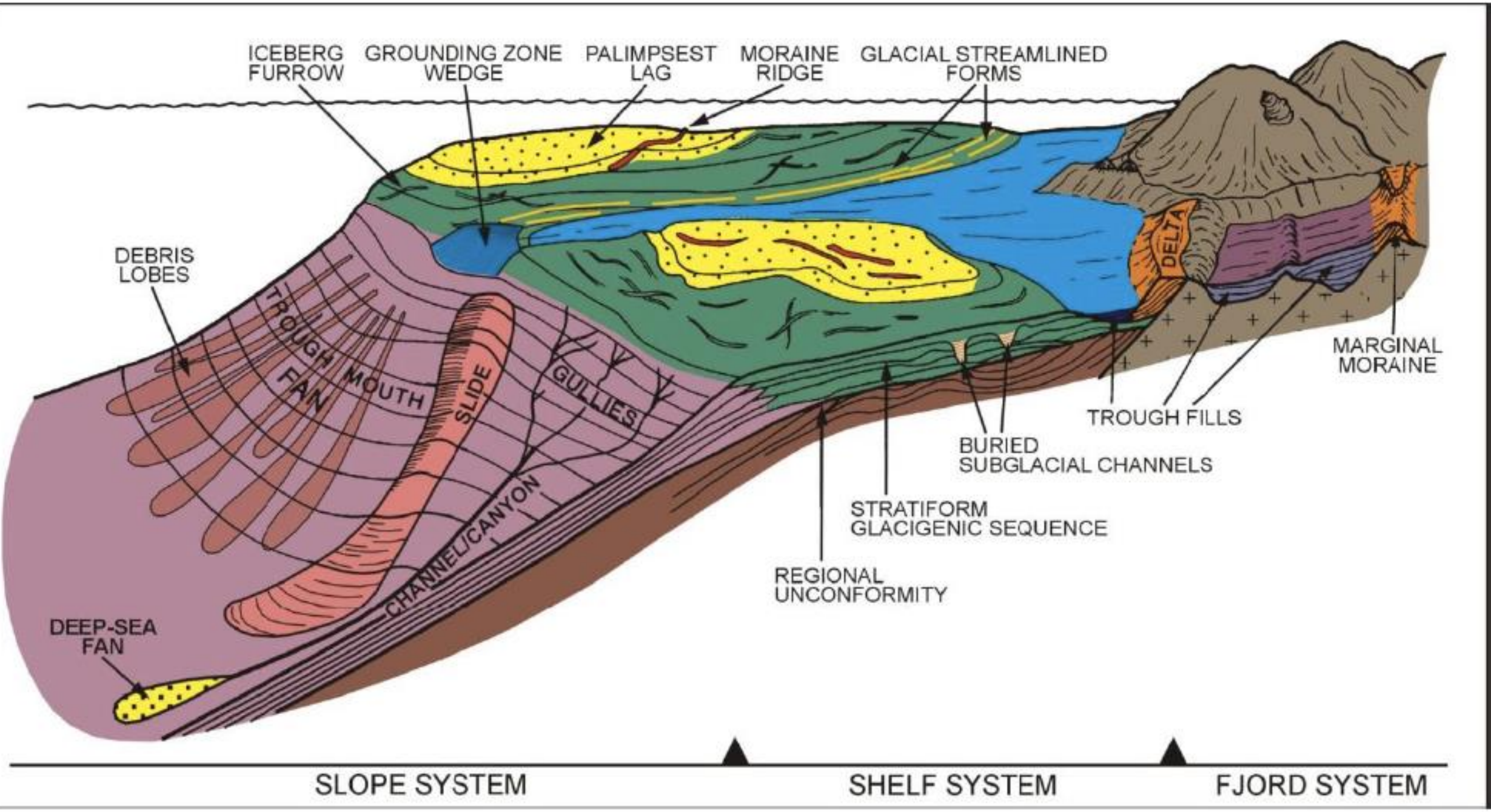
OUTLINE



Diagnostic features

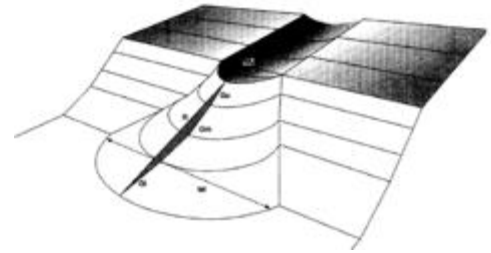
- Glacial valleys and banks topography
- Trough mouth fans
- Landward deepening continental shelf
- Ice grounding zone wedge
- Glacial lineations, outwash channels

Trough/bank topography Trough mouth fans

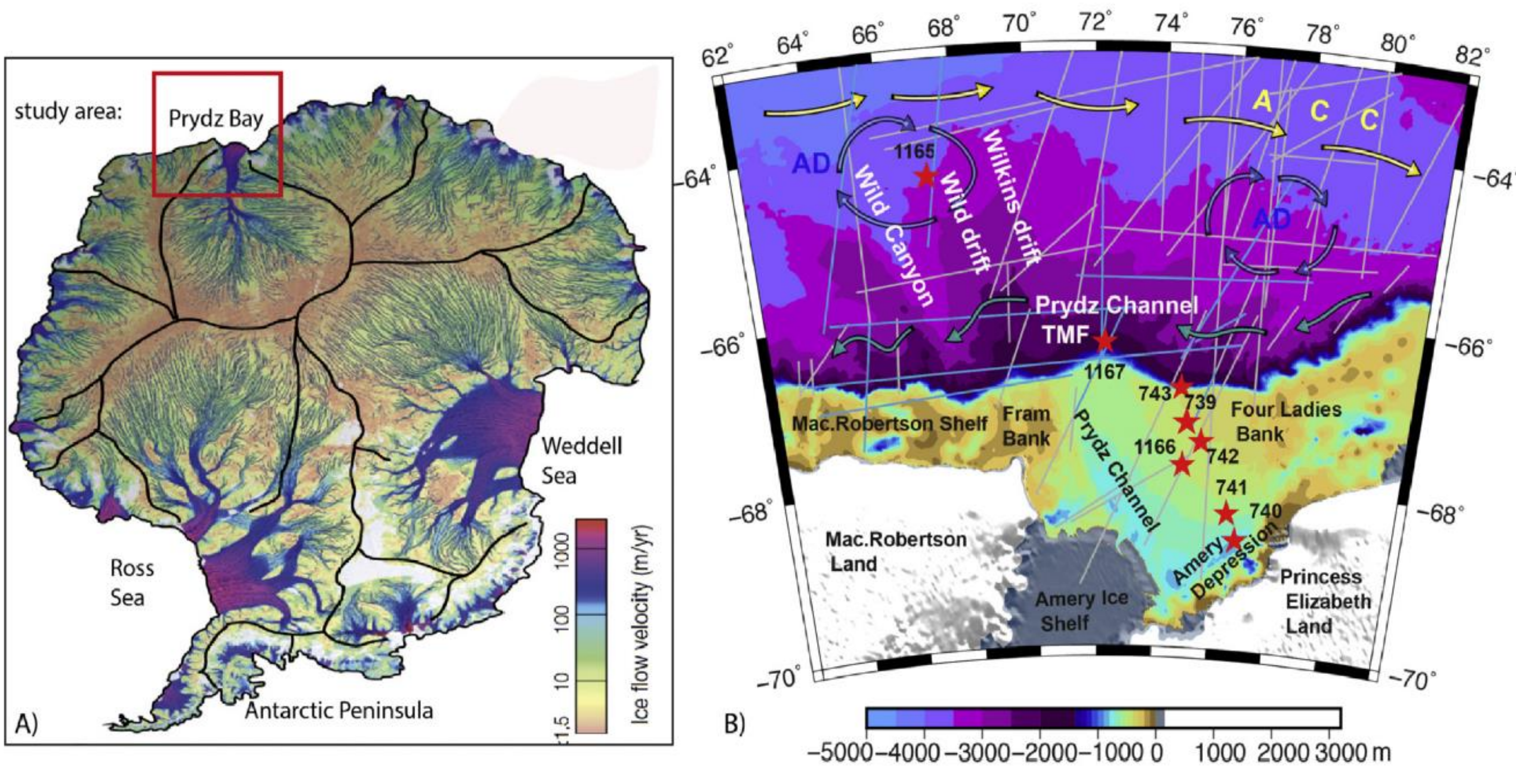


Vorren, 2003

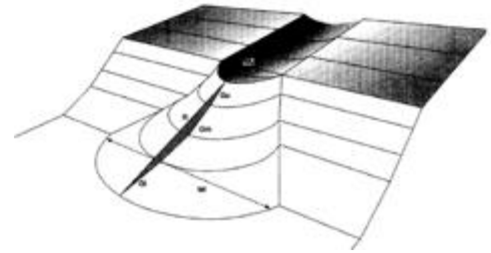
Trough/bank topography
Trough mouth fans



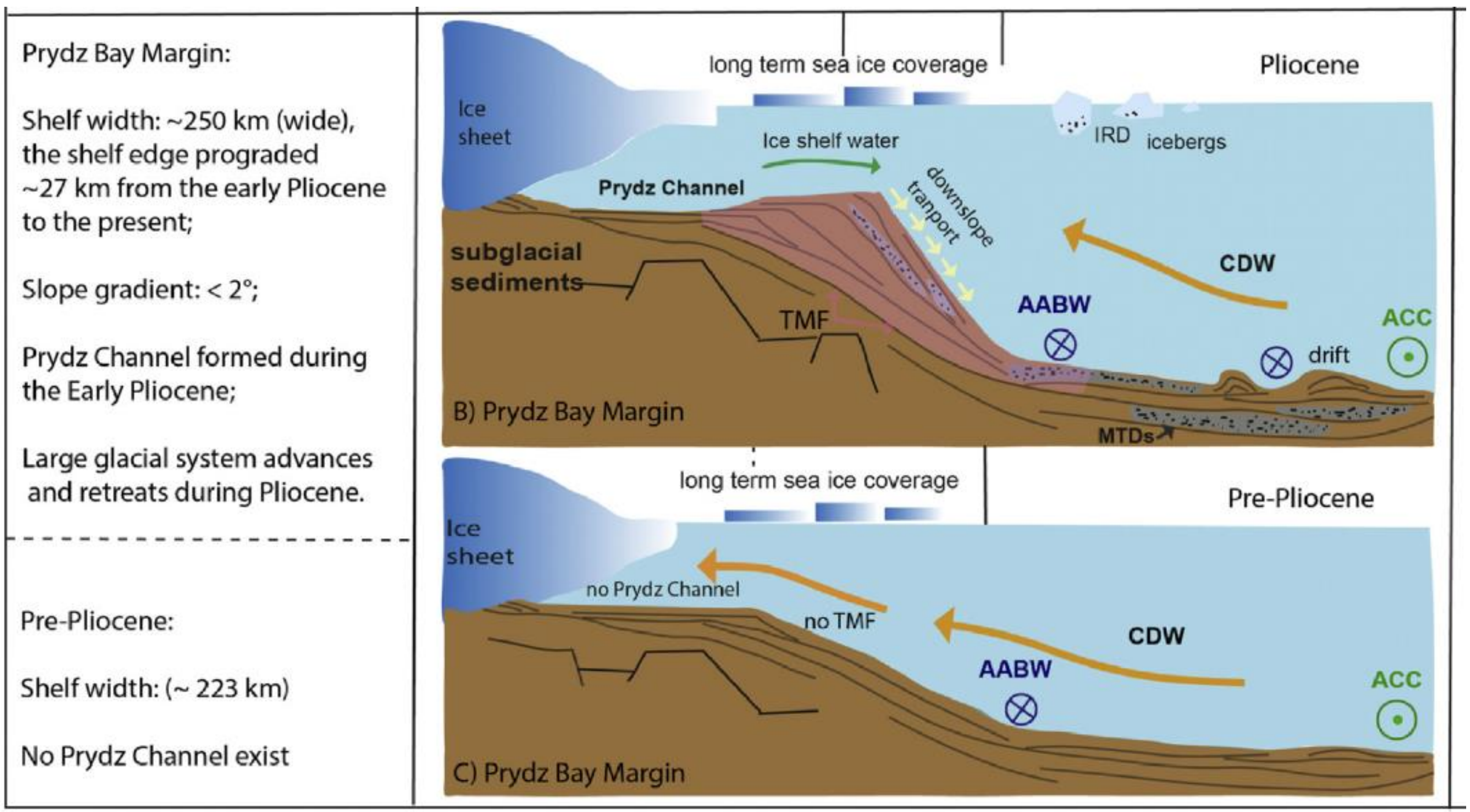
X. Huang, et al. *Marine Geology 430 (2020) 106339*



Trough/bank topography
Trough mouth fans

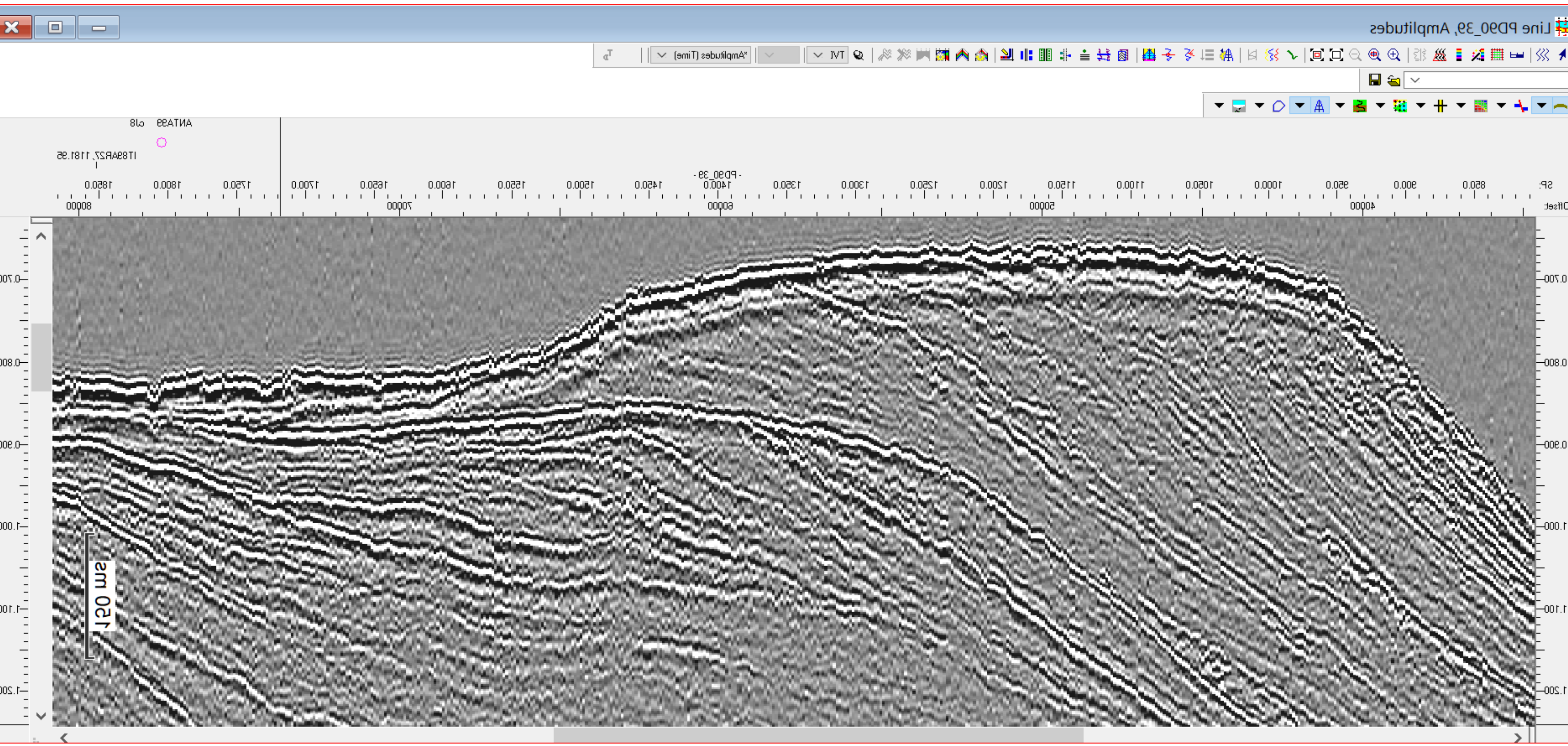


Glacial erosion (interior) and deposition (margin) => landward deepening cont. shelf



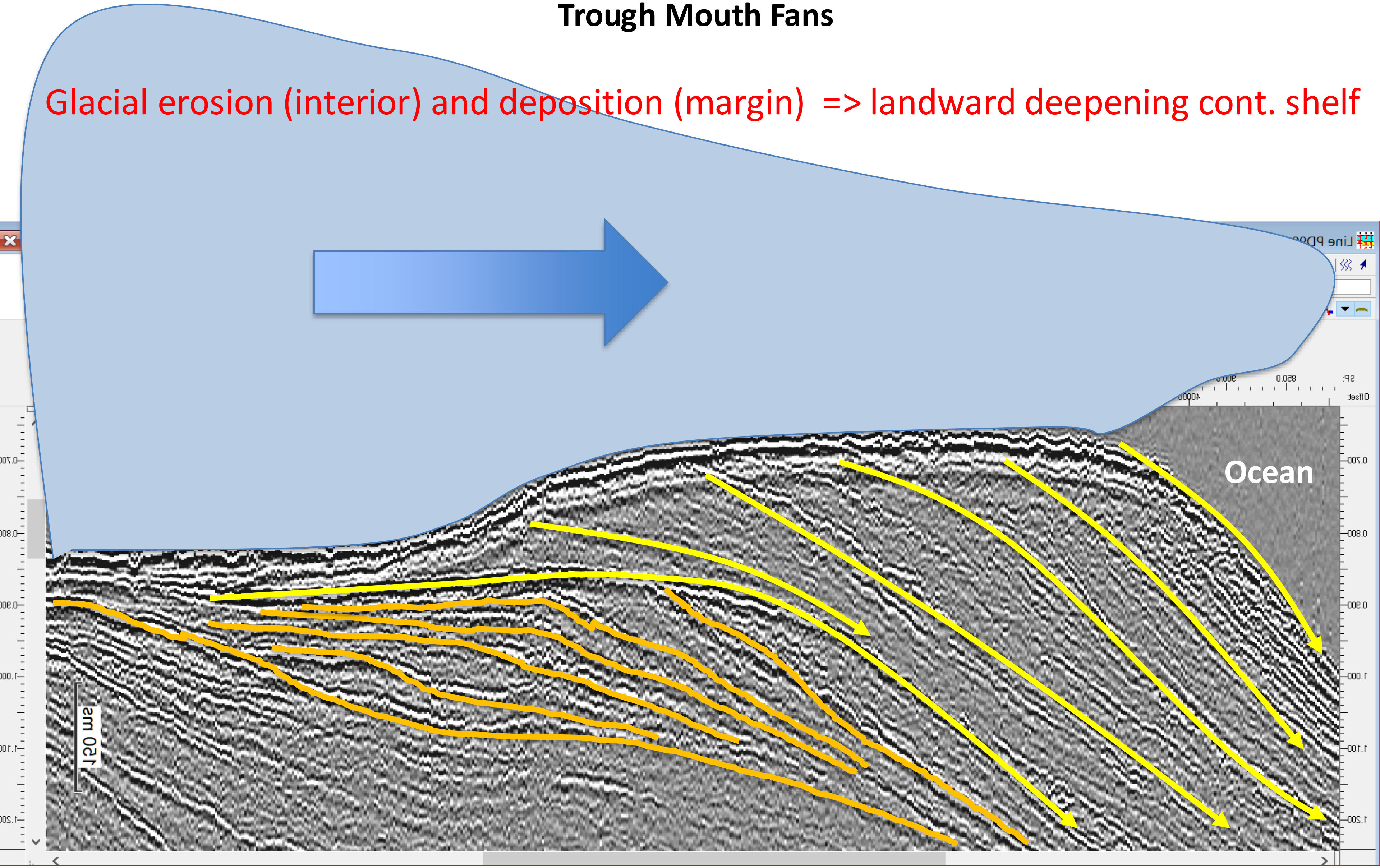
Huang et al., 2020

Trough Mouth Fans



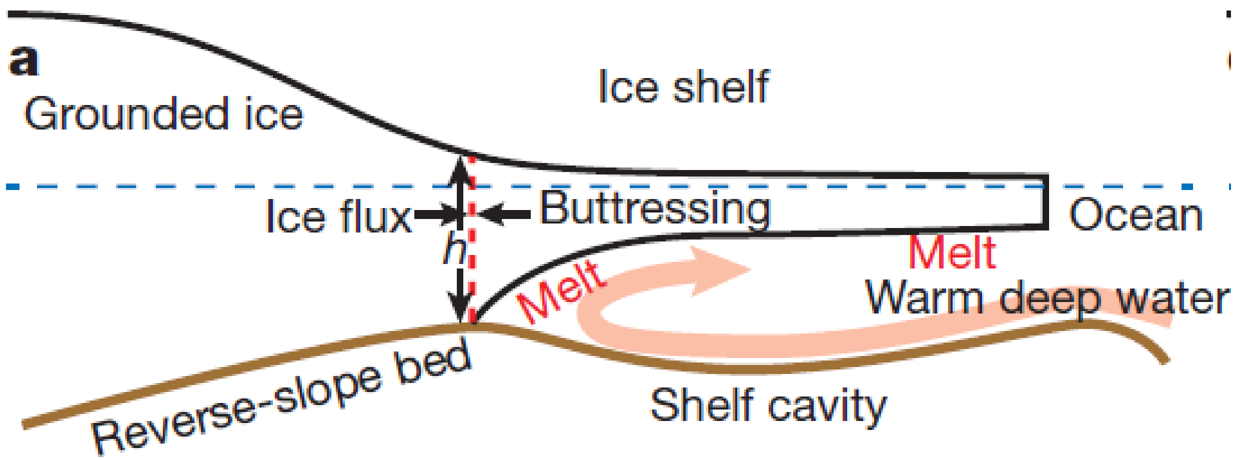
Trough Mouth Fans

Glacial erosion (interior) and deposition (margin) => landward deepening cont. shelf



Marine Ice Sheet Instability (MISI)

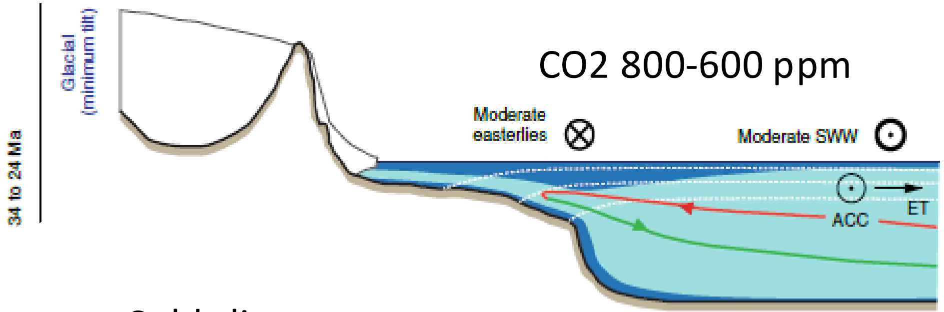
Sub-ice shelf melting due to ocean warming retreat onto a reverse-sloping bed runaway



DeConto and Pollard 2016

AIS sensitivity to ocean and climate dynamics

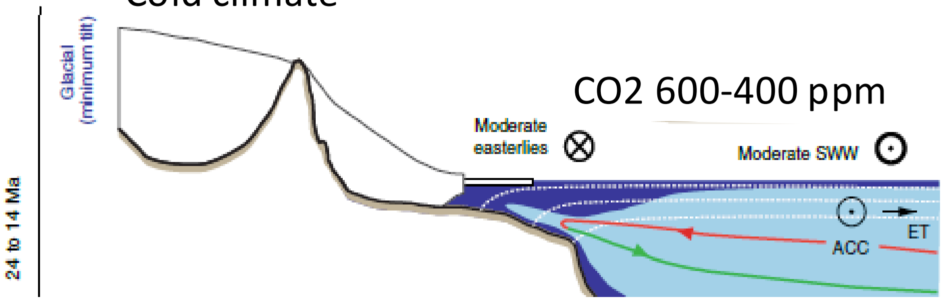
Cool climate



Levy et al., 2019

Terrestrial ice → low sensitivity to ocean warming

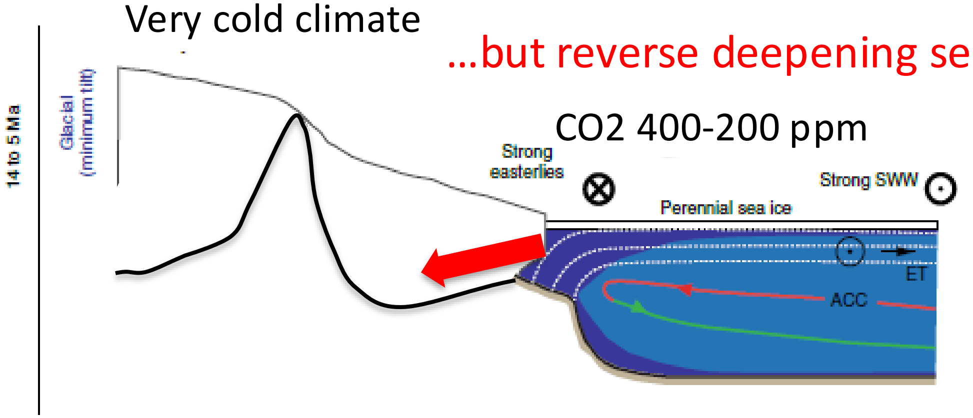
Cold climate



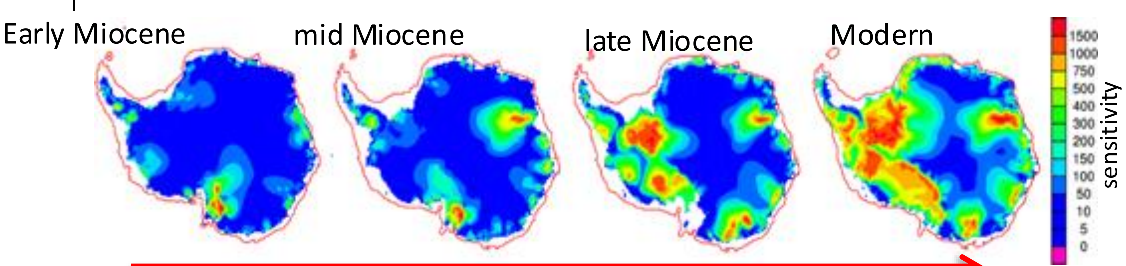
Marine ice-sheet extent → high sensitivity to ocean warming

Very cold climate

…but reverse deepening self profile



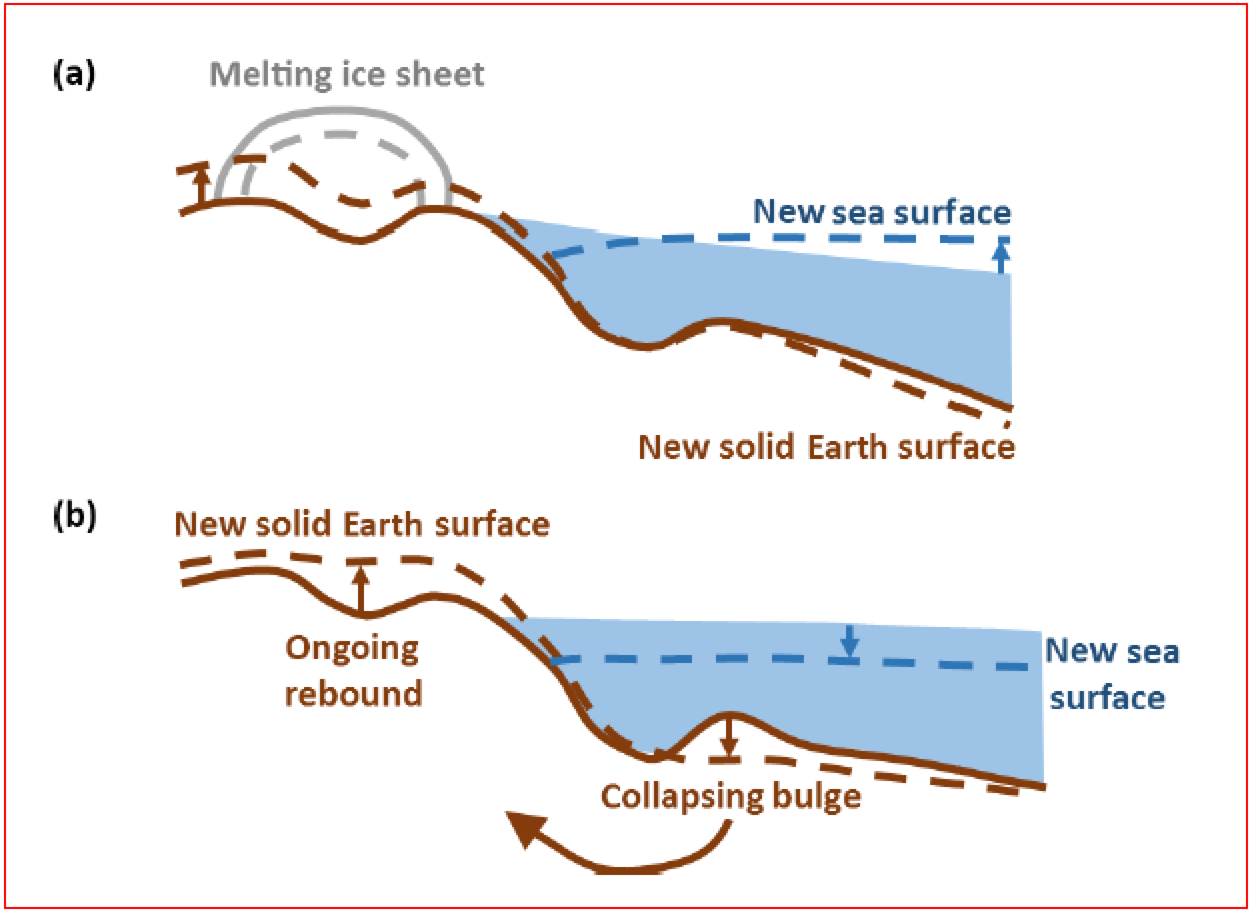
Persistent terrestrial and variable marine ice sheets. Sea ice and cold surface water 'insulate' marine ice sheet from warm ocean = decreased sensitivity to ocean warming



Bedrock deepening from terrestrial to marine based ice sheet

Colleoni, F., et al. 2018

Topography/Bathymetry evolution => **increase ice sheet sensitivity to warming**



Whitehouse 2018

NATURE COMMUNICATIONS | https://doi.org/10.1038/s41467-018-08068-y

REVIEW ARTICLE

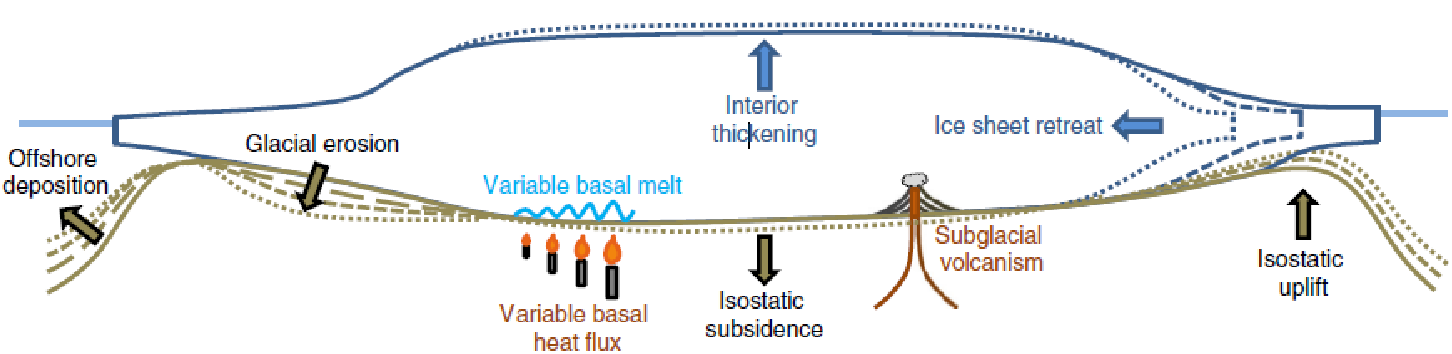
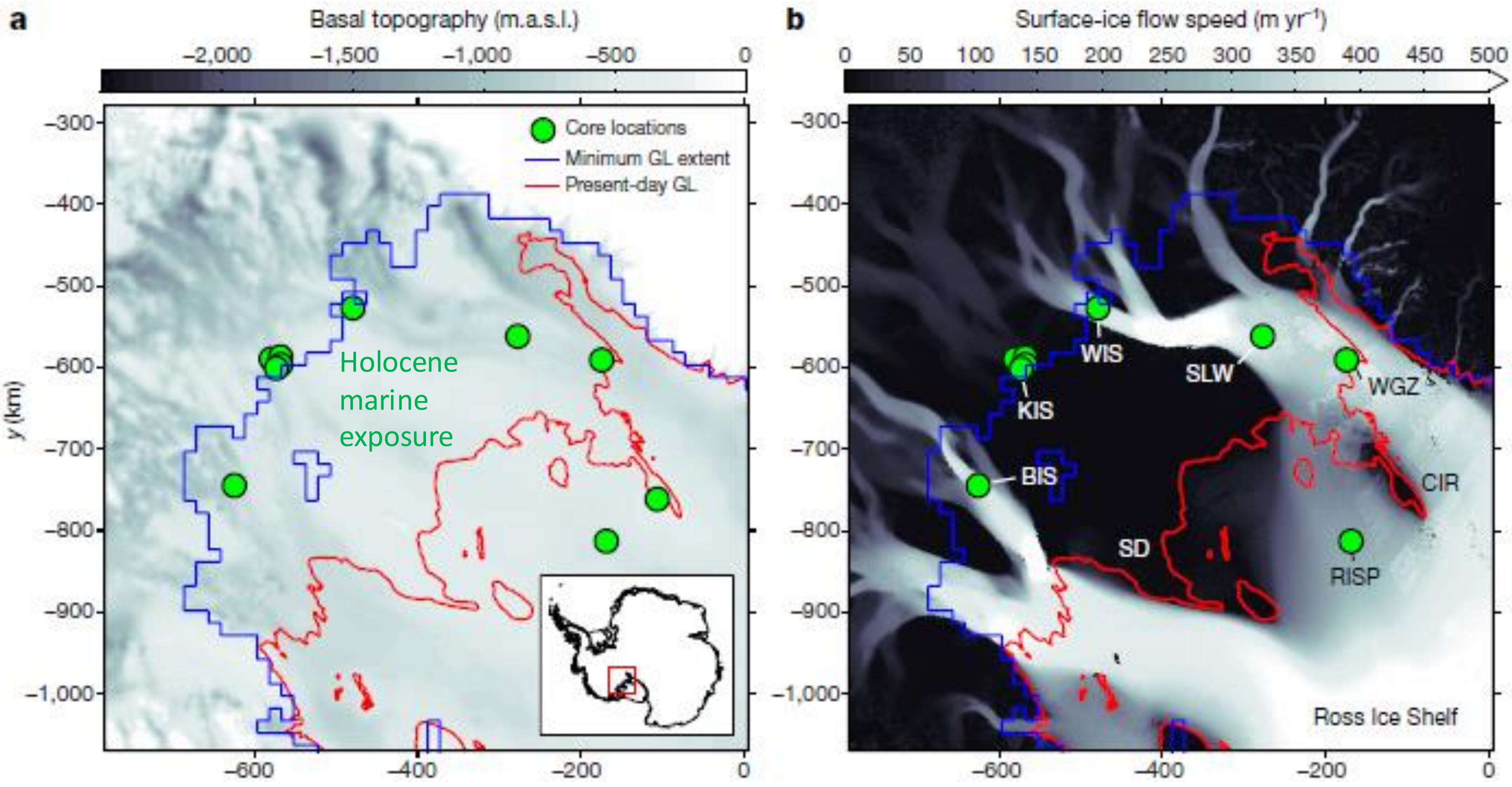


Fig. 1 Summary of interactions between the solid Earth and the Antarctic Ice Sheet. Local isostatic uplift occurs in response to ice-sheet thinning or retreat, isostatic subsidence occurs in response to ice-sheet thickening or advance. Subglacial volcanism and basal heat flux alter thermal conditions at the base of the ice sheet. Erosion and deposition also trigger an isostatic response (not shown). Increasing time indicated by finer dashed lines

Whitehouse et al., 2019

Presence or absence of **pinning points** influences ice sheet advances and retreat

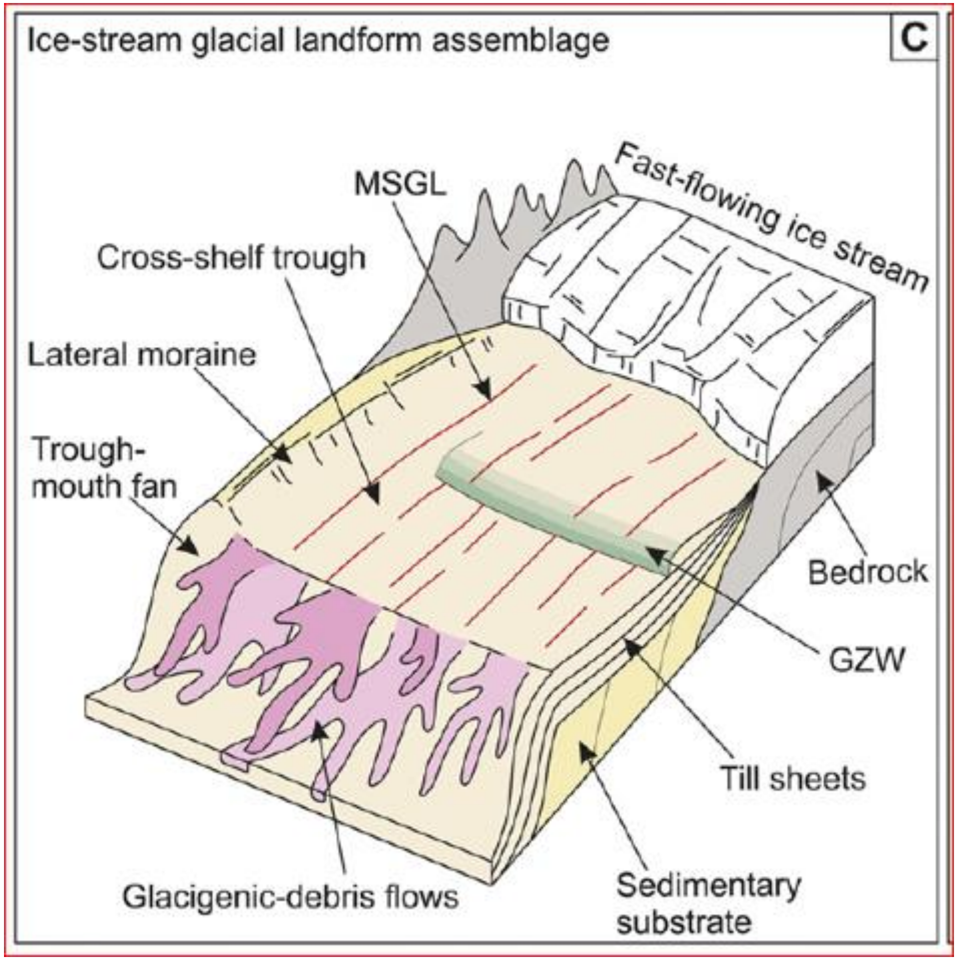


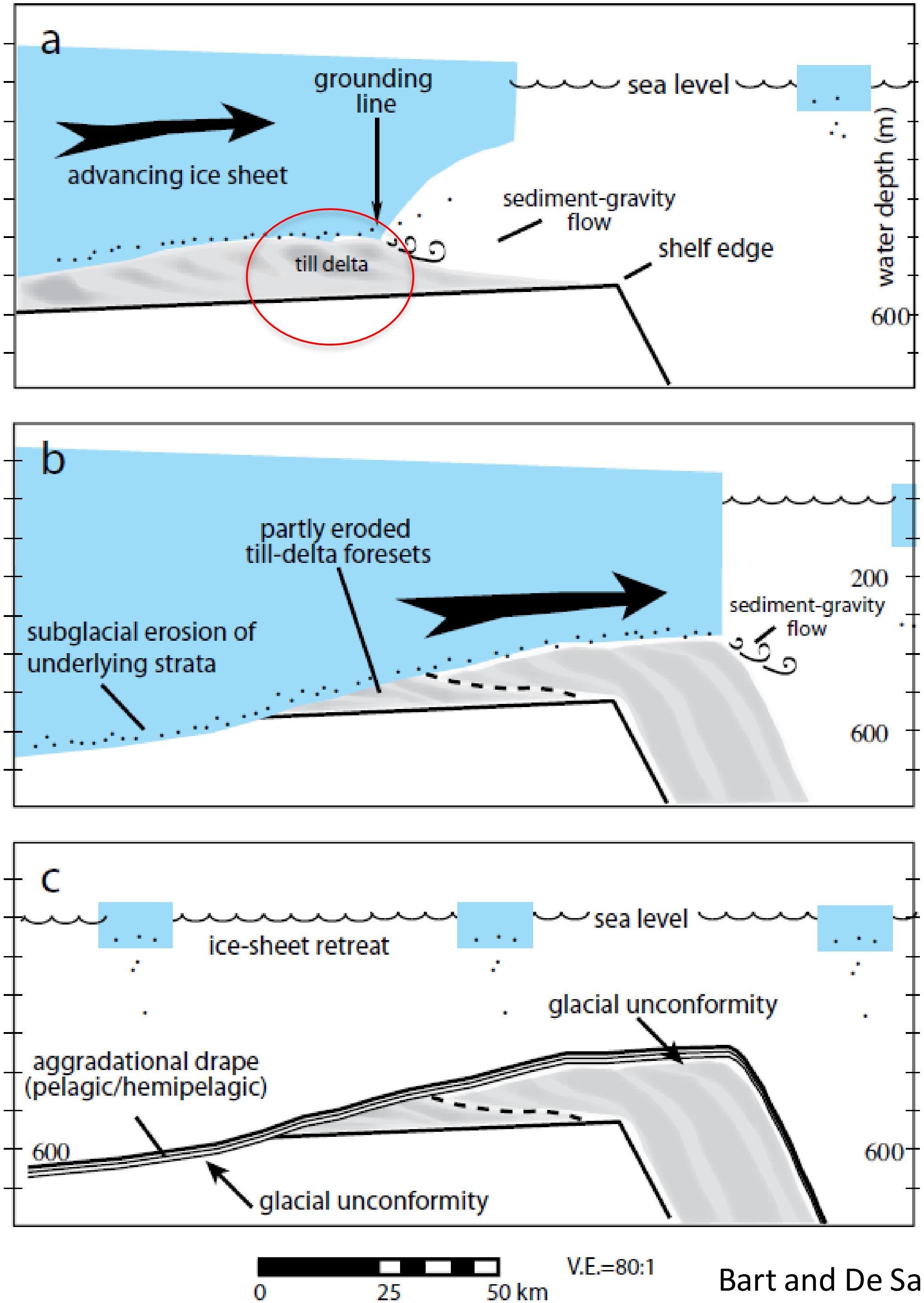
Grounding line retreated several hundred kilometres inland of today's position, before isostatic rebound caused it to re-advance

J. Kingslake et al., 2018

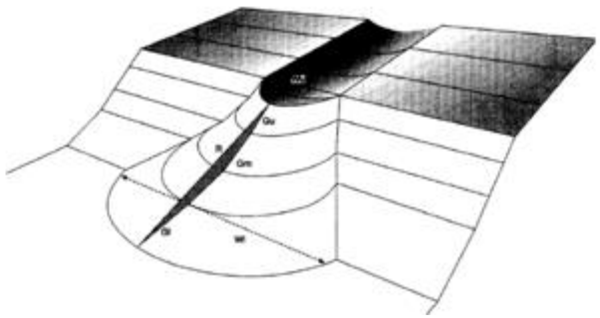
Diagnostic features

- Glacial valleys and banks topography
- Trough mouth fans
- Landward deepening continental shelf
- Ice grounding zone wedge
- Glacial lineations, outwash channels





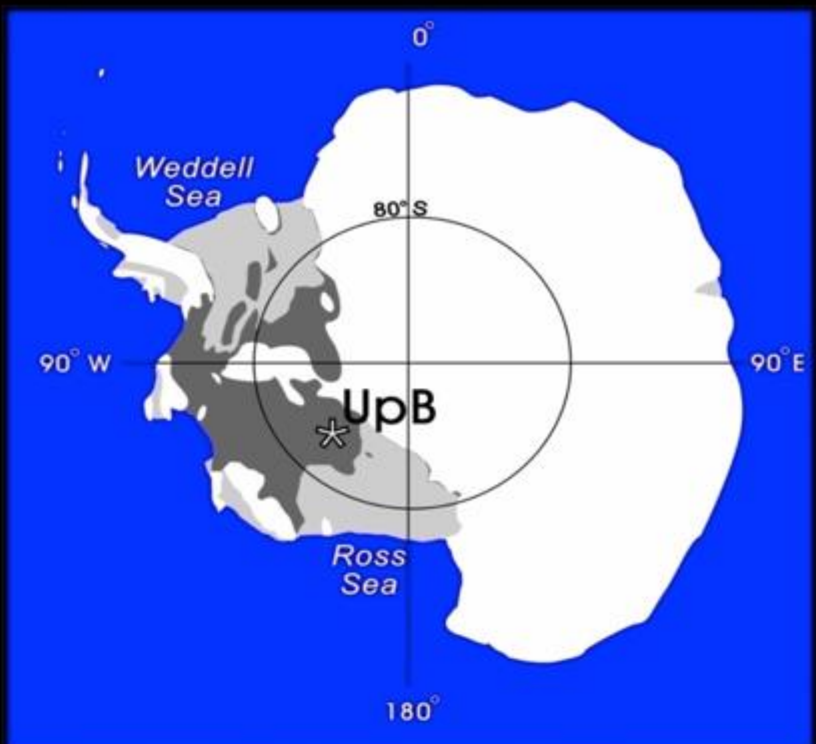
- Trough-mouth fans
- Till delta



Bart and De Santis 2012

Sediments recovered from beneath the ice

RISP J9 site
Brady and Martin
1979, Science



Caltech hot water drill at Upstream B, Antarctica, 1991

Scherer

The grounding zone of marine-terminating ice sheets is the transitional zone at which the ice-sheet base ceases to be in contact with the underlying substrate.

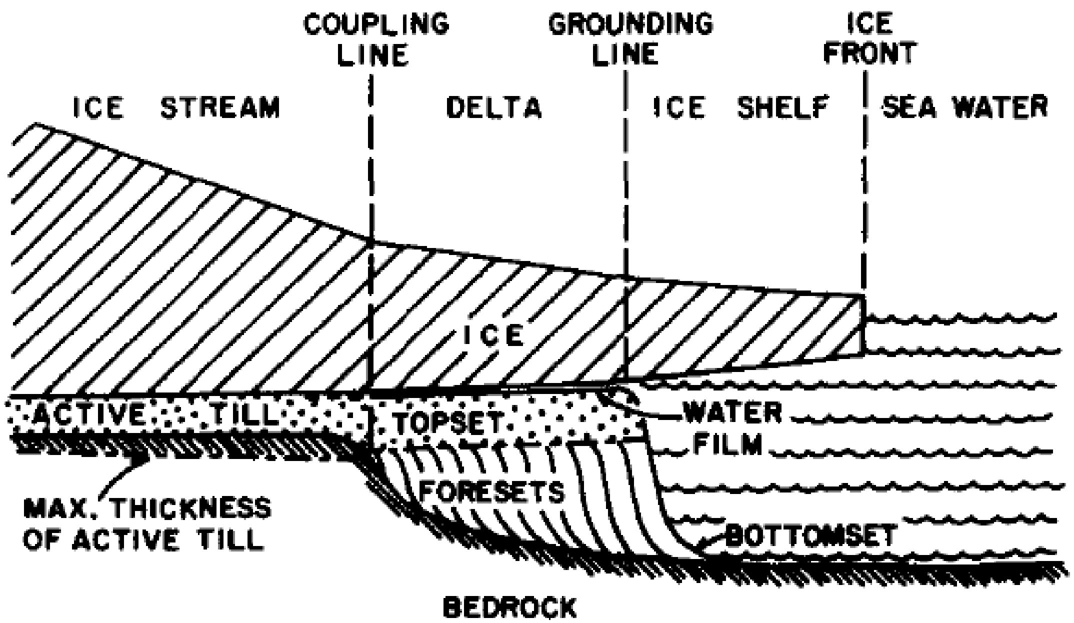


Fig.3. Cartoon of the likely configuration of the ice stream, till delta, and ice shelf.

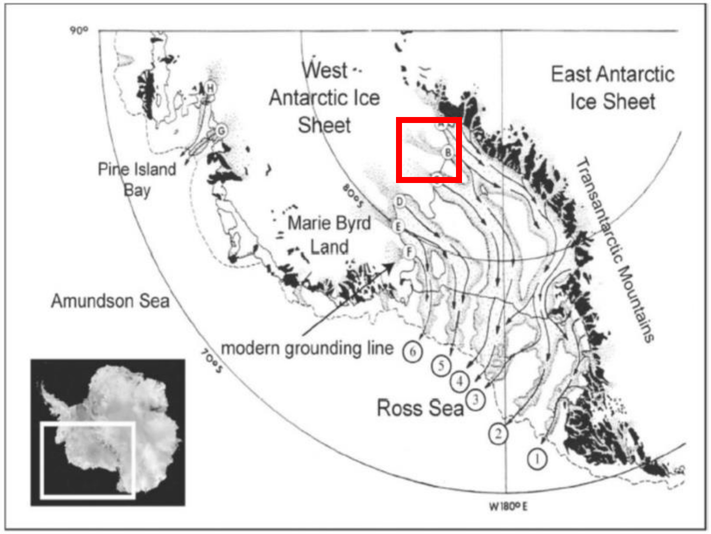
Discovery of a 6 m-thick layer of deforming till beneath the Whillans Ice Stream

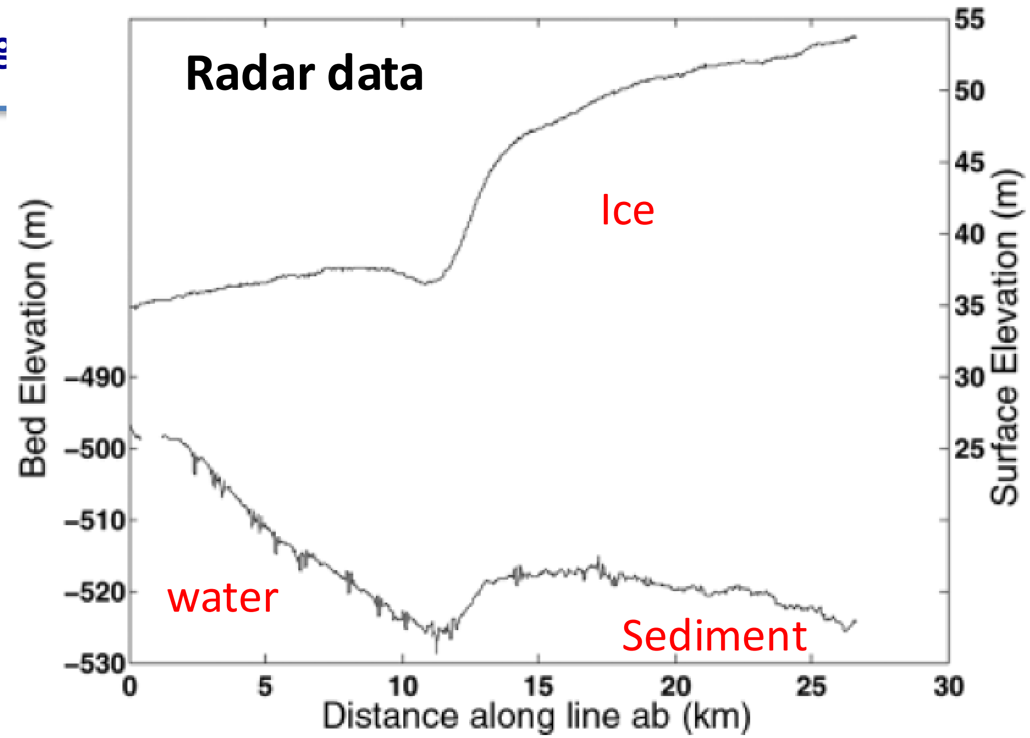
If the grounding line has been near its present position for the last 5-10 ka

A sedimentary deposit tens of kilometers long into water tens of meters deep formed

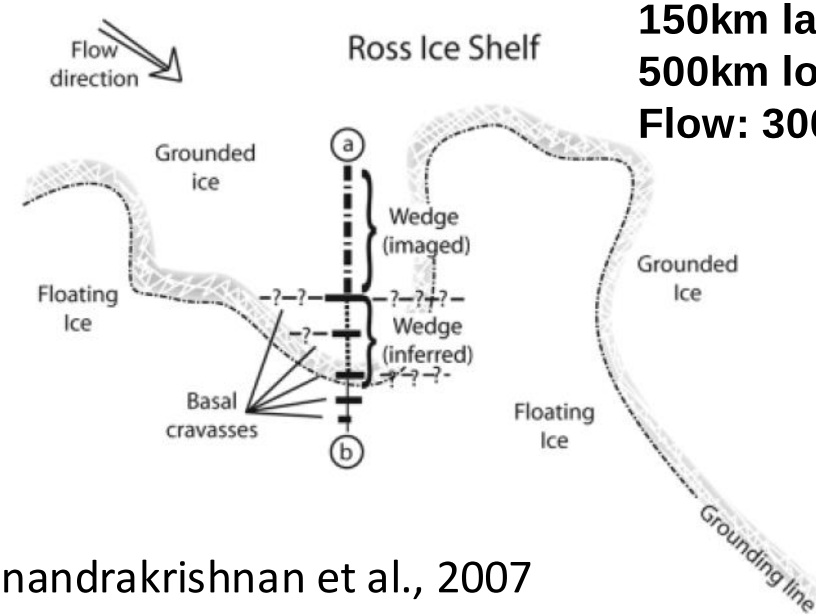
assuming a constant rock flux of hundreds of cubic meters/year at the grounding line

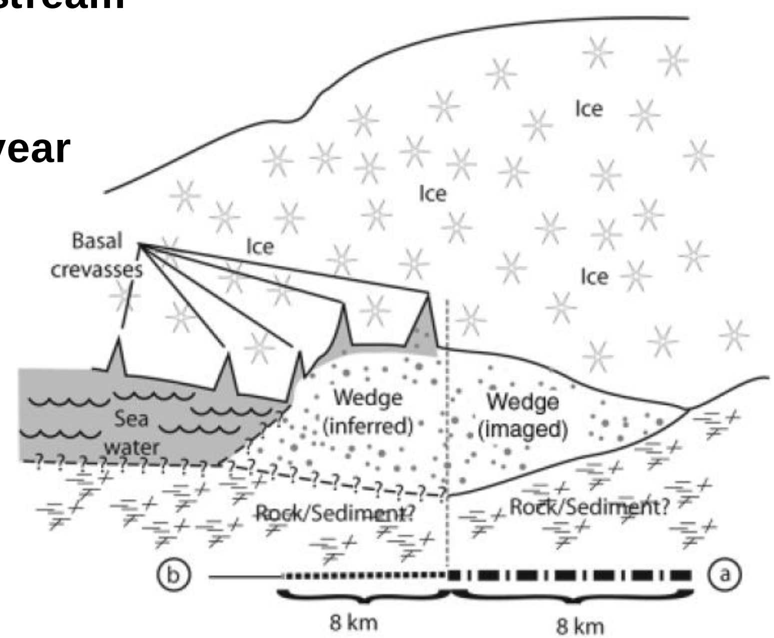
Alley et al., 1987; 1989





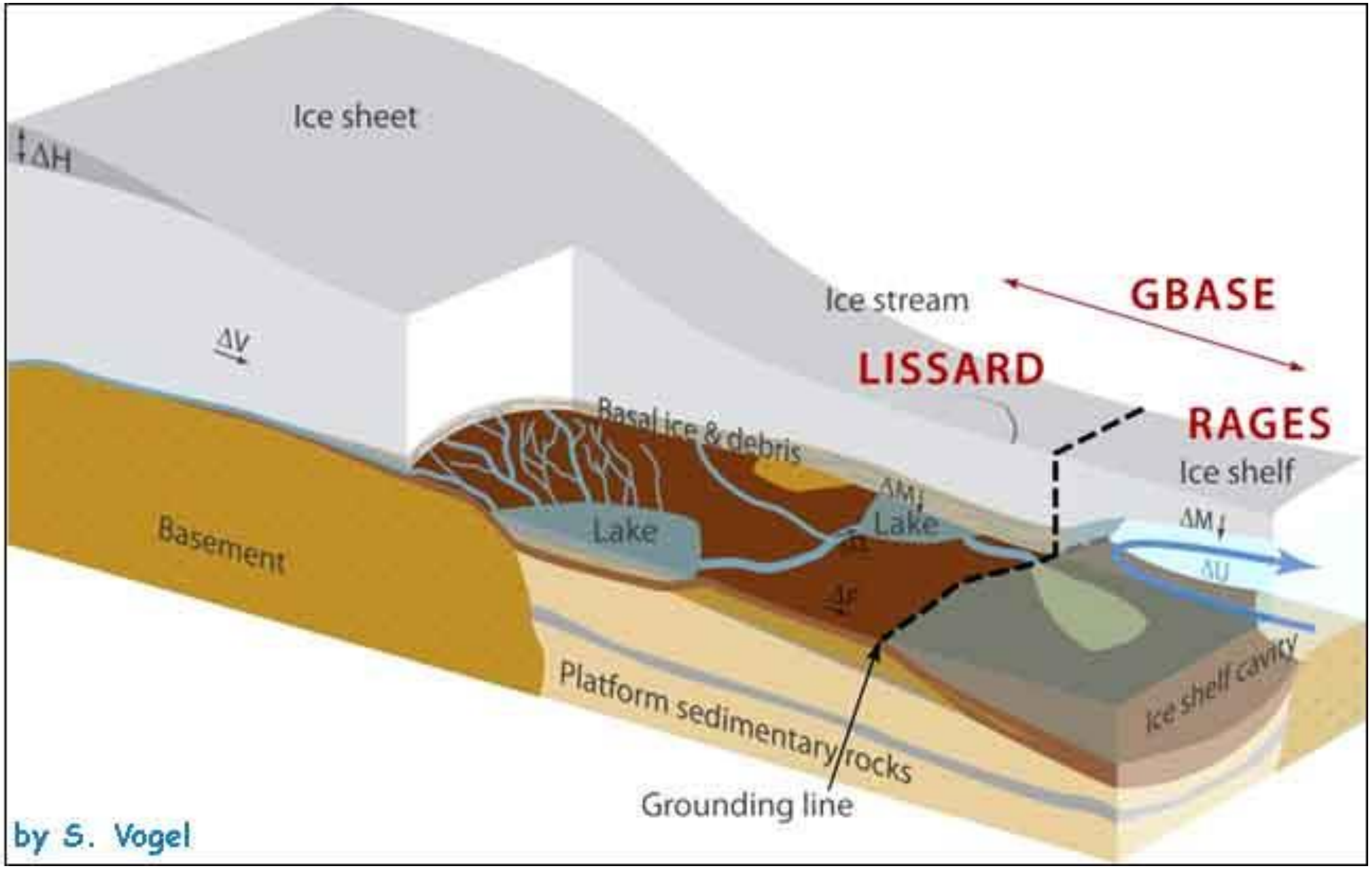
Whillans ice stream
150km large
500km long
Flow: 300 m/year





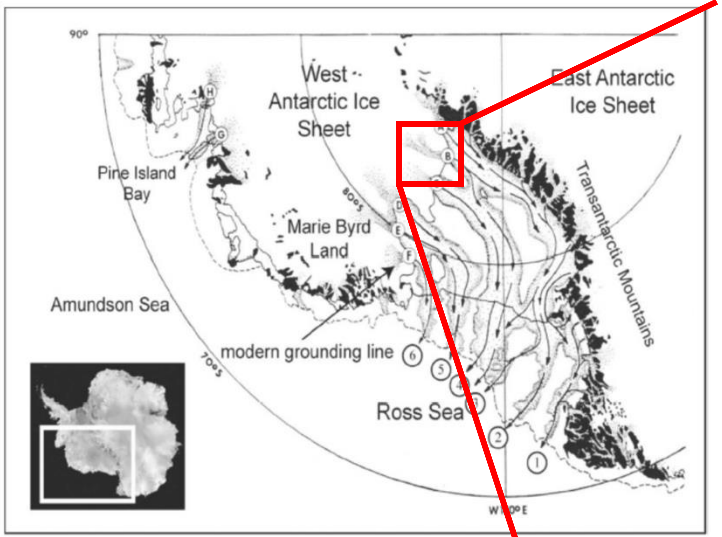
Anandrakrishnan et al., 2007

location of ice-sheet grounding is affected by short-term variations (e.g tides) and climatically-induced variations in thinning and rates of mass loss. The grounding zone is a key site for meltwater transfer from the ice sheet to the marine environment

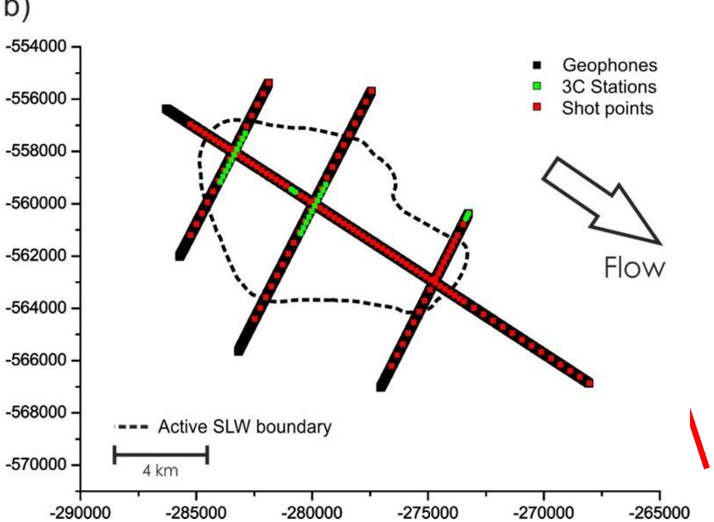


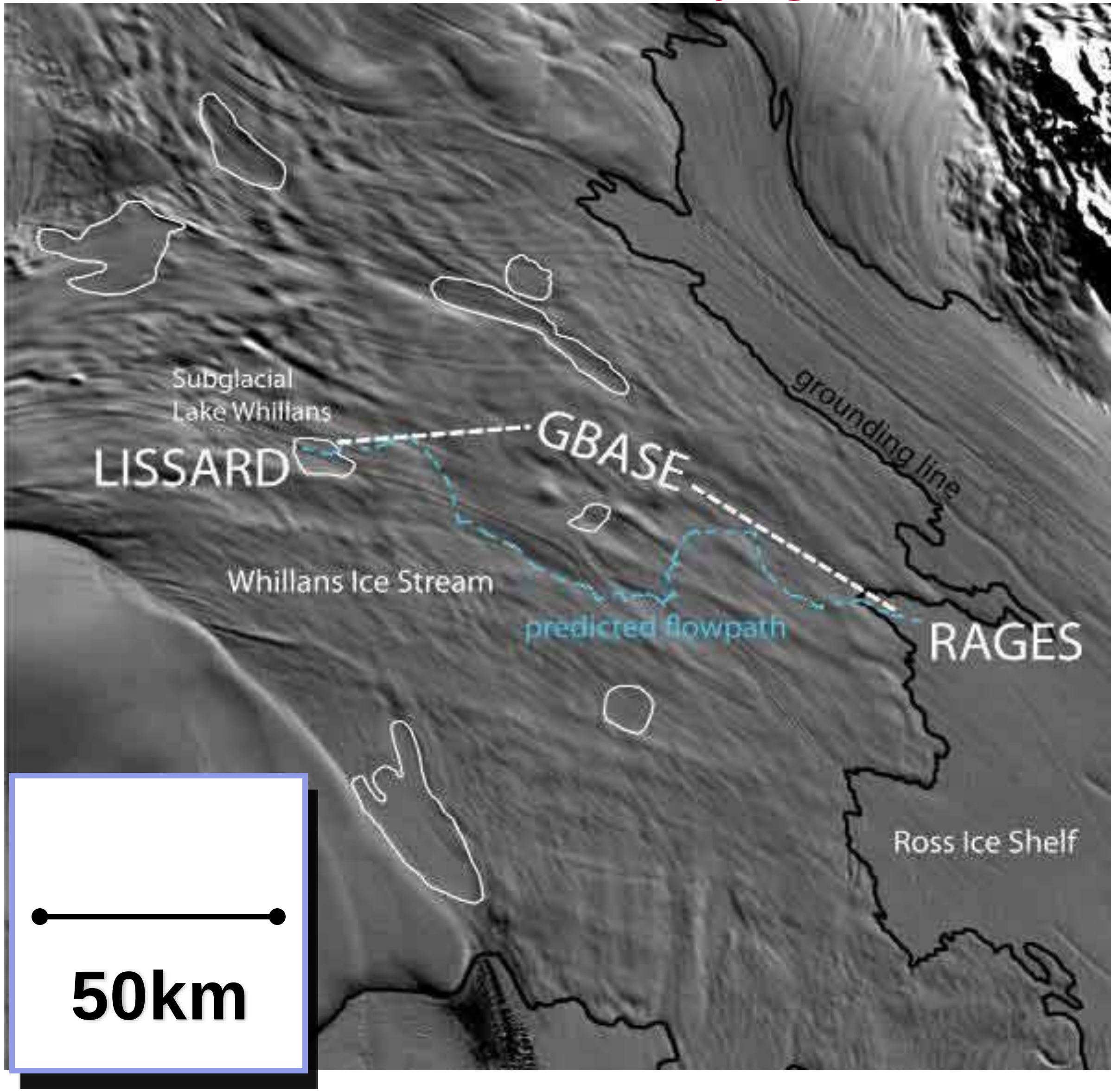
Subglacial and grounding-zone sedimentation aggradation may act as a negative feedback that counters dynamic thinning of the ice stream and stabilizes the ice-stream grounding zones (e.g., Alley et al., 2007).

Whillans Ice Stream – 2010-2011 Antarctic Campaign



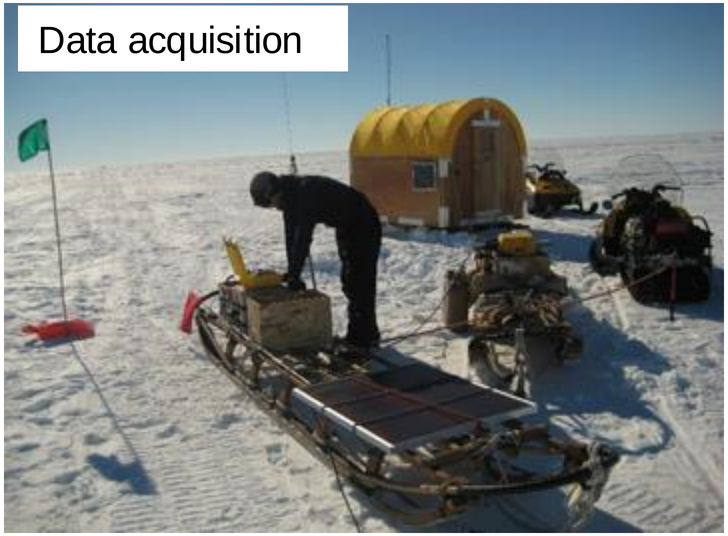
Subglacial Lake Whillans (SLW)





Whillans Ice Stream – 2010-2011 Antarctic Campaign

All the logistic was organized and financed by the US NSF (WISSARD Project).



Whillans Ice Stream – 2010-2011 Antarctic Campaign

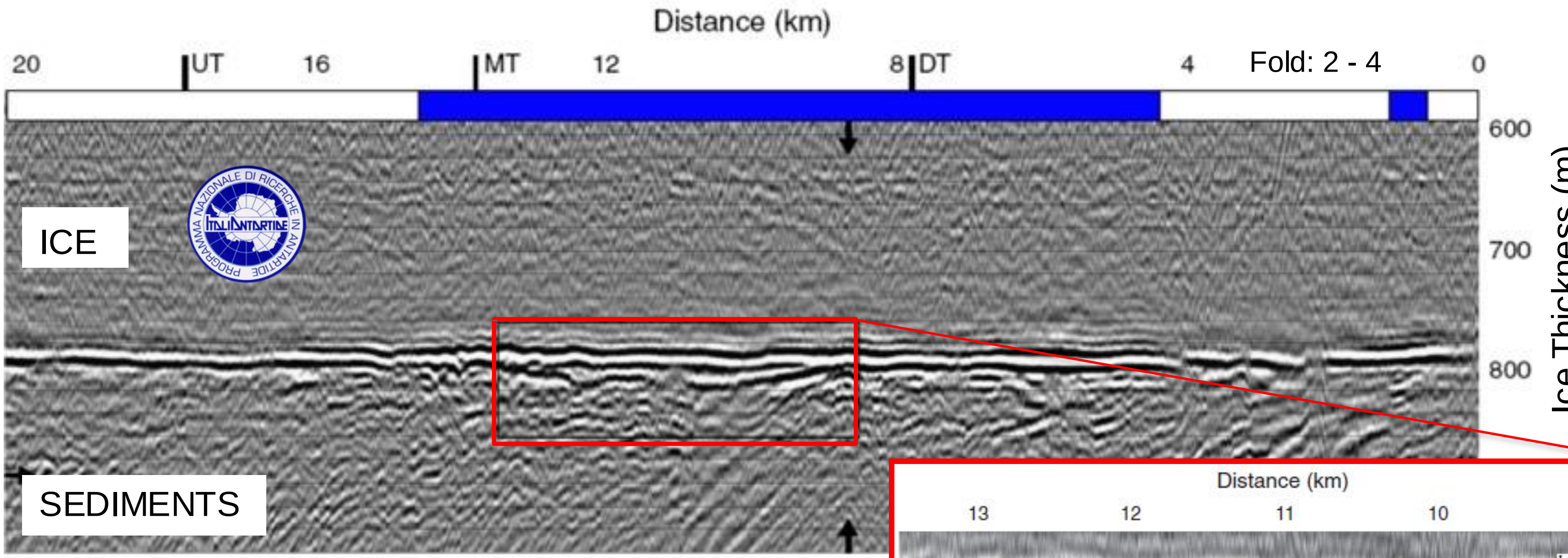
While drilling the holes for the explosive

A hole in the ice for the explosive

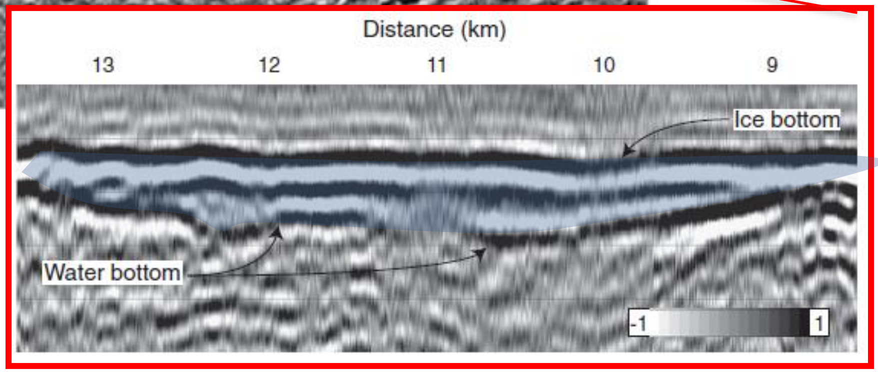
Digging after the wind....!

3C Stations deployment

Seismic Imaging of Subglacial Lake Whillans (Siple coast - WAIS)



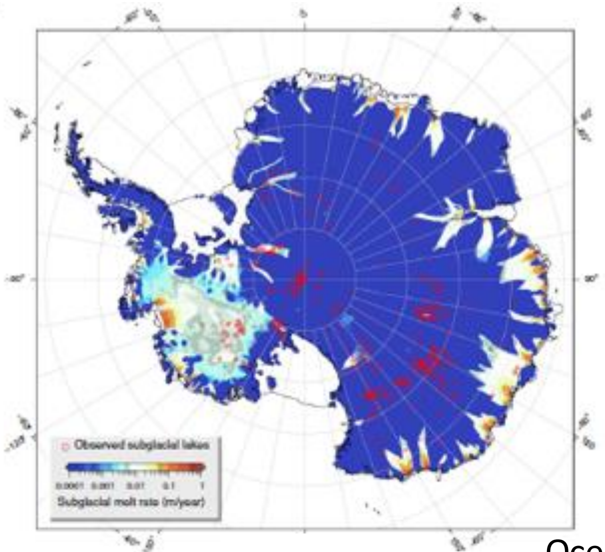
The survey, carried out in a low-tide period, evidenced that **the lake exists** and its water column is up to 8 m thick, along 5 km of the 45 km profiled. These findings were later confirmed by drilling operations.



AVO (Amplitude Versus Offset) analysis shows that the major part of the bed around the lake consists of soft sediments and thin water lenses.

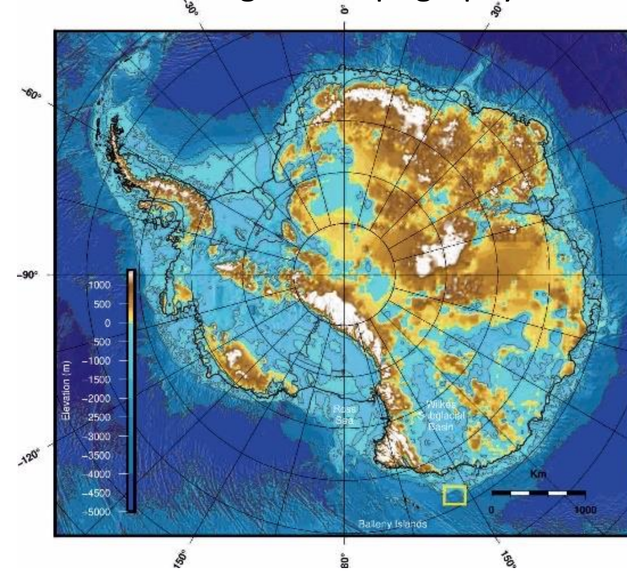
Picotti et. al 2011; 2015

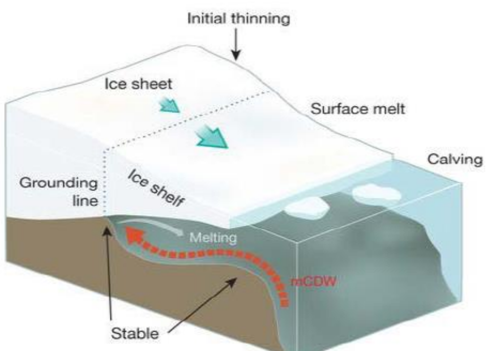
subglacial lakes location and ice basal melt rate



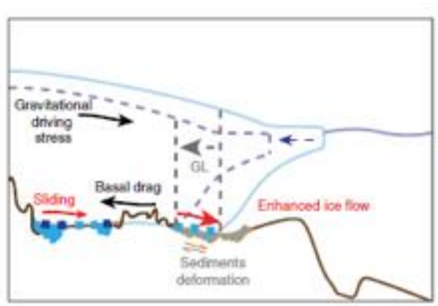
Wright, A. & Siegert 2012.
Duncan et al., 2006
Colleoni et al., 2018
Pritchard et al., 2013

subglacial topography

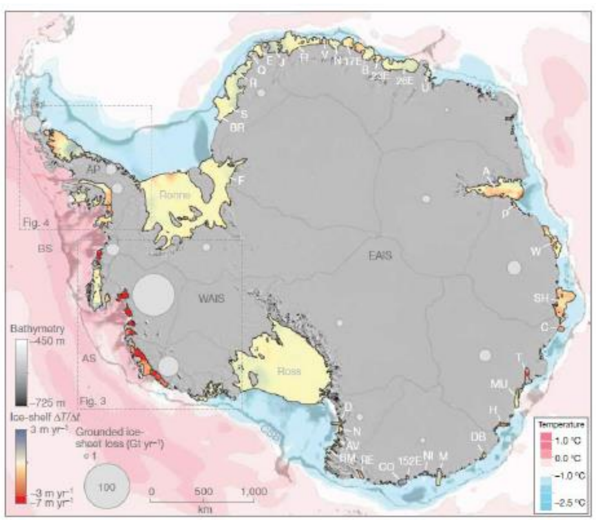




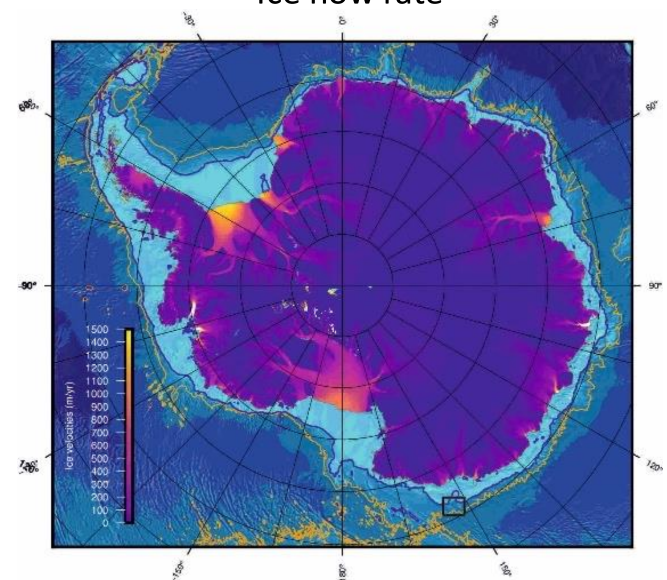
a



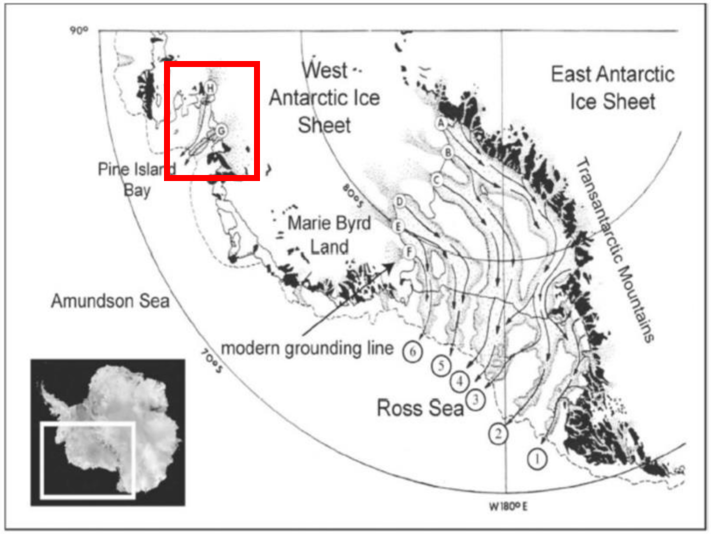
Ocean temperature



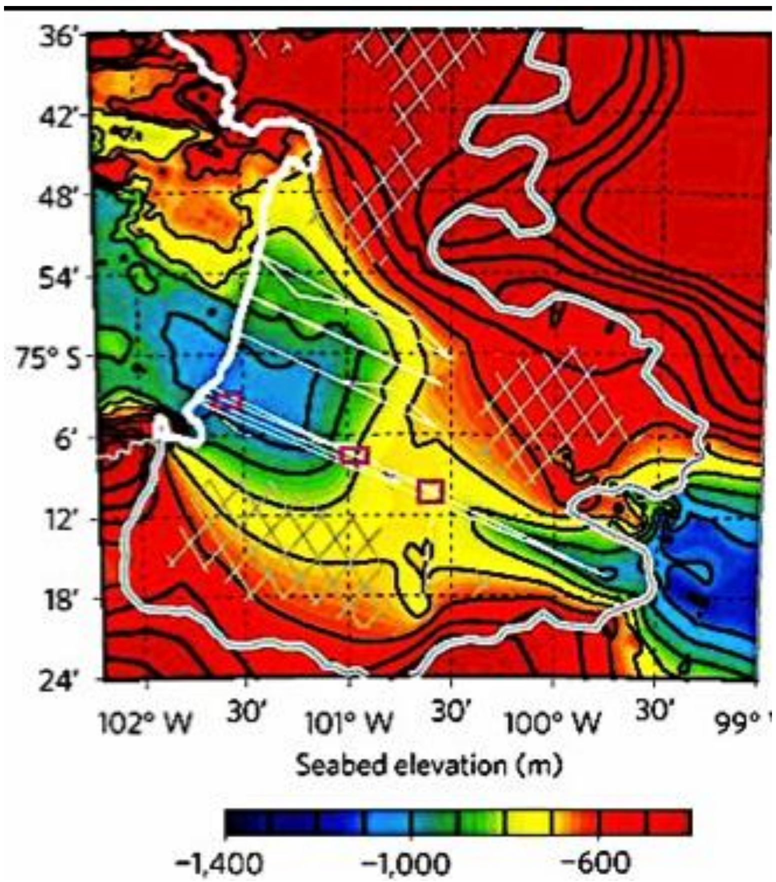
Ice flow rate

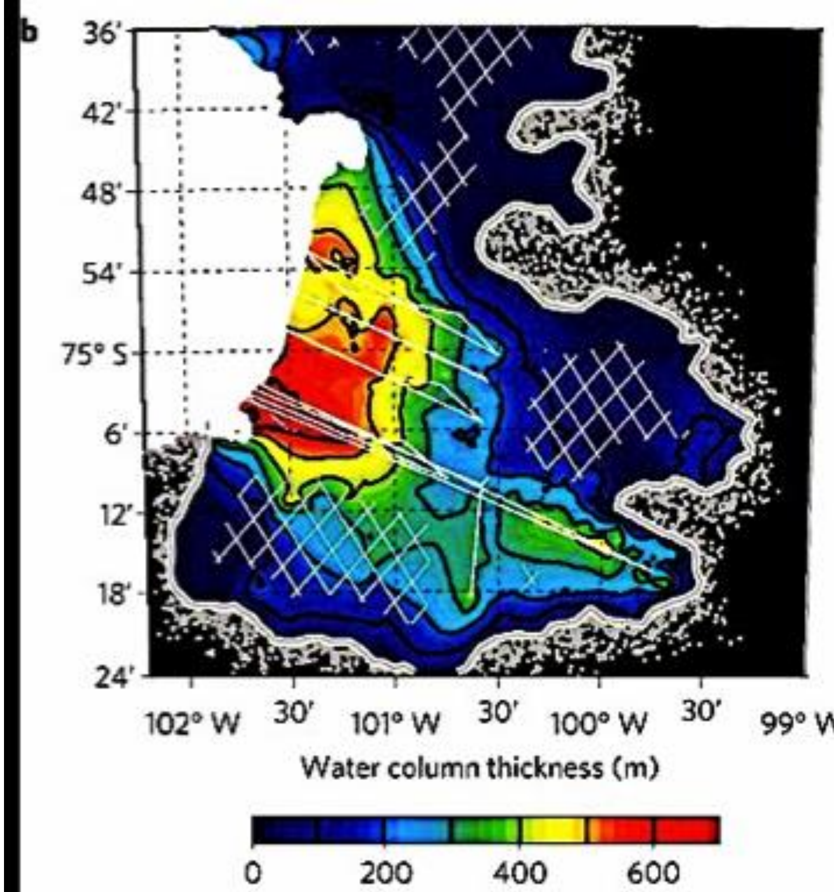


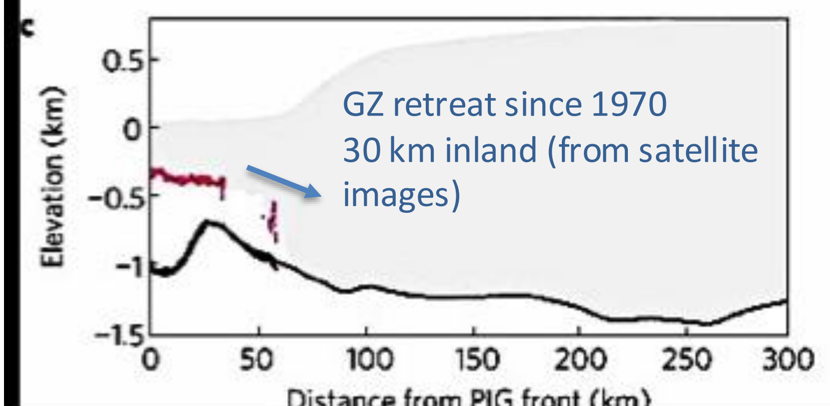
Pine Island Glacier



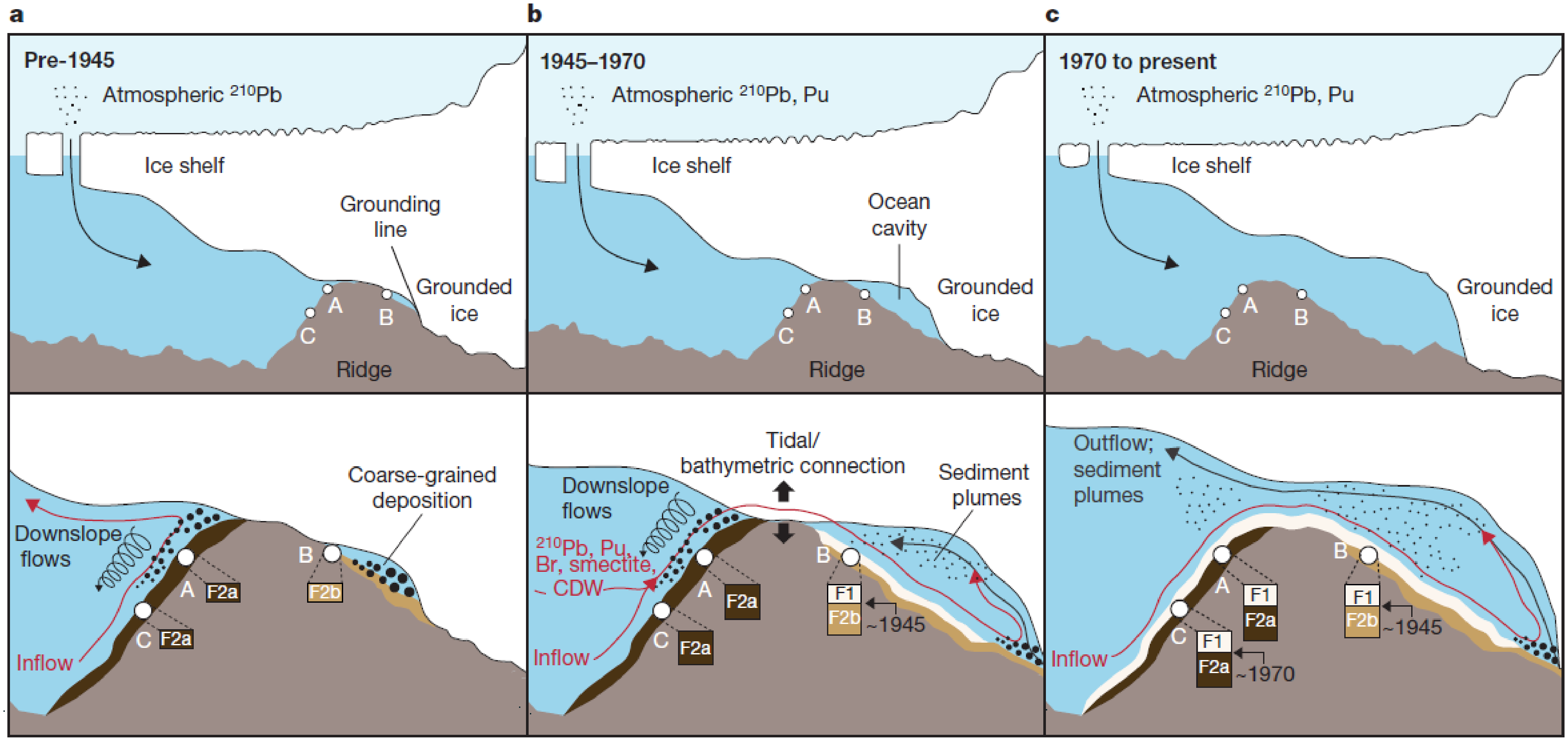
autonomous underwater vehicle







PIG - Jenkins et al. 2010



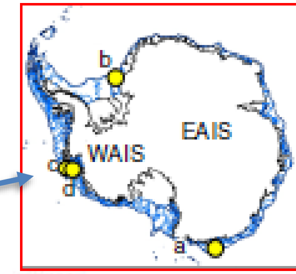
Smith et al., 2017

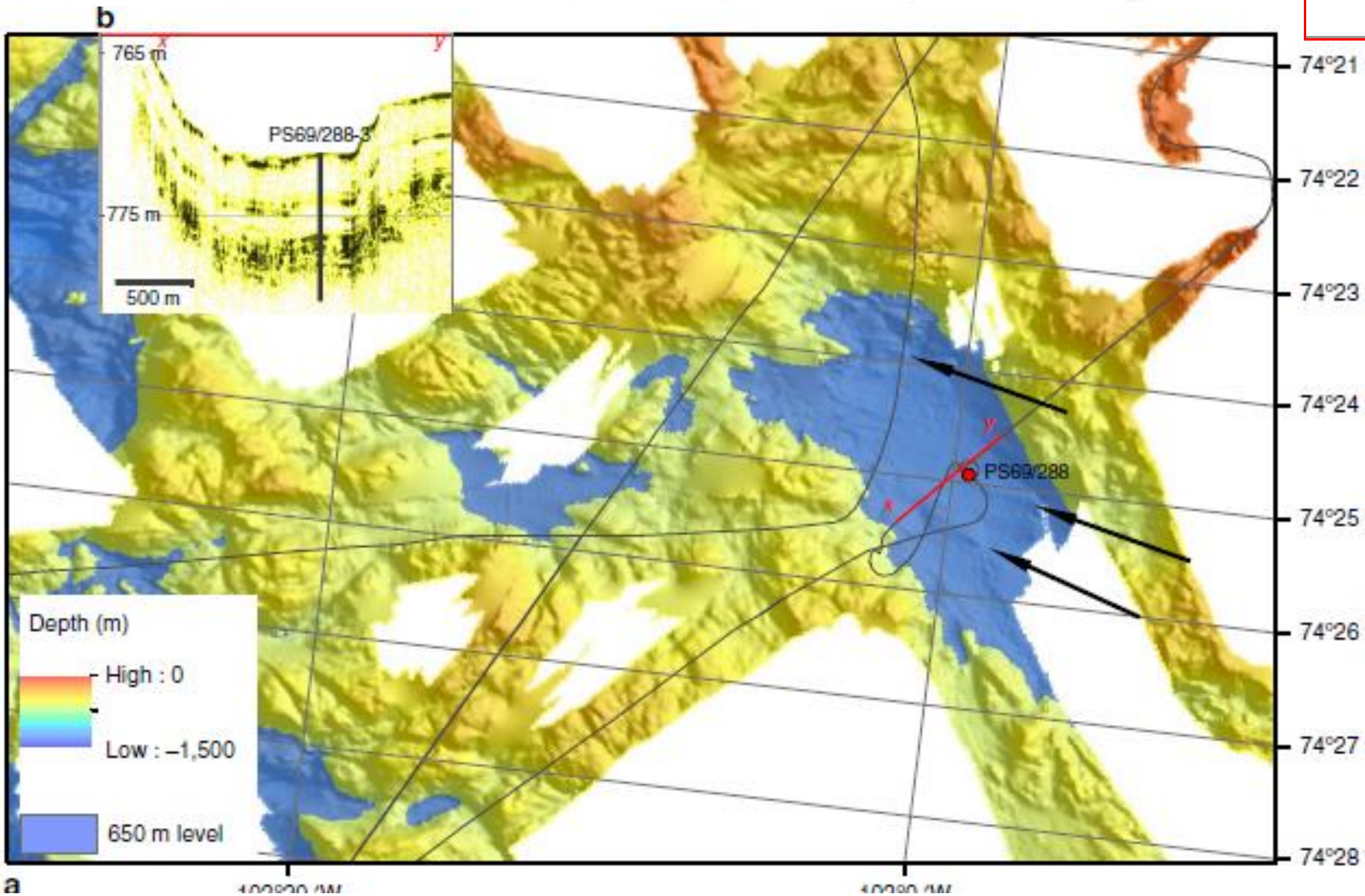
ARTICLE

Received 23 Jun 2016 | Accepted 11 Apr 2017 | Published 1 Jun 2017 DOI: 10.1038/ncomms15591 OPEN

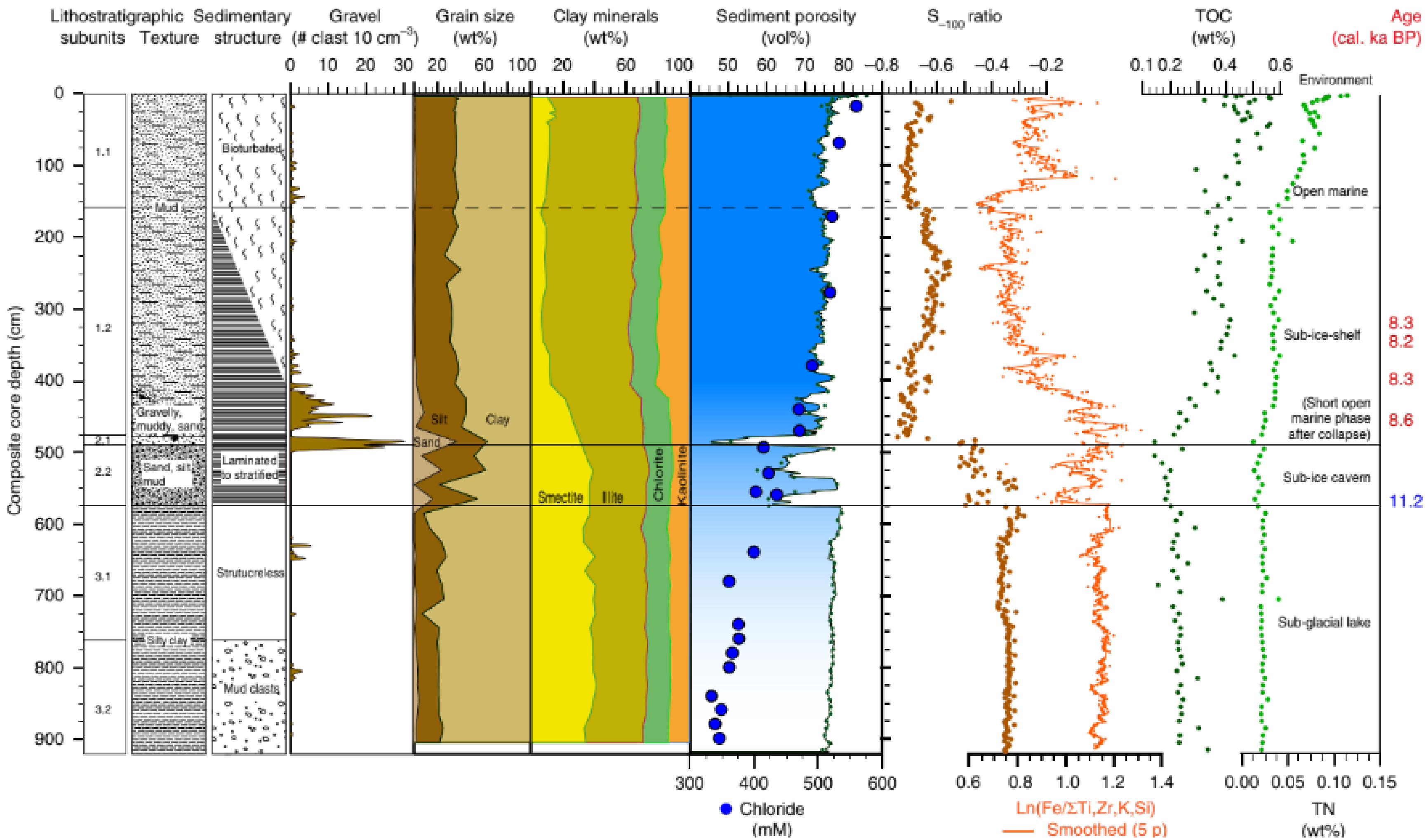
Evidence for a palaeo-subglacial lake on the Antarctic continental shelf

Gerhard Kuhn[1], Claus-Dieter Hillenbrand[2], Sabine Kasten[1], James A. Smith[2], Frank O. Nitsche[3], Thomas Frederichs[4], Steffen Wiers[4], Werner Ehrmann[5], Johann P. Klages[1] & José M. Mogollón[6]

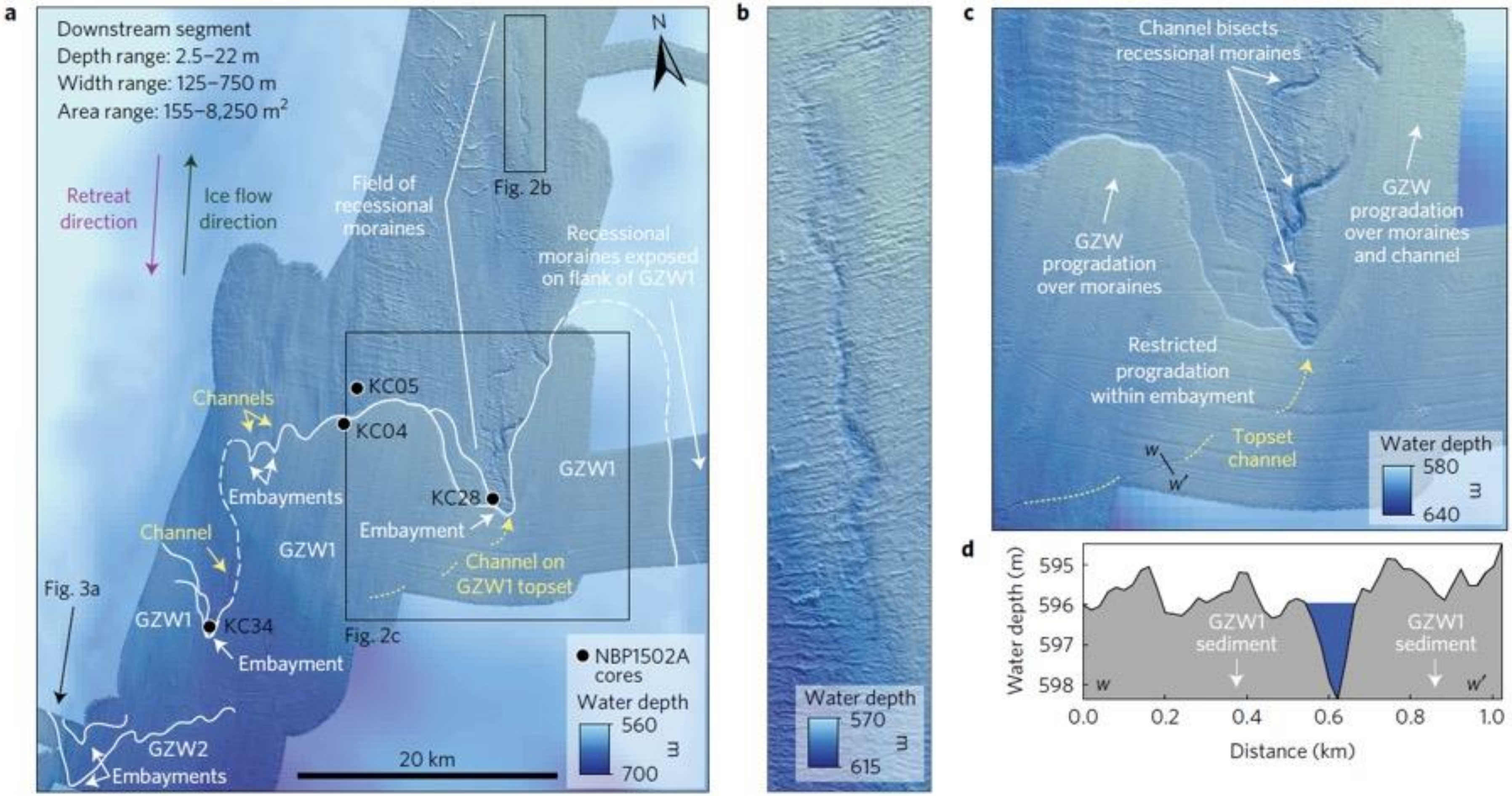




ARTICLE NATURE COMMUNICATIONS | DOI: 10.1038/ncomms15591

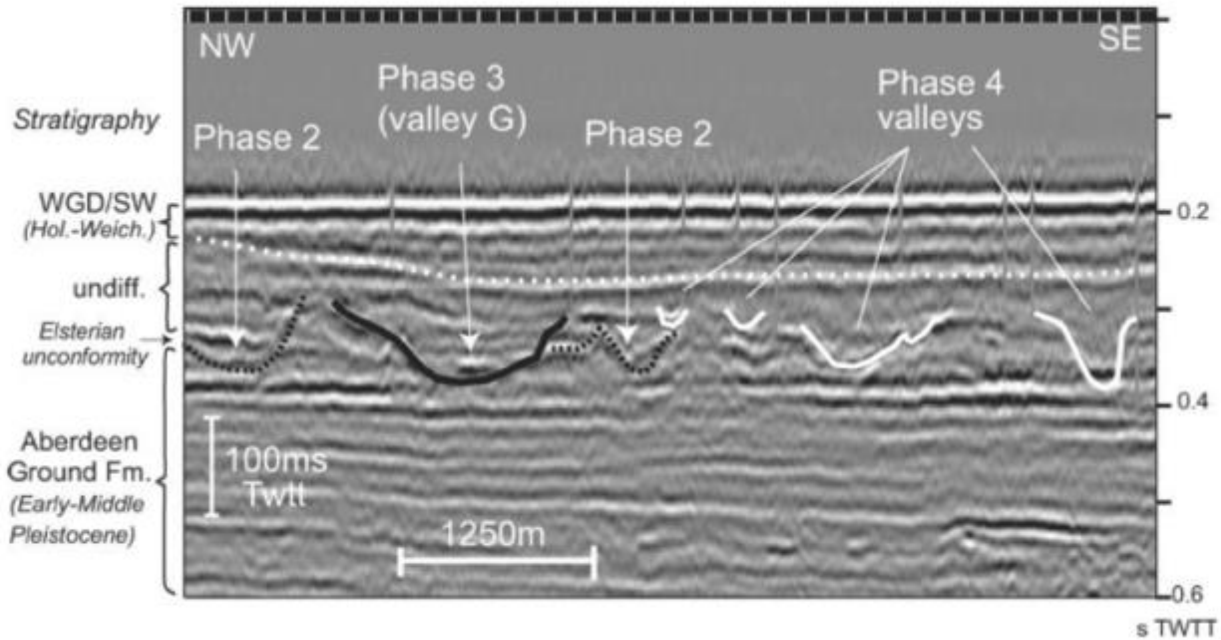


Outwash channels

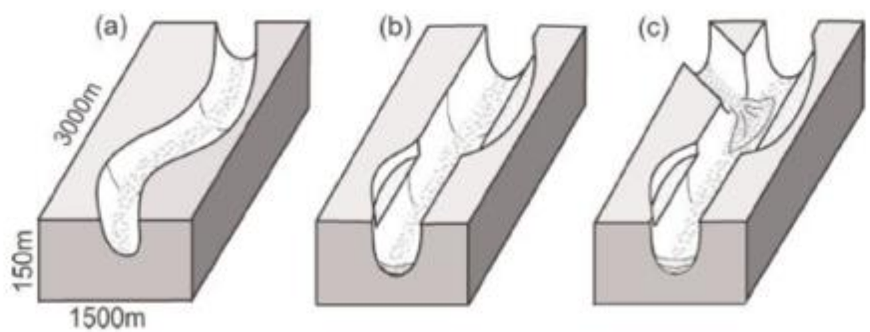


Simkins et al., 2017

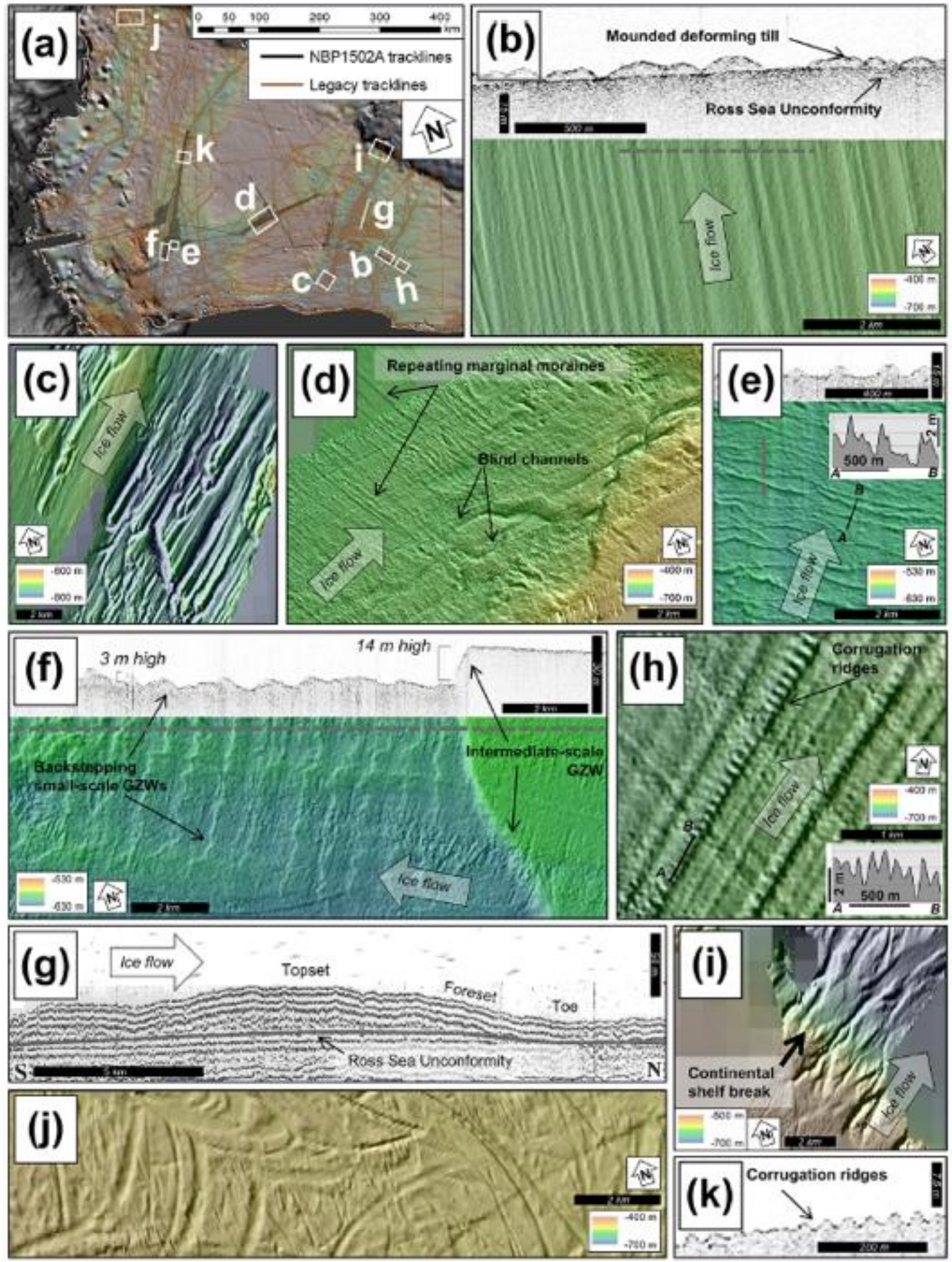
Outwash channels



Sand fill



Bojer Kristensen et al., 2008, *Earth Surf. Process. Landforms*

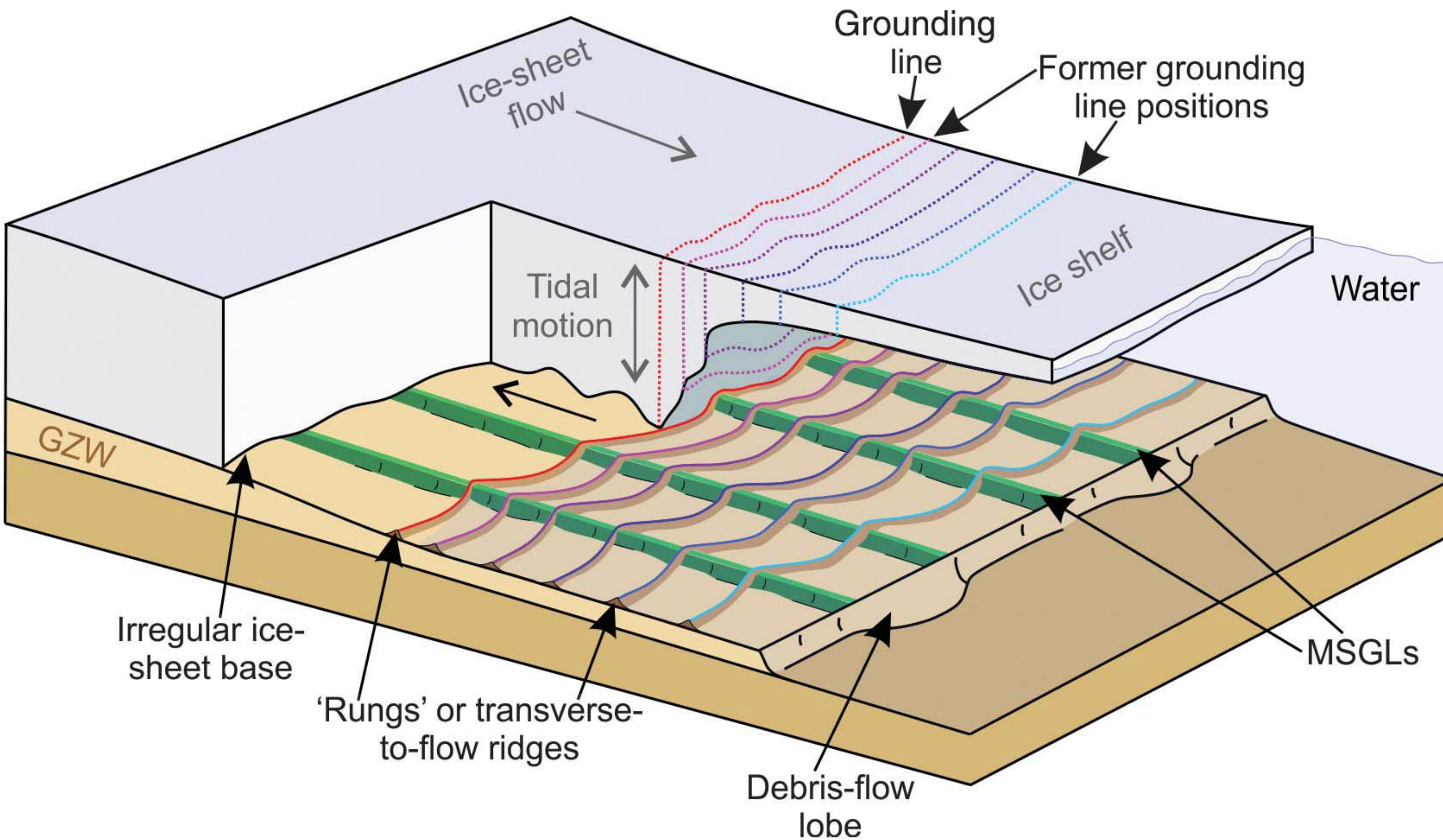


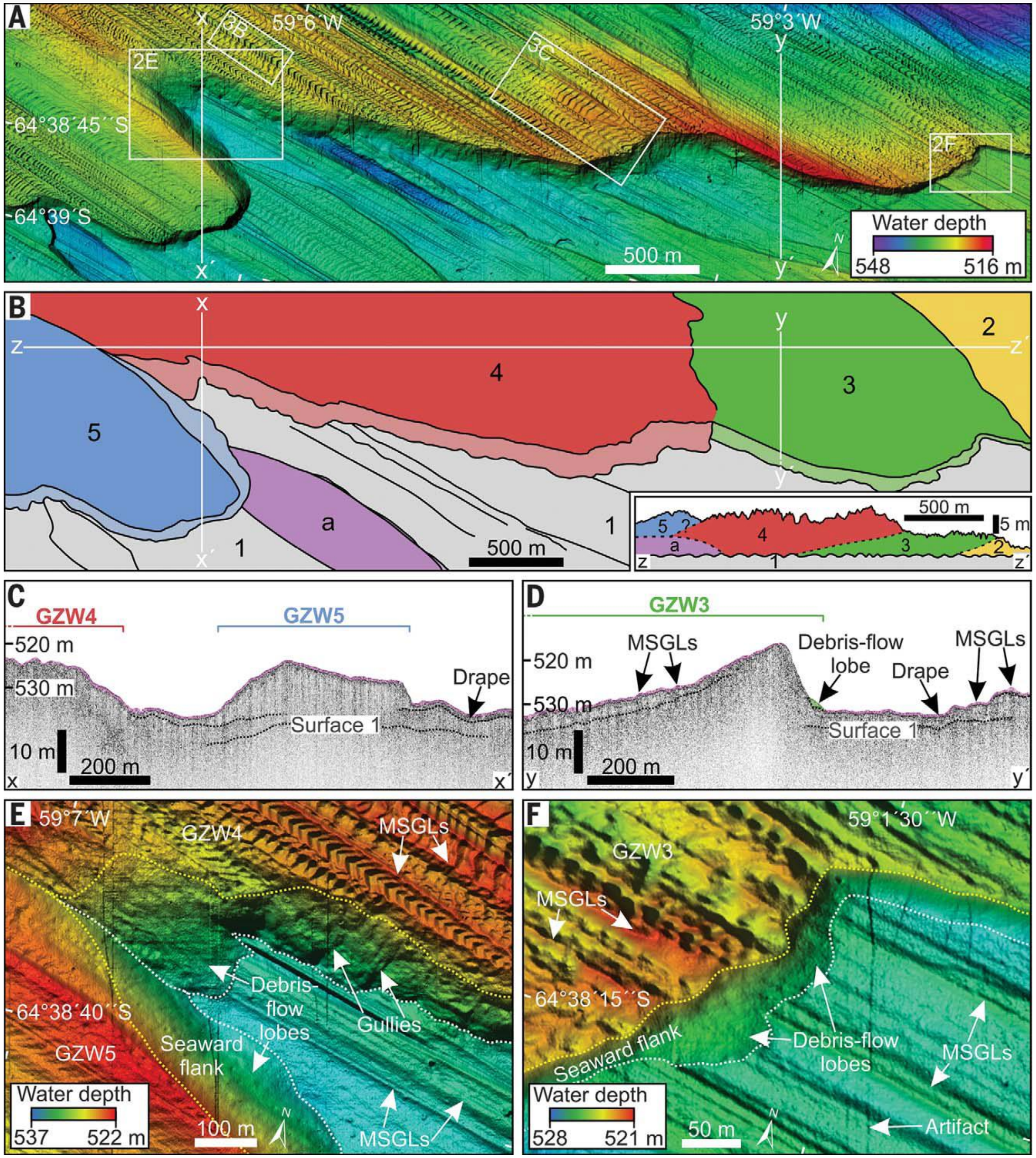
Megascale glacial lineations

drumlins, crag and tails, and megaflutes

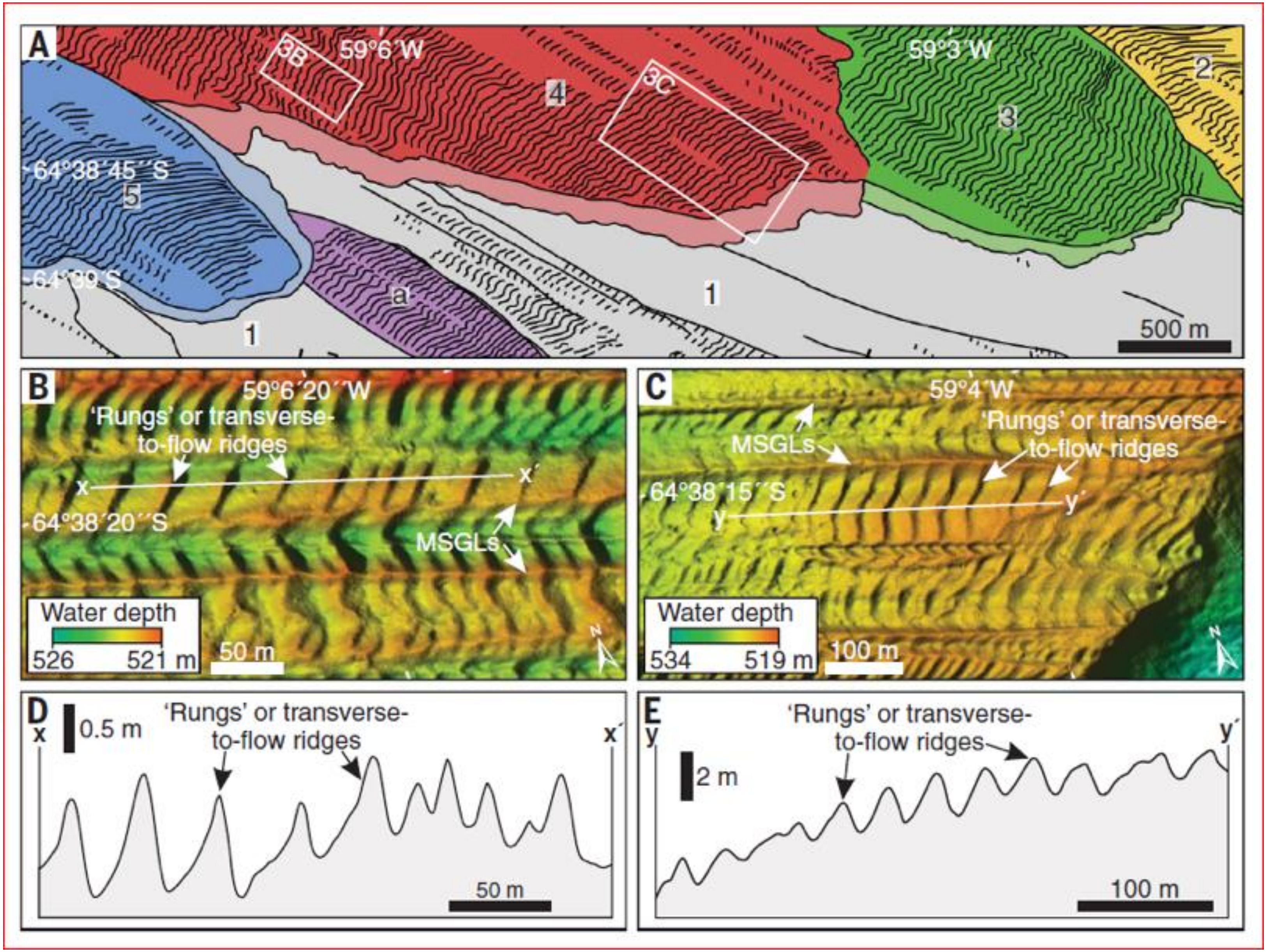
‘corrugation ridges’ are the expression of tidal lifting and settling of the ice shelf during scour formation

Halberstadt et al., 2016
Smith et al., 2019


Grounding line
Former grounding line positions
Ice-sheet flow
Tidal motion
Ice shelf
Water
GZW
Irregular ice-sheet base
'Rungs' or transverse-to-flow ridges
Debris-flow lobe
MSGLs



Dowdeswell et al. 2020


A
3B
59°6′W
4
3C
59°3′W
3
2
64°38′45′′S
5
64°39′S
a
1
1
500 m
B
59°6′20′′W
'Rungs' or transverse-to-flow ridges
x
x′
64°38′20′′S
MSGLs
Water depth
526
521 m
50 m
C
59°4′W
MSGLs
'Rungs' or transverse-to-flow ridges
64°38′15′′S
y
y′
Water depth
534
519 m
100 m
D
x
0.5 m
'Rungs' or transverse-to-flow ridges
x′
50 m
E
y
2 m
'Rungs' or transverse-to-flow ridges
y′
100 m

L.O. Prothro et al.

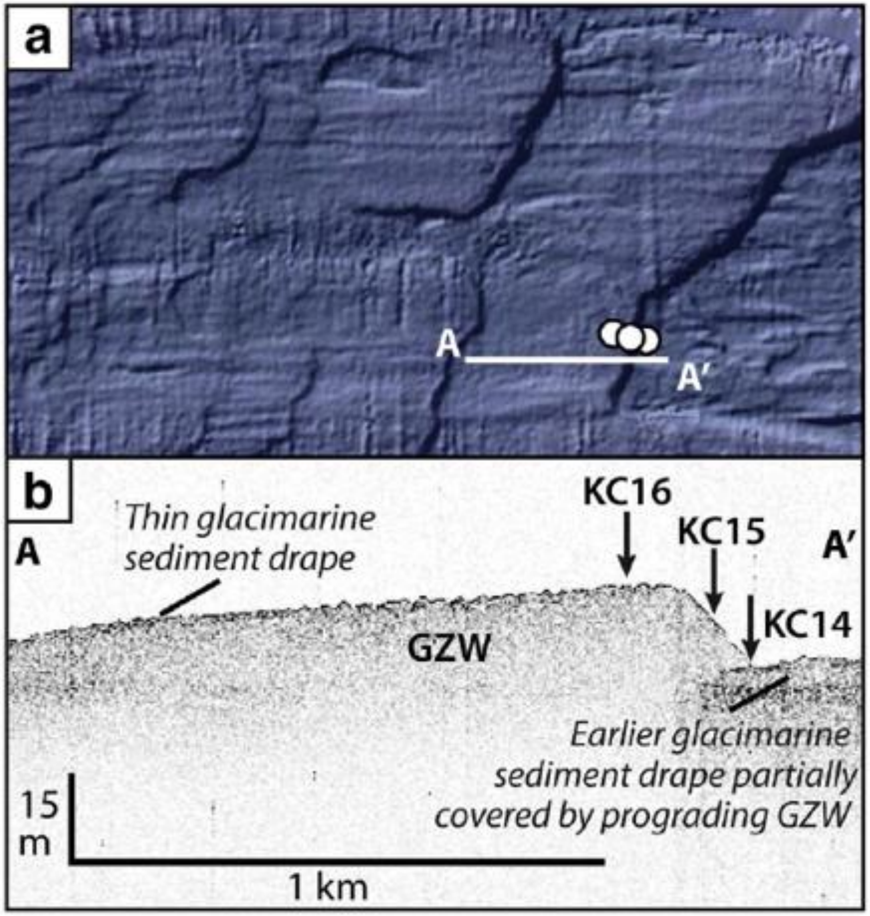
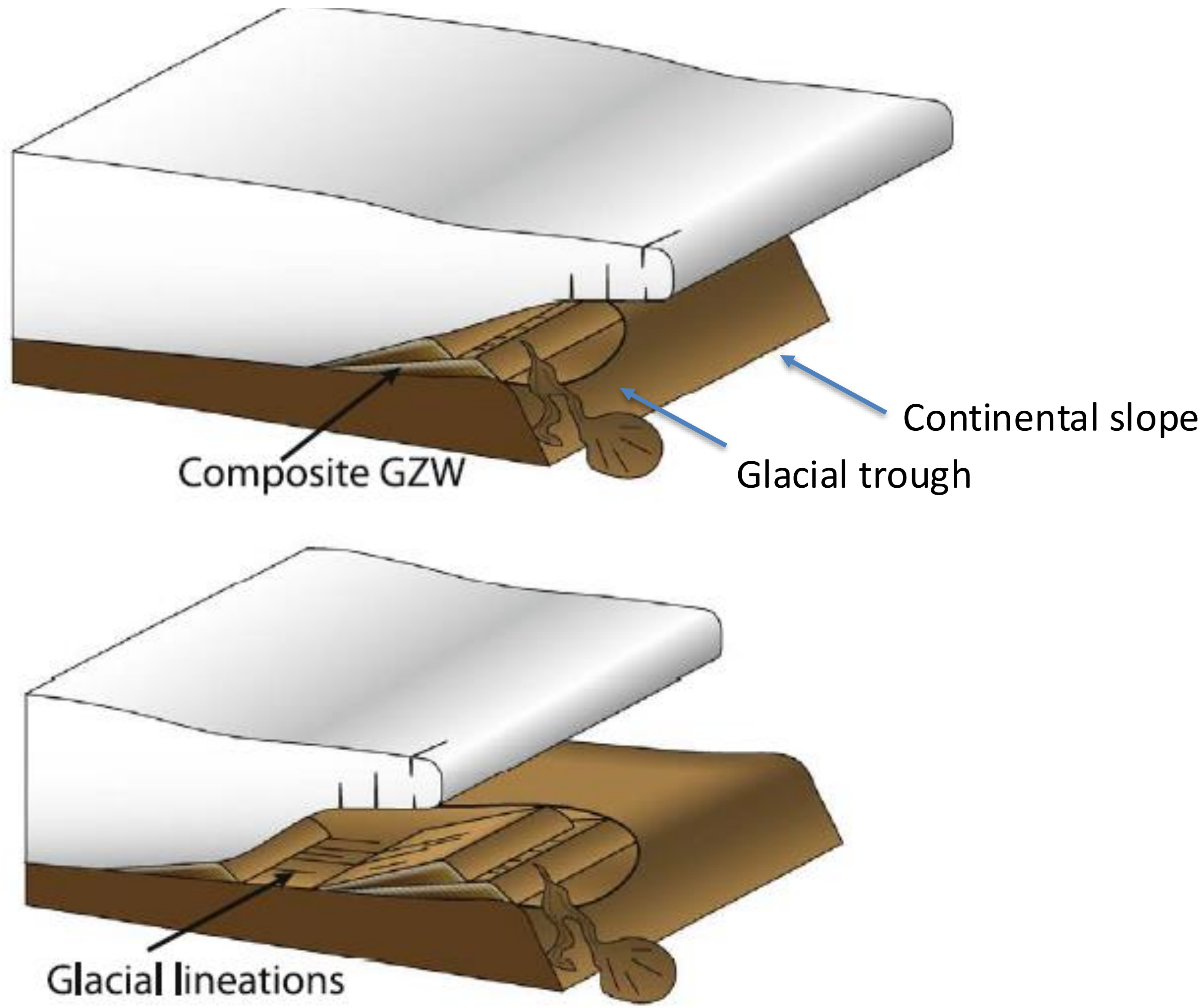


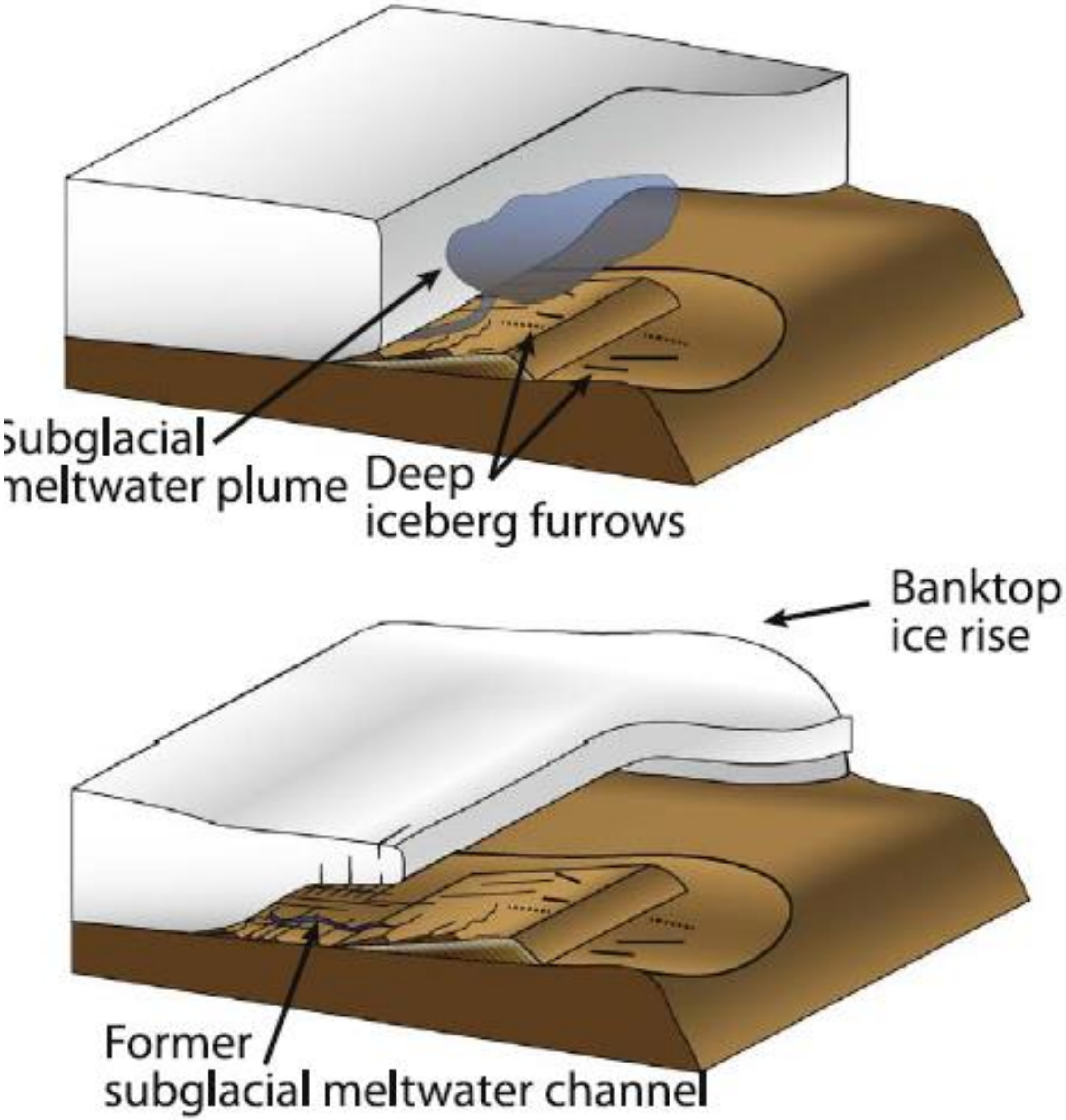
Fig. 3. Example of coring transect demonstrating targeted coring along a grounding-zone wedge using both (a) multibeam swath bathymetry and (b) CHIRP data. Core locations are shown in multibeam context in Fig. 3a, seismic context in Fig. 3b, and regional context in Fig. 1.

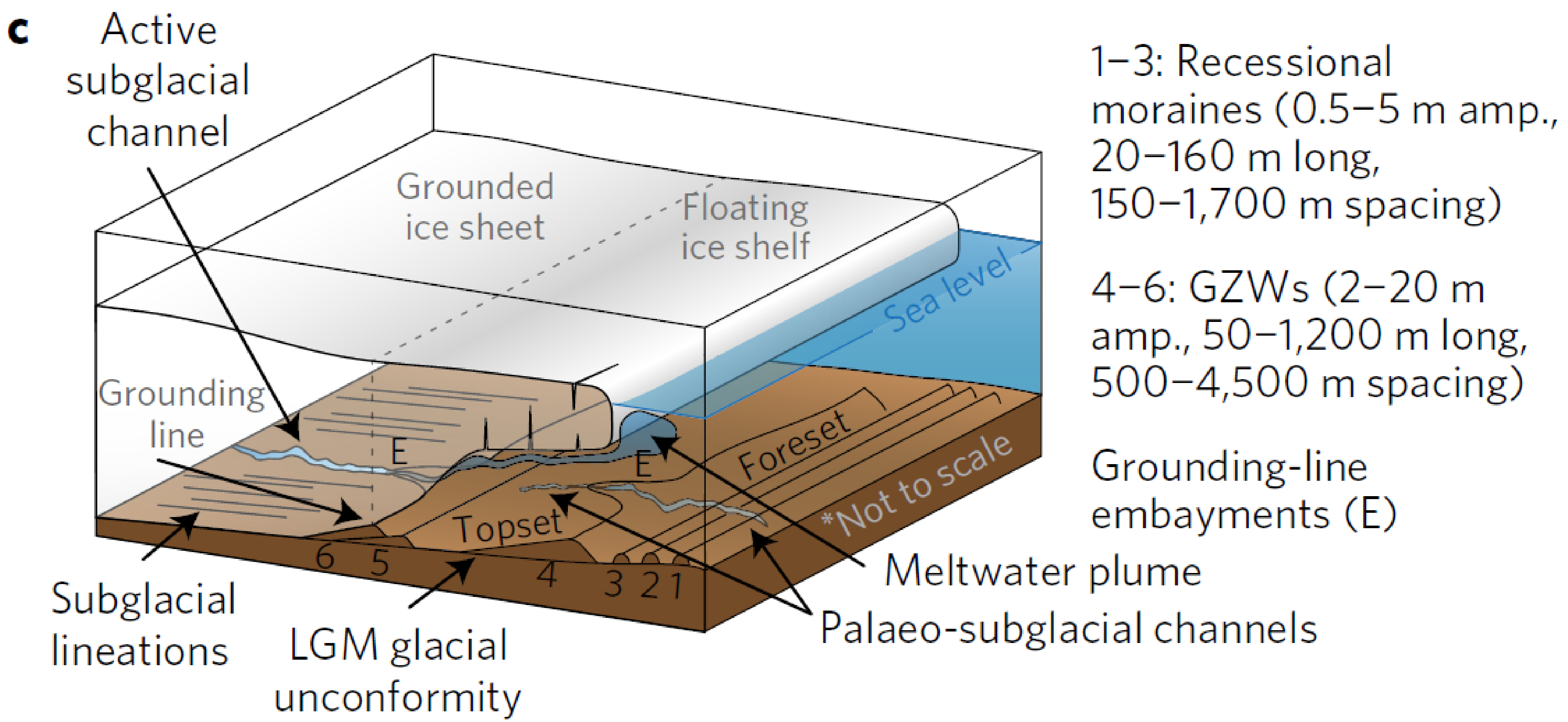
Prothro et al., 2018

The presence of GZWs in the geological record indicates an episodic style of ice retreat punctuated by still-stands in grounding-zone position.

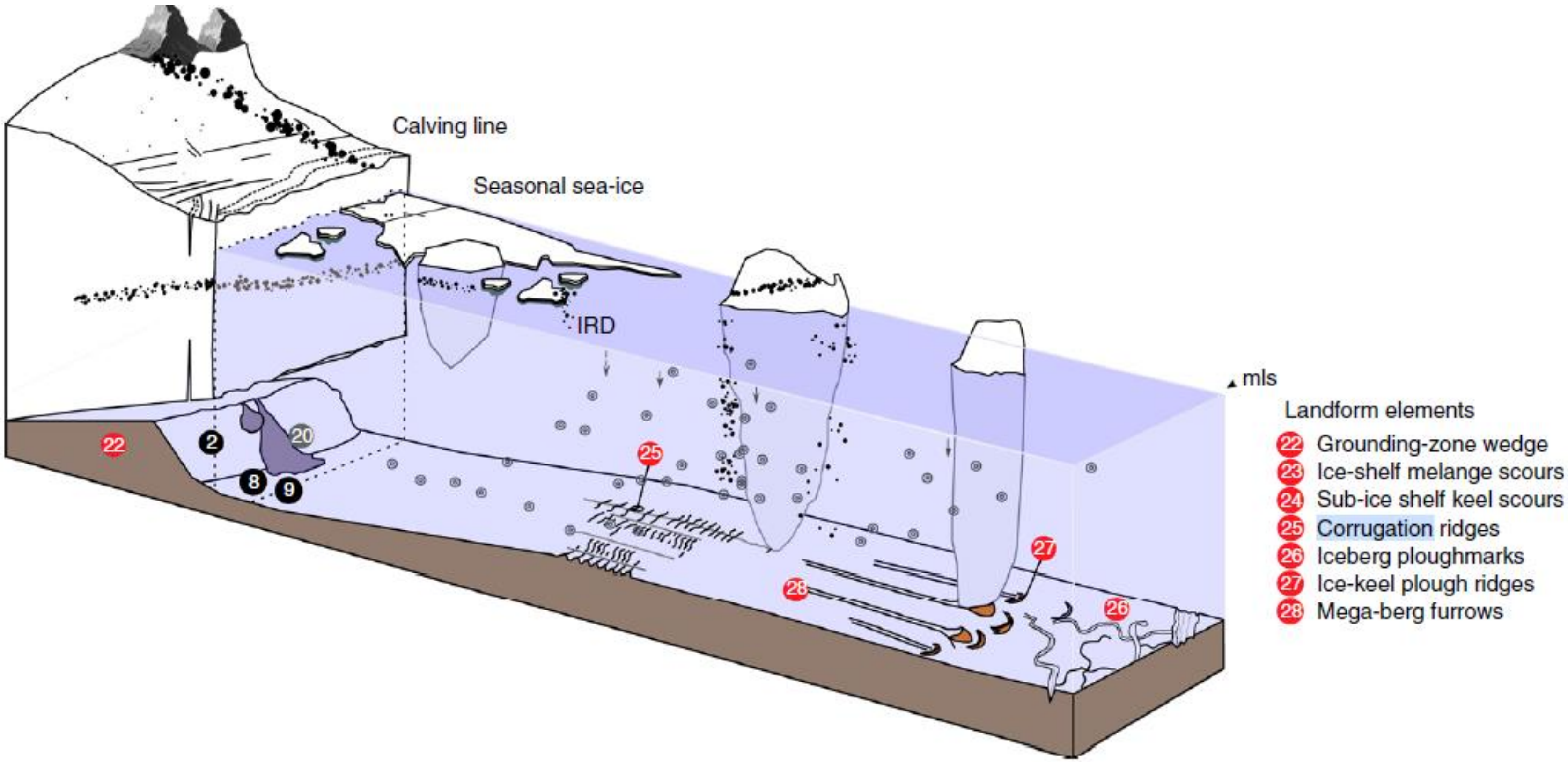


Prothro et al., 2018

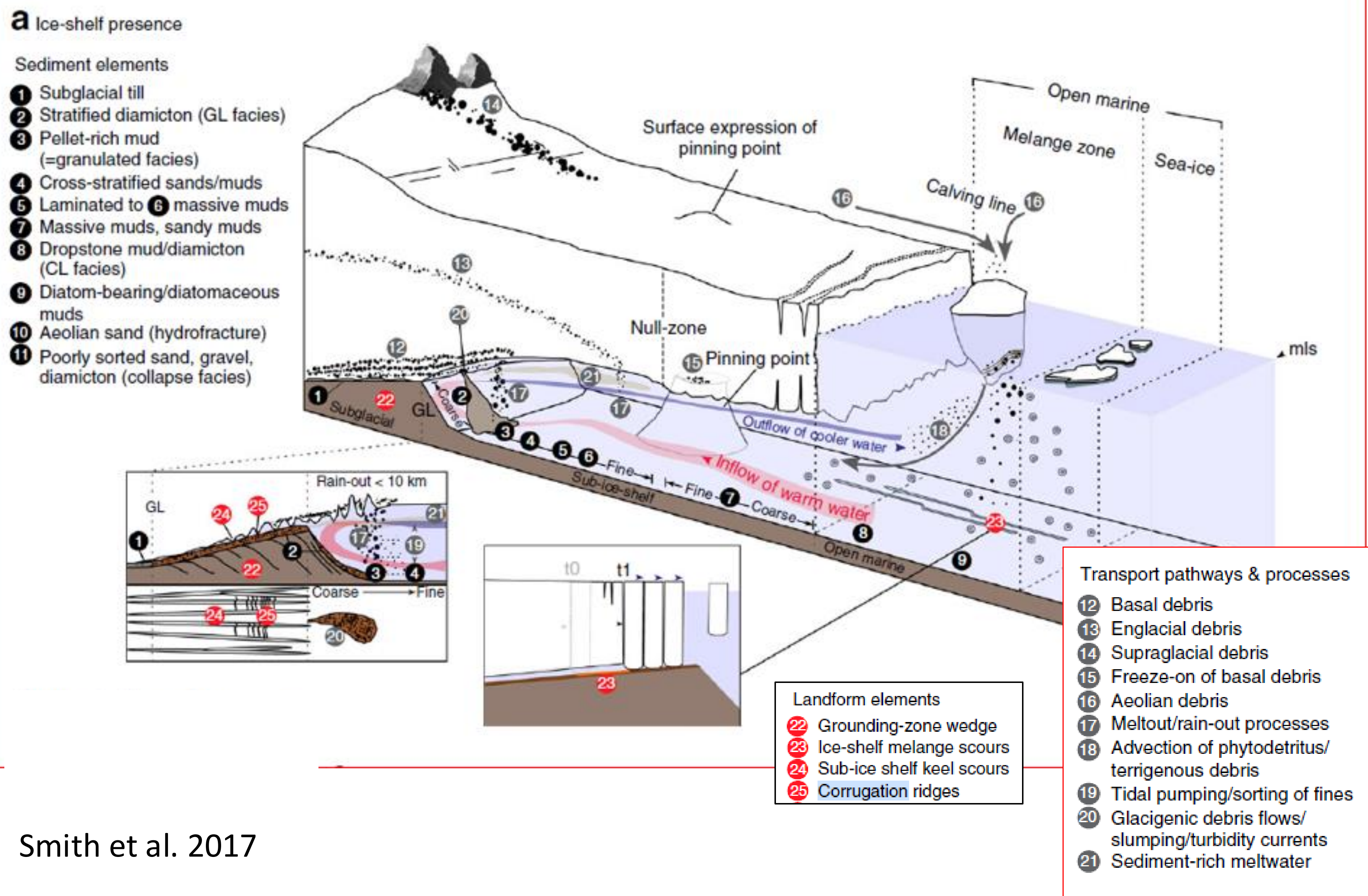

Subglacial meltwater plume
Deep iceberg furrows
Banktop ice rise
Former subglacial meltwater channel



Simkins et al., 2017



Smith et al. 2017



Smith et al. 2017

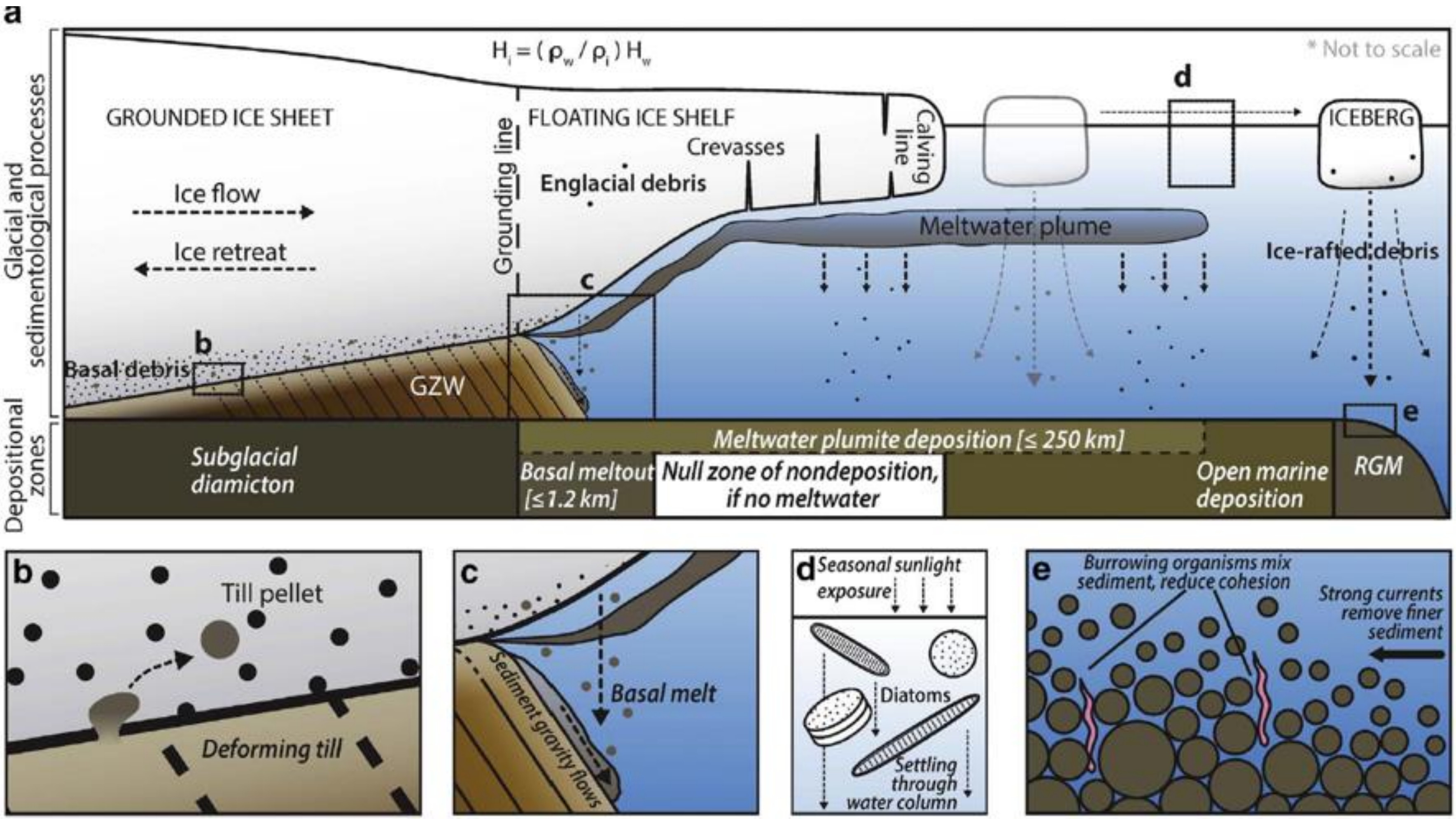
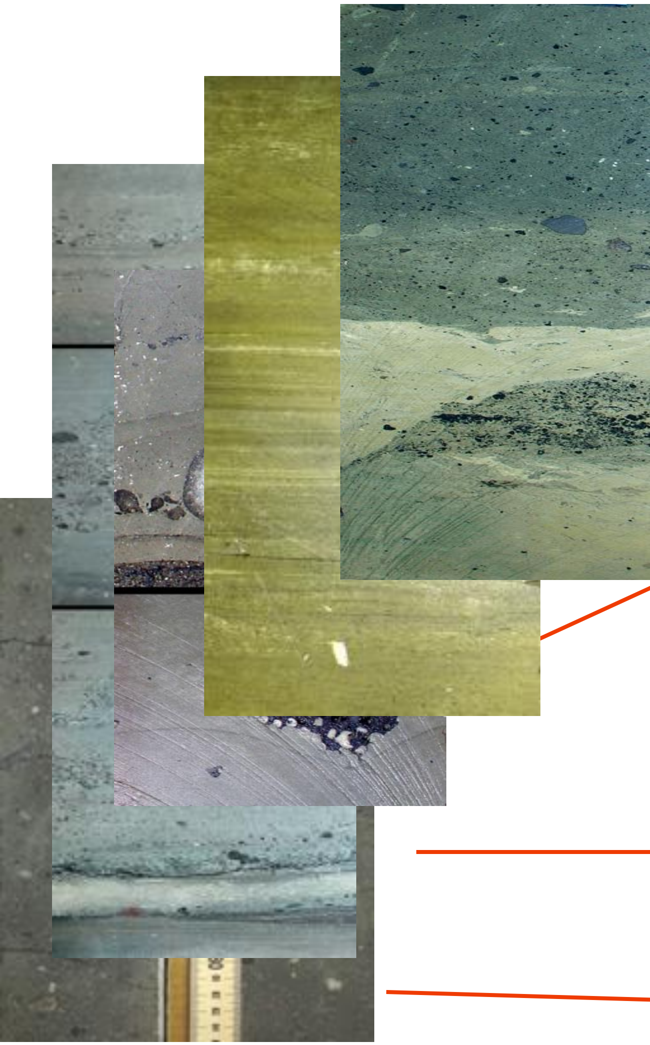


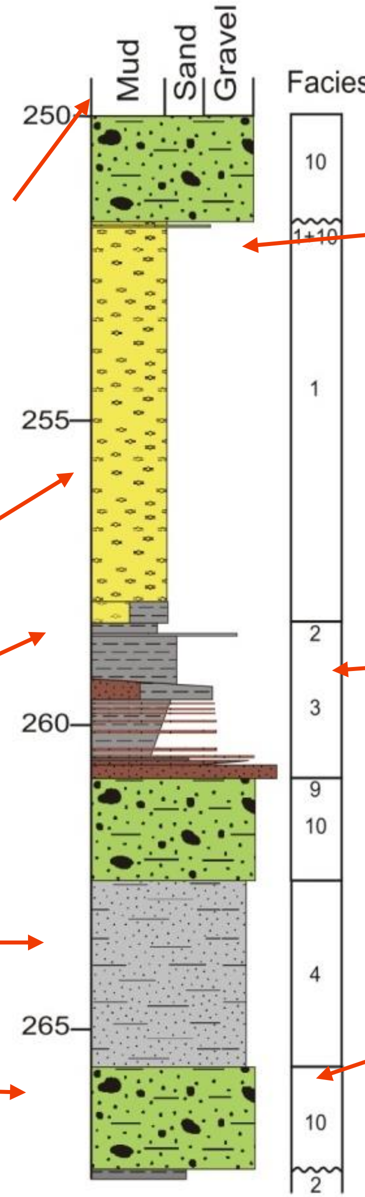
Fig. 2. (a) Conceptual diagram of a grounding-zone wedge (GZW) and proglacial environment, with associated glacial and sedimentary processes. Definitions of terms for buoyancy equation: H_i = ice thickness, Hw = water depth, ρ_i = density of ice (917 kg m^{-3}), ρ_w = density of seawater (~1025 kg m^{-3}—may vary). Terrigenous input from meltwater plumes (level in water column unknown) is observed as far as 250 km from subglacial meltwater channels in the Ross Sea. (b) Formation of till pellets. (c) Deposition of basal meltout debris (limited to within 1.2 km of the grounding line) and debris flows (restricted to foreset length). (d) Open marine sedimentation dominated by rainout of organic detritus. (e) Reworking of glacial and glacimarine sediments by marine currents on banktops and the shelf margin, facilitated by bioturbation or iceberg turbation.

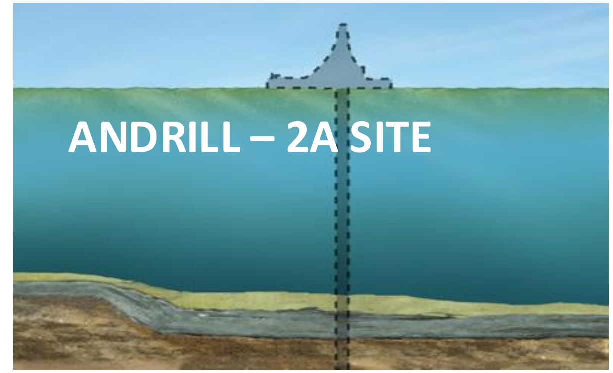
Prothro et al., 2018

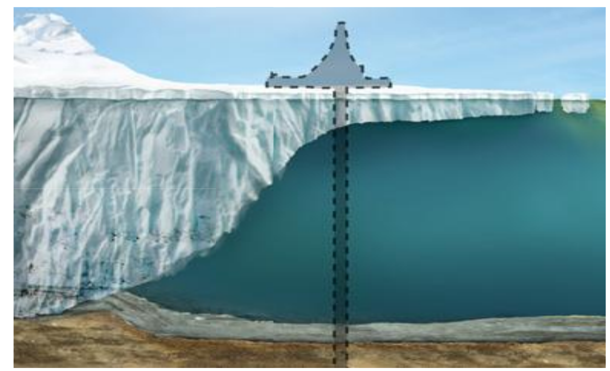
Glacial-Interglacial glacimarine cycles

From Mckay et al. 2009 GSA Bull.

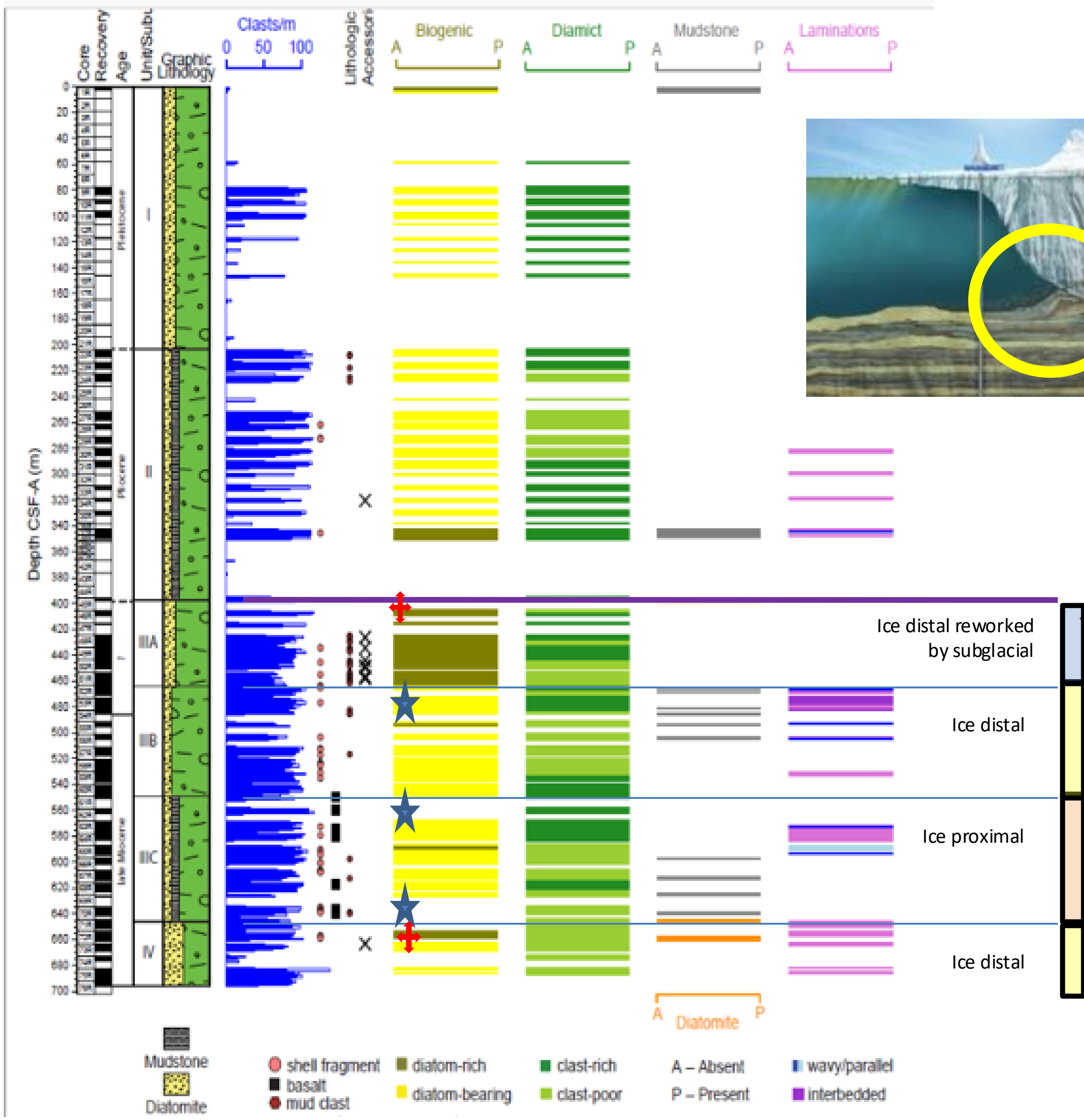


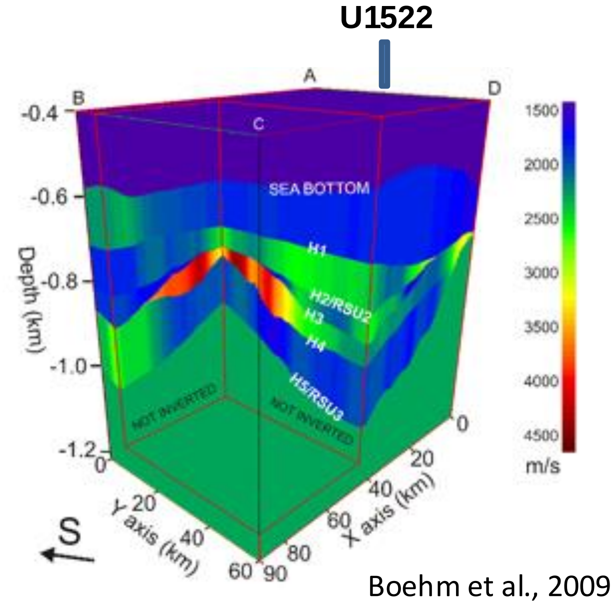


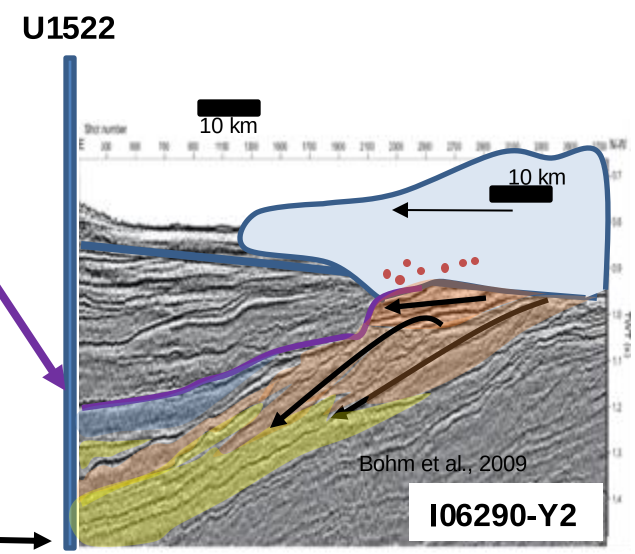




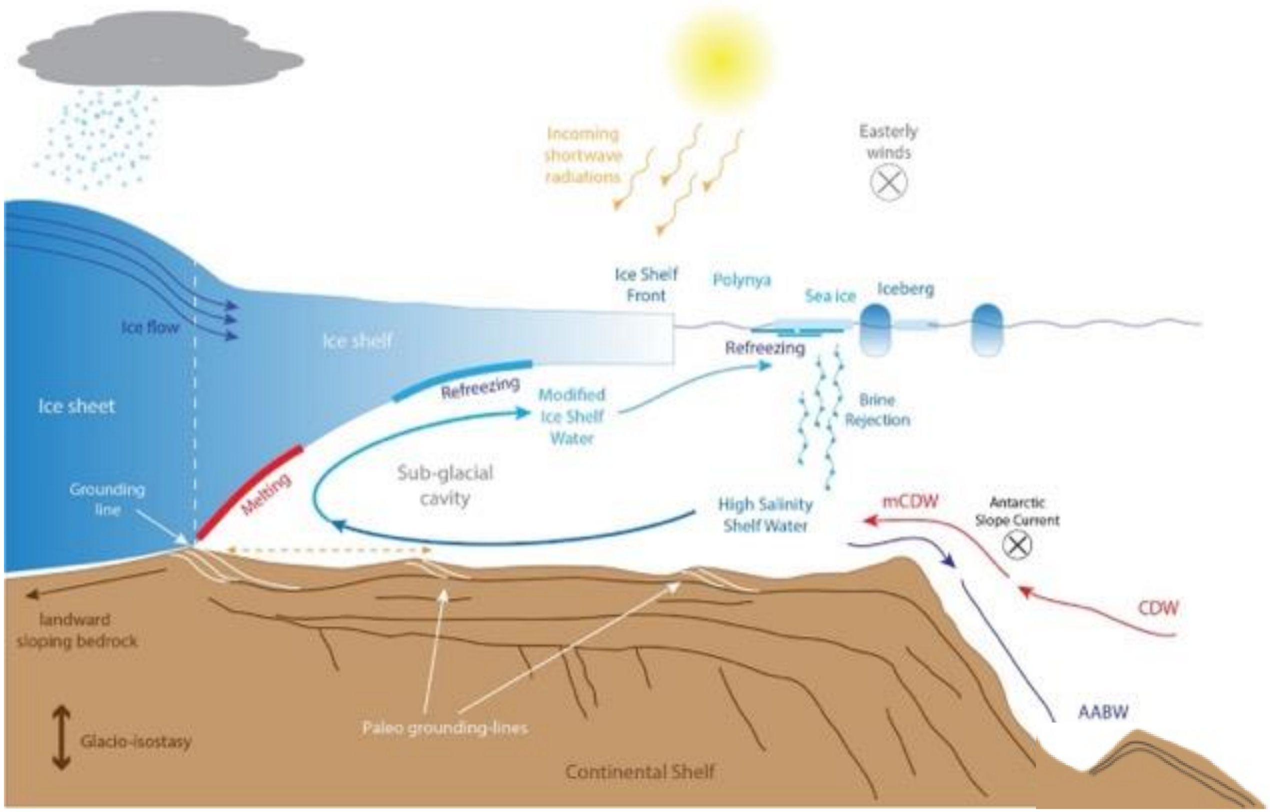
IODP
INTERNATIONAL OCEAN DISCOVERY PROGRAM







Palaeo-ice streams exerted a major influence on ice-sheet behaviour and had the potential to cause abrupt climatic change through the rapid delivery of ice and freshwater to the ocean.

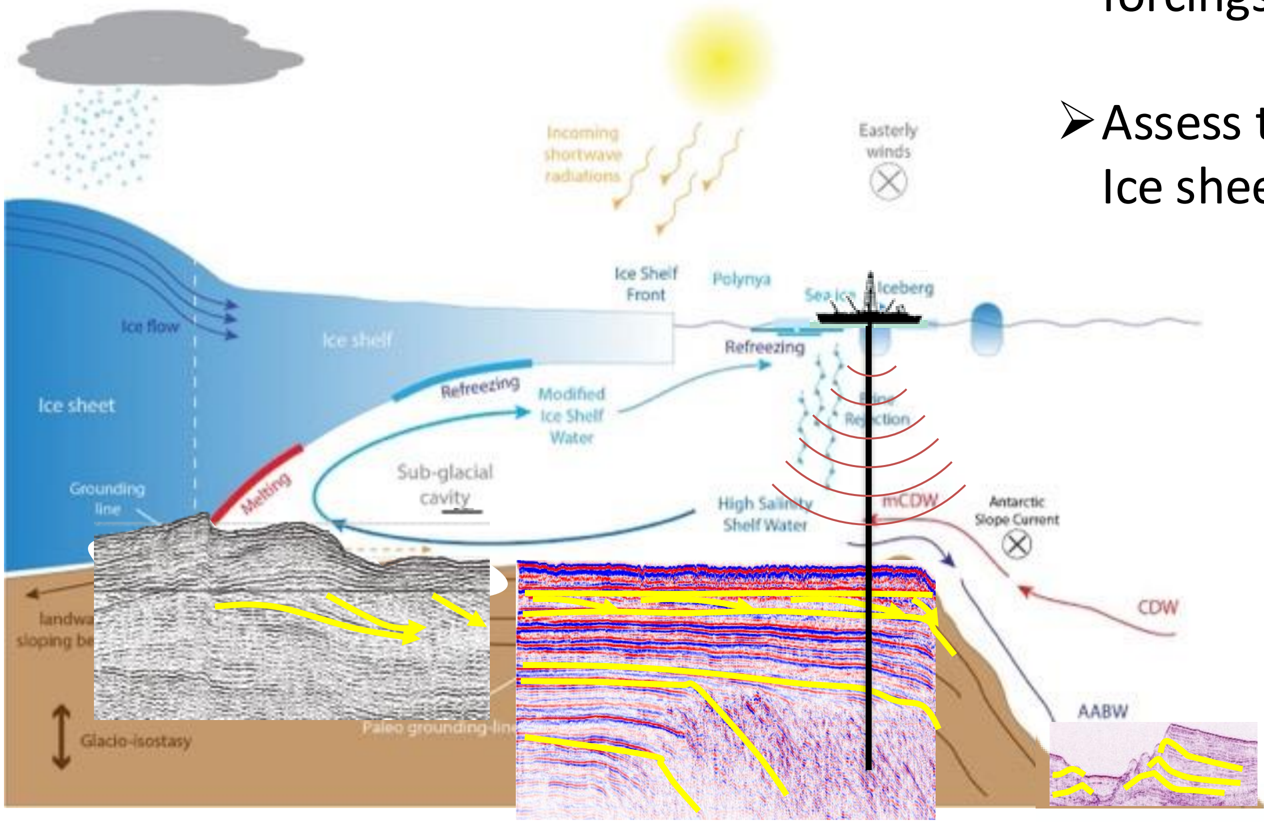


Colleoni et al., 2018

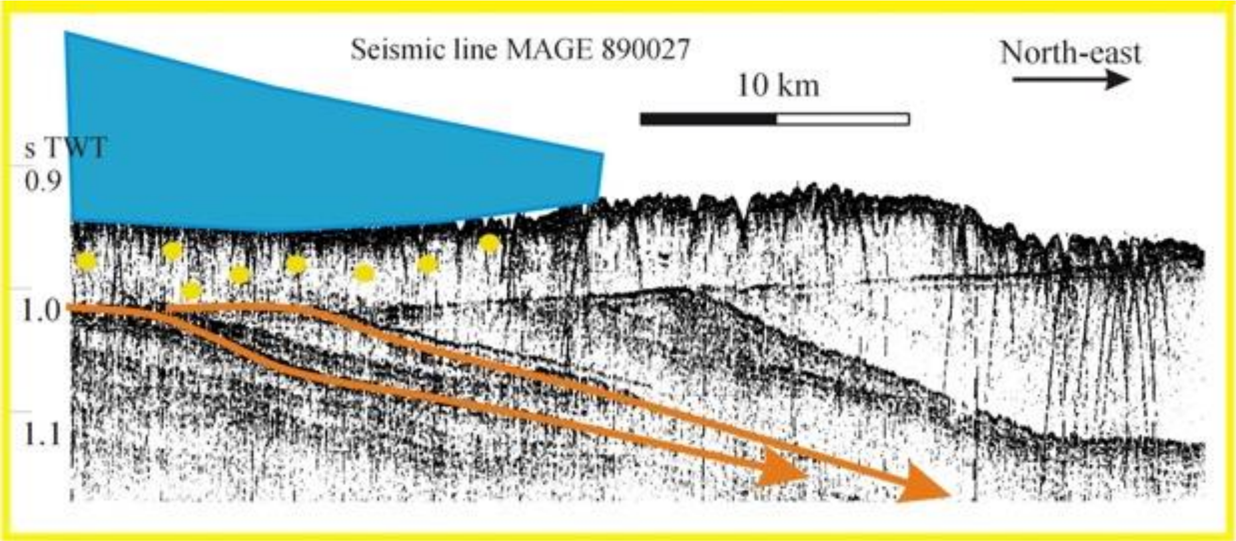
Paleo GZW indicate episodic palaeo ice-stream retreat punctuated by still-stands in the grounding-zone position (Dowdeswell et al., 2008; Ó Cofaigh et al., 2008).

- Reconstruct ice volume change, atmospheric and oceanic temperatures to identify past polar amplification and assess its forcings/feedbacks

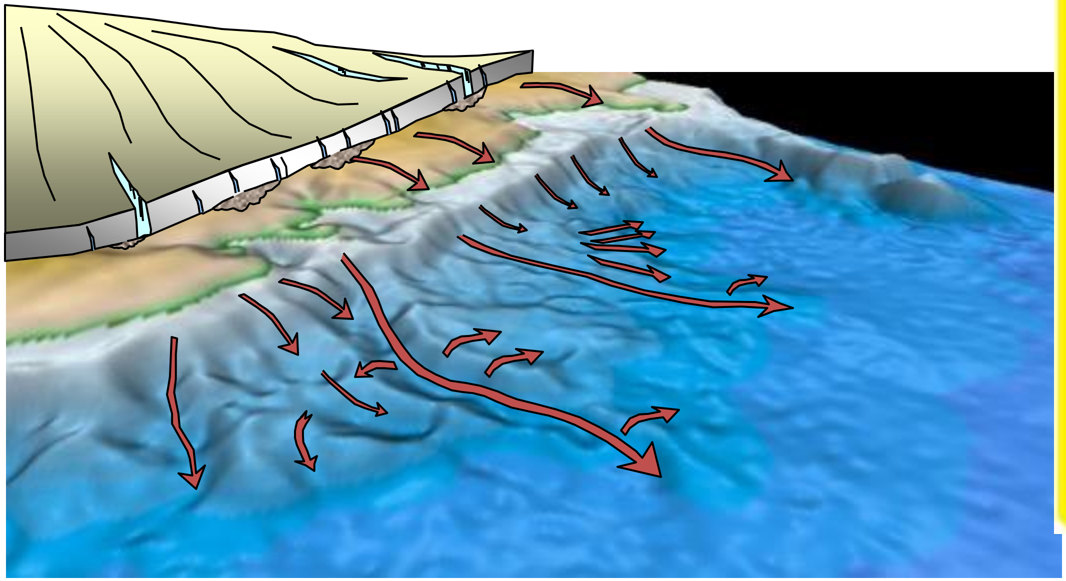
- Assess the role of oceanic forcing on Ice sheet stability/instability

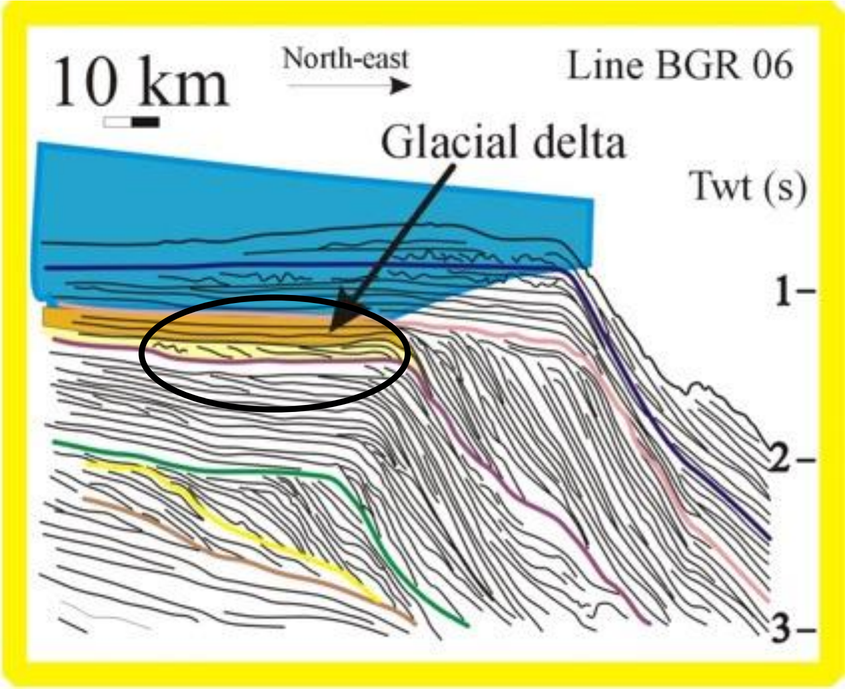


Colleoni et al., 2018



Grounding-zone wedges form along a line-source at the grounding zone of marine-terminating ice sheets.





Grounding-zone wedges (GZWs) (replace "till delta") are asymmetric sedimentary depocentres which form through the rapid accumulation of glacigenic debris during still-stands in ice-sheet retreat. GZWs form largely through the delivery of deforming subglacial sediments.

Foreset surfaces indicating that till deposition occurred by progradation (implying subglacial sediment transport-deformation conveyor belt).

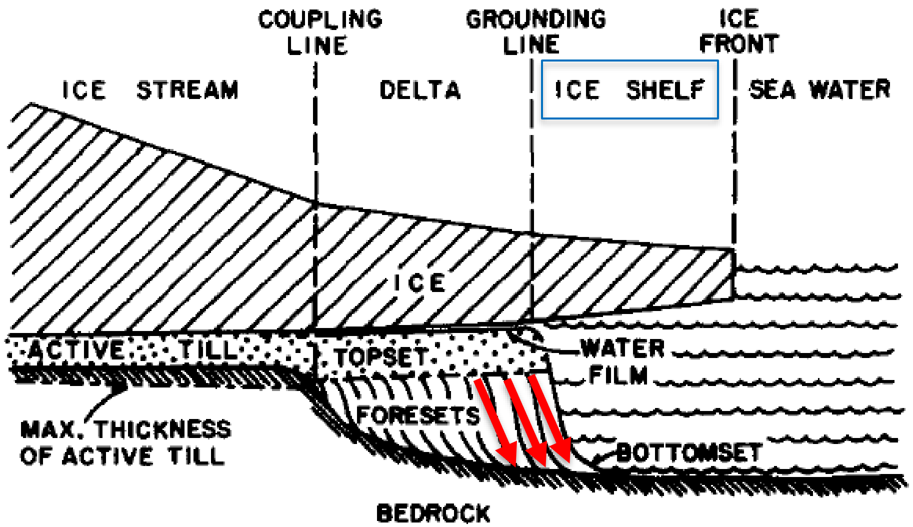
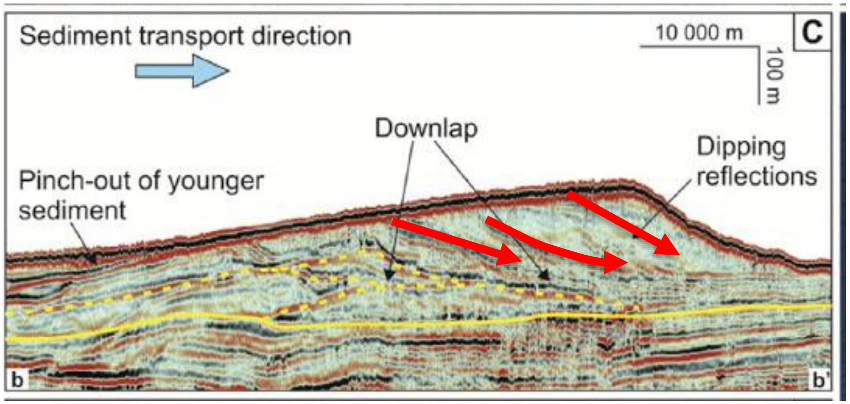
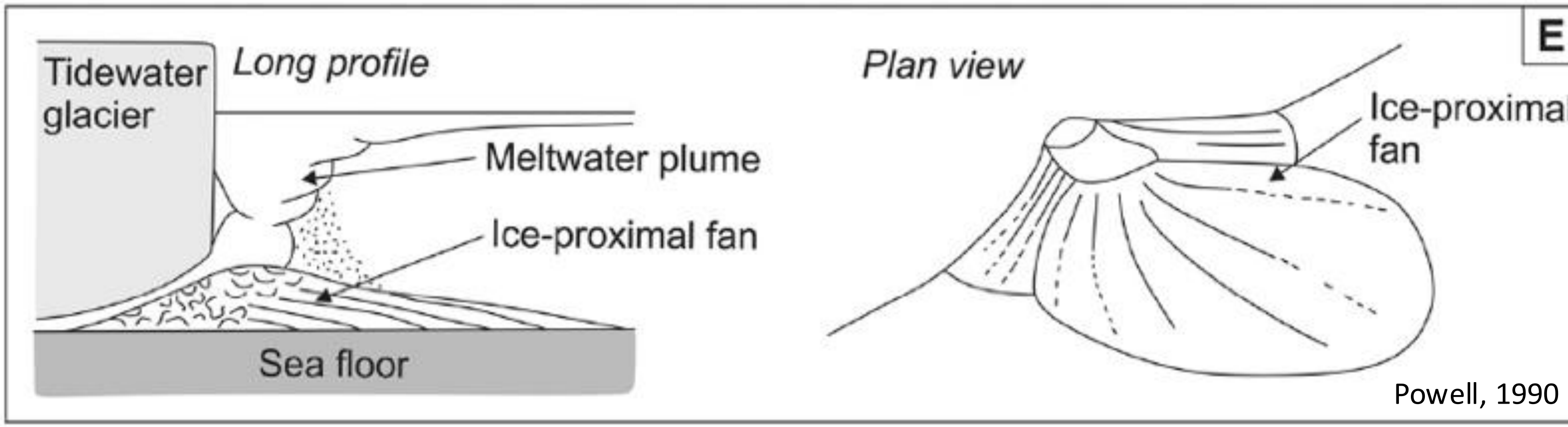


Fig.3. Cartoon of the likely configuration of the ice stream, till delta, and ice shelf.



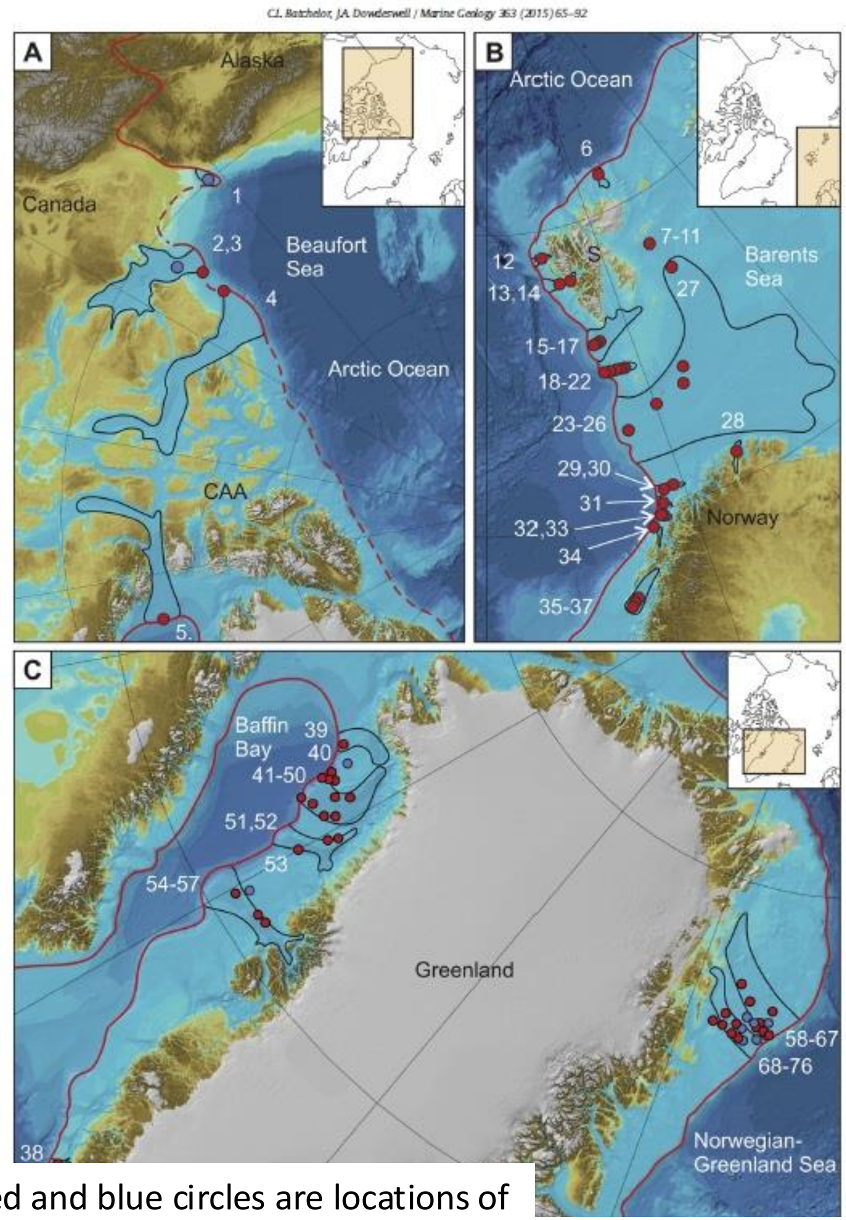
GZW form mainly where **floating ice shelves** constrain vertical accommodation space immediately beyond the grounding-zone. The low-gradient ice roofed cavities of ice shelves restrict vertical accommodation space and prevent the aggradation of high-amplitude moraine ridges.

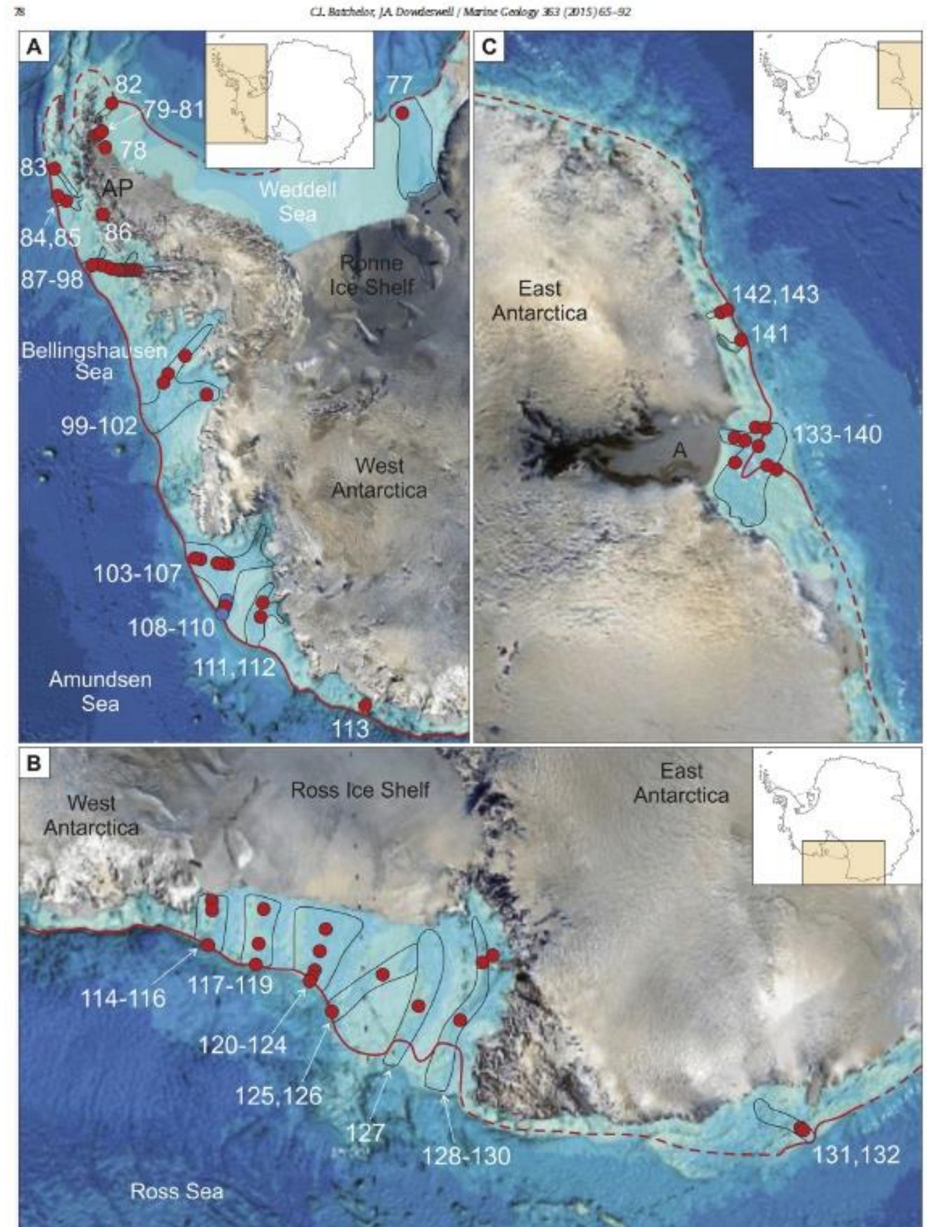
Moraine ridges and ice-proximal fans may also build up at the grounding zone during still-stands of the ice margin, but these require either considerable vertical accommodation space or sediment derived from point-sourced subglacial meltwater streams



Ice-proximal fans form **at the mouths of subglacial meltwater conduits** at the grounding zone of a marine-terminating ice mass (Powell, 1984). They are made of sub-aquatic outwash, gravity flow sediments and suspension settling deposits

Ice-proximal fans that formed during the last glaciation to present interglacial have been described from the fjords of Alaska, Norway and Svalbard. They are typically up to a few tens of metres thick and up to a few kilometres in length.

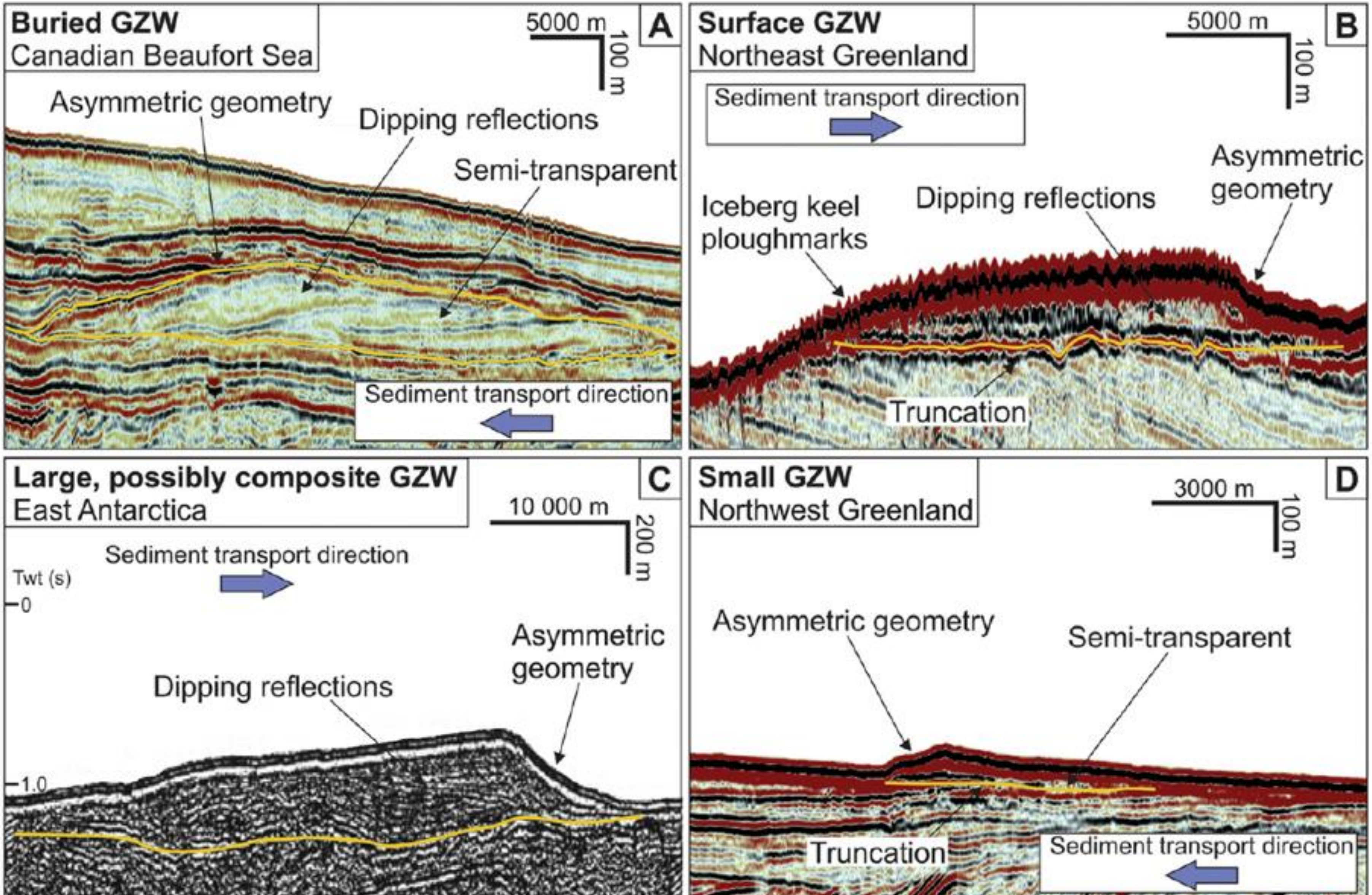




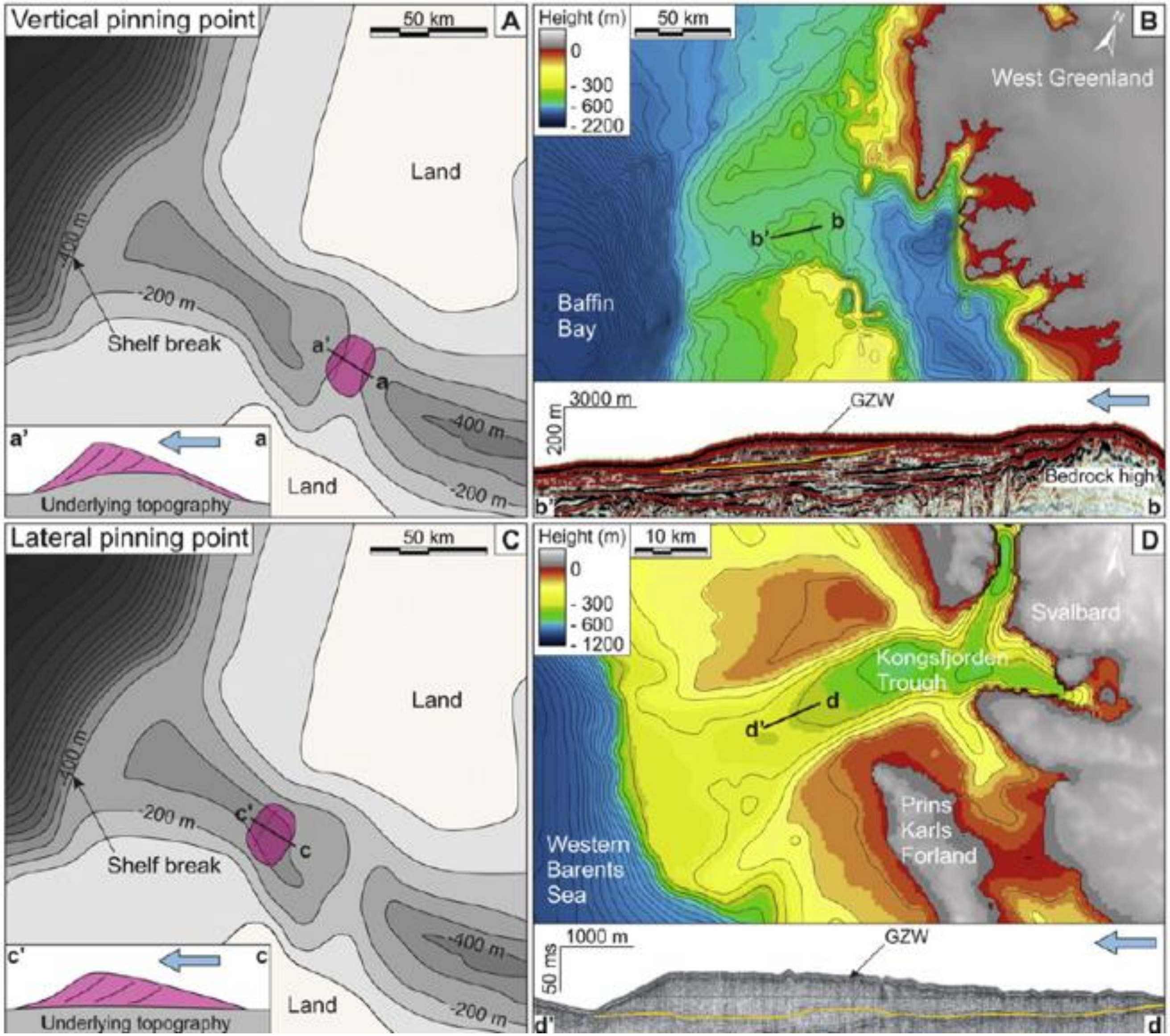
Red and blue circles are locations of surface and buried GZWs

Batchelor et al., 2015

82 C.L. Batchelor, J.A. Dowdeswell / Marine Geology 363 (2015) 65–92



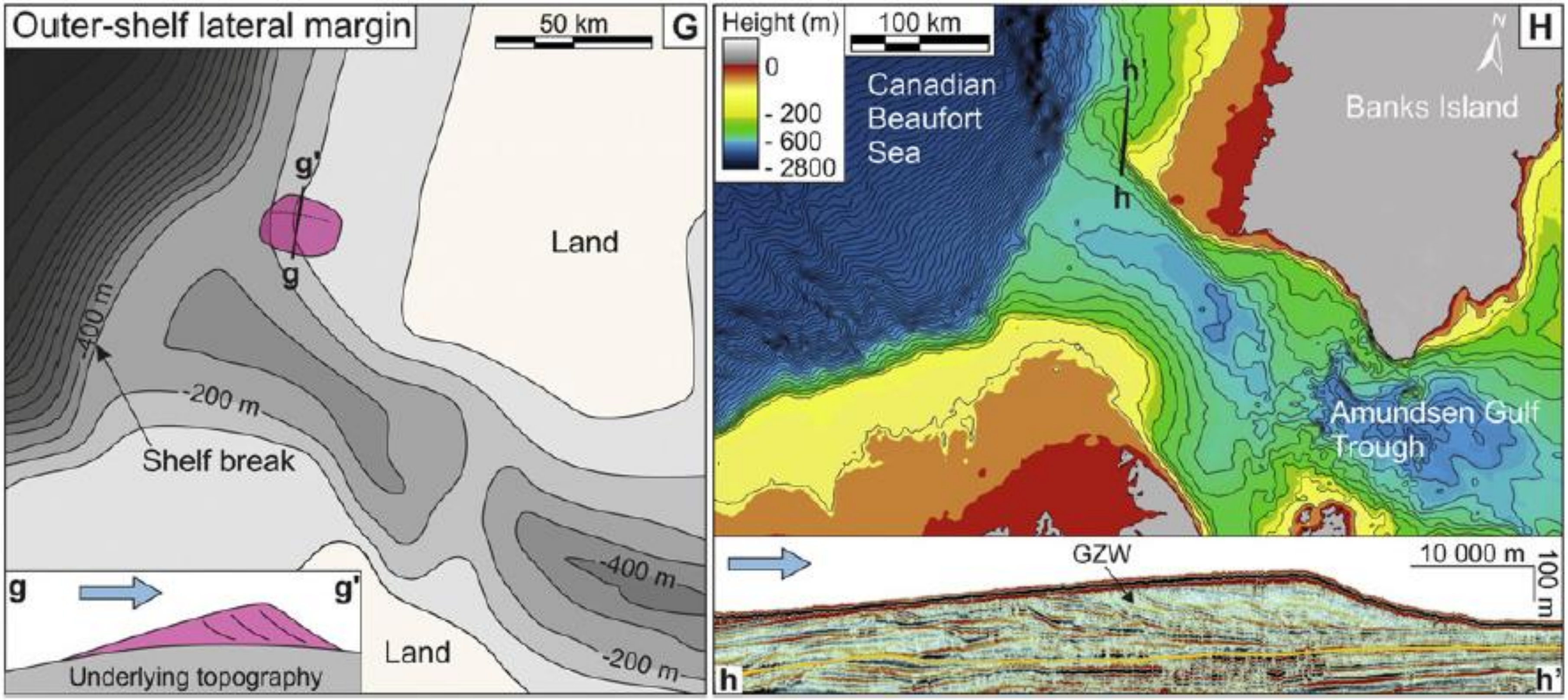
C.L. Batchelor, J.A. Dowdeswell / Marine Geology 363 (2015) 65–92



Bedrock outcrops on the seafloor can act as vertical pinning points

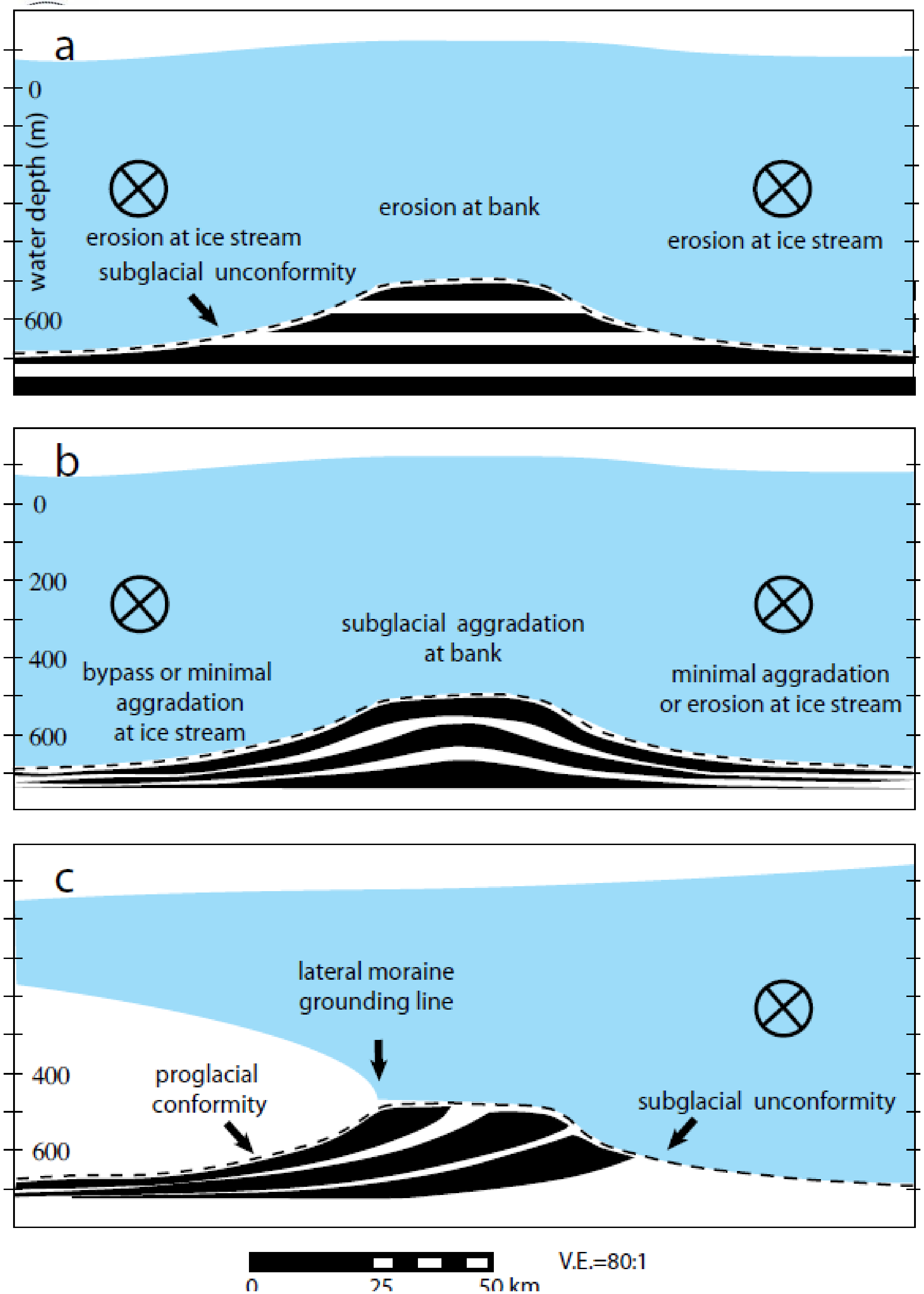
sediment aggradation within water-filled cavities below ice shelves may provide a mechanism **for ice-sheet stabilisation**

The lateral GZWs may represent the boundary between fast, icestreaming flow in the troughs and slower, cold-based ice on the adjacent shelf.



Batchelor et al., 2015

Paleotrough/sedimentary Bank



Conceptual models of erosion/deposition in strike-oriented view below grounded ice sheet on the outer shelf.

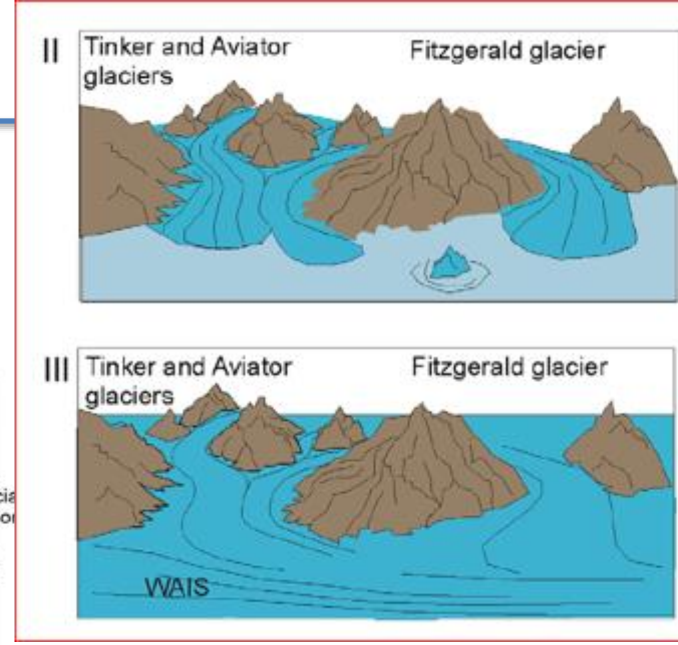
(a) Ice streams erode deep basins into the underlying strata whereas erosion between ice streams is minimal.

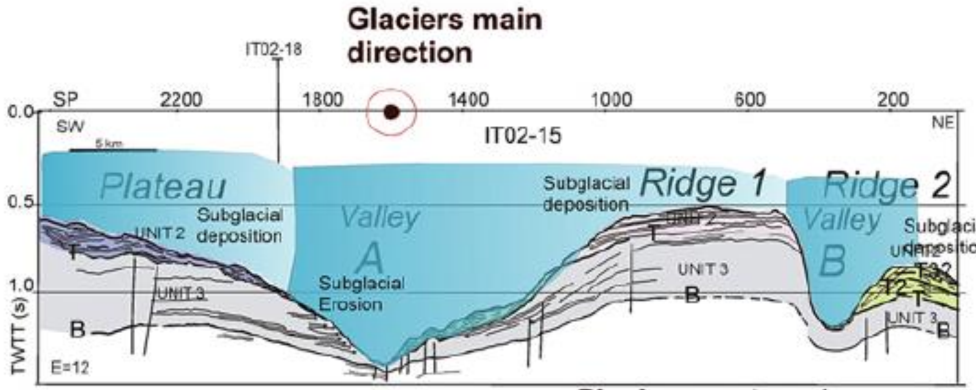
(b) Subglacial aggradation of sediment where ice flow is slowest between ice streams constructs a bank.

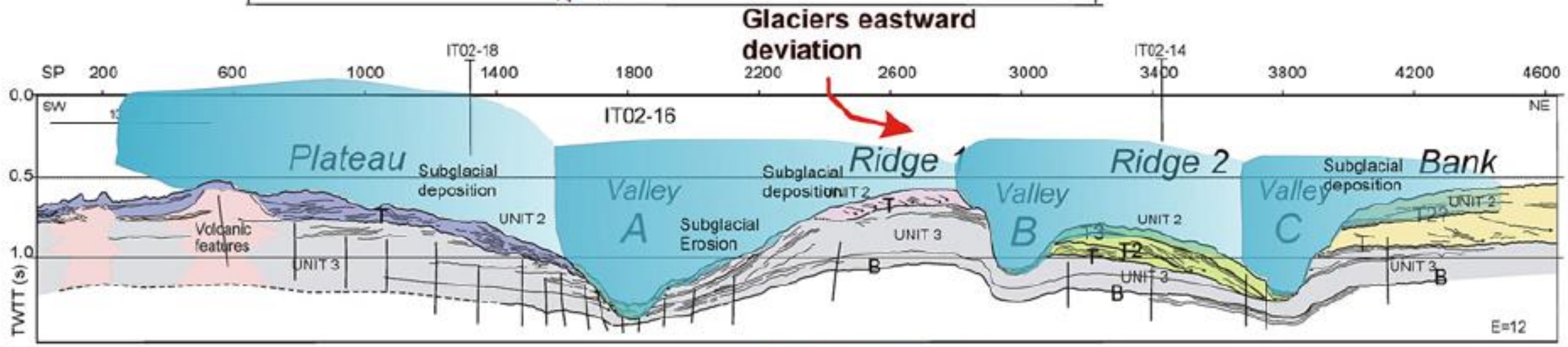
(c) Lateral accretion of till delta foresets into open water from a tongue of grounded ice.

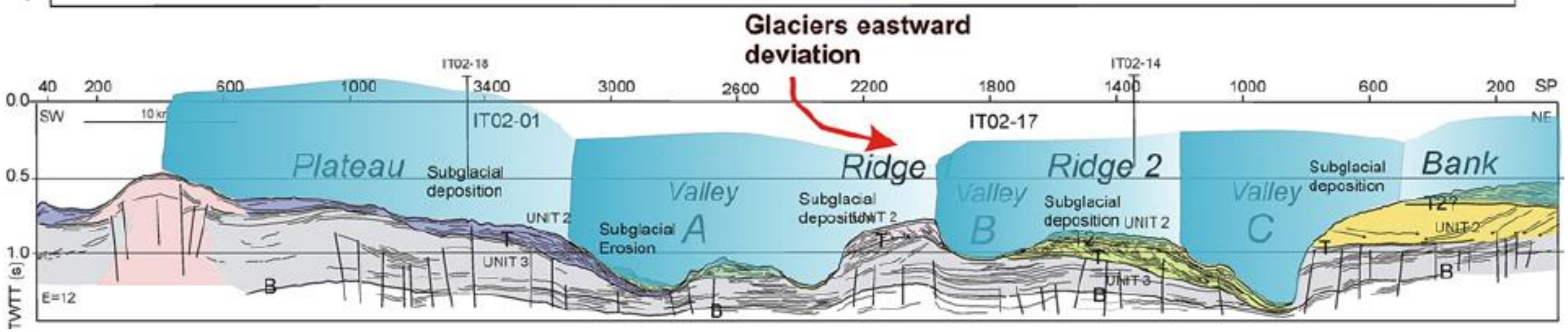
Bart and De Santis 2012

Sauli et al., 2014



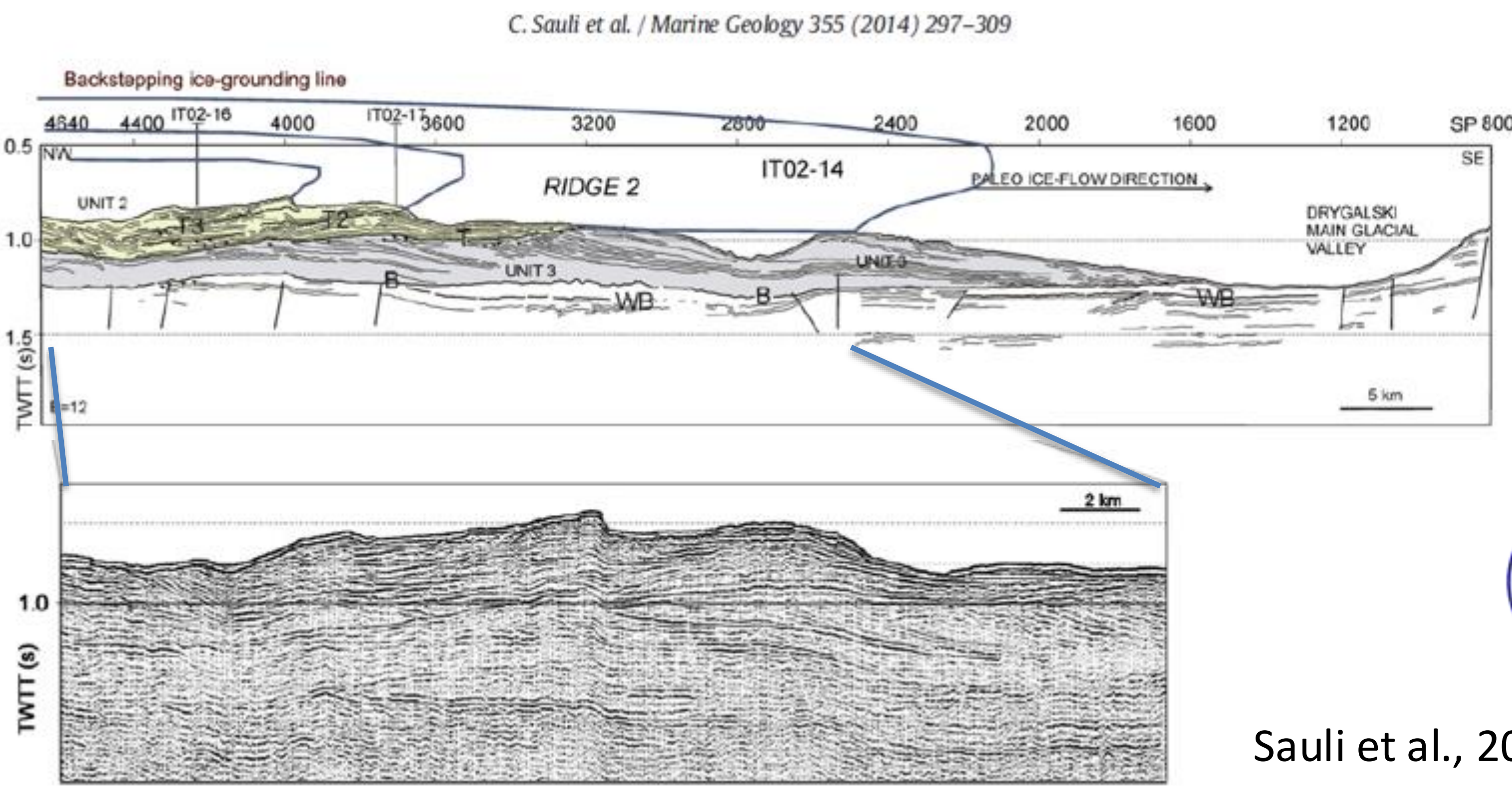






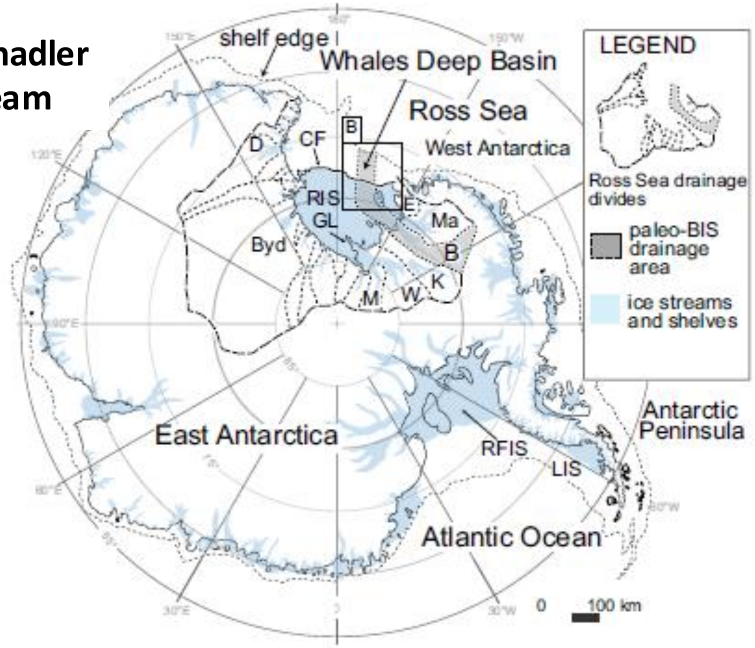
Moraines are typically composed of various unsorted ice-contact sediments and therefore possess a semitransparent to chaotic character on acoustic profiles.

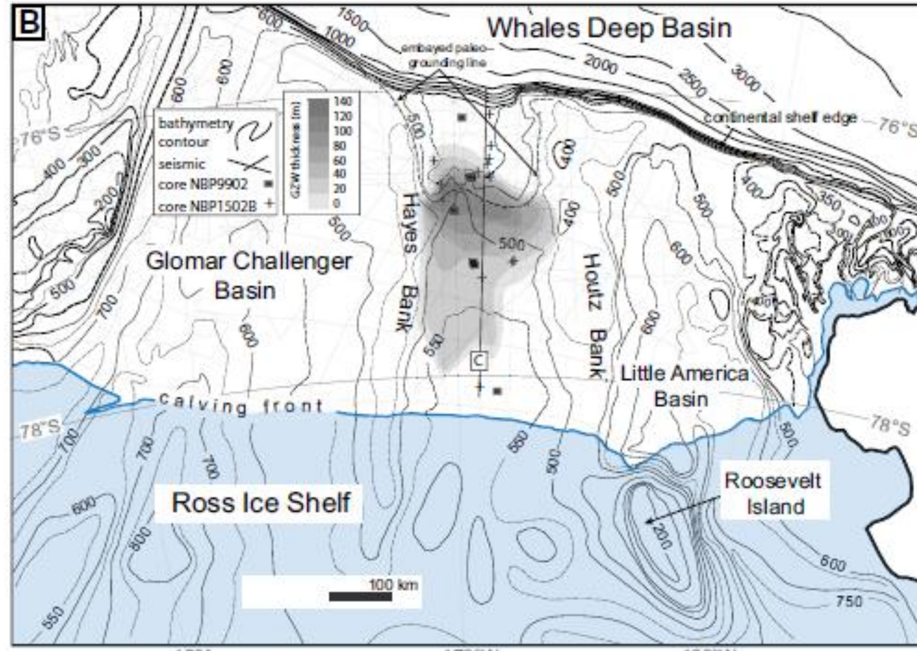
Recessional-moraine ridges record the position of still-stands in the grounding zone during deglaciation



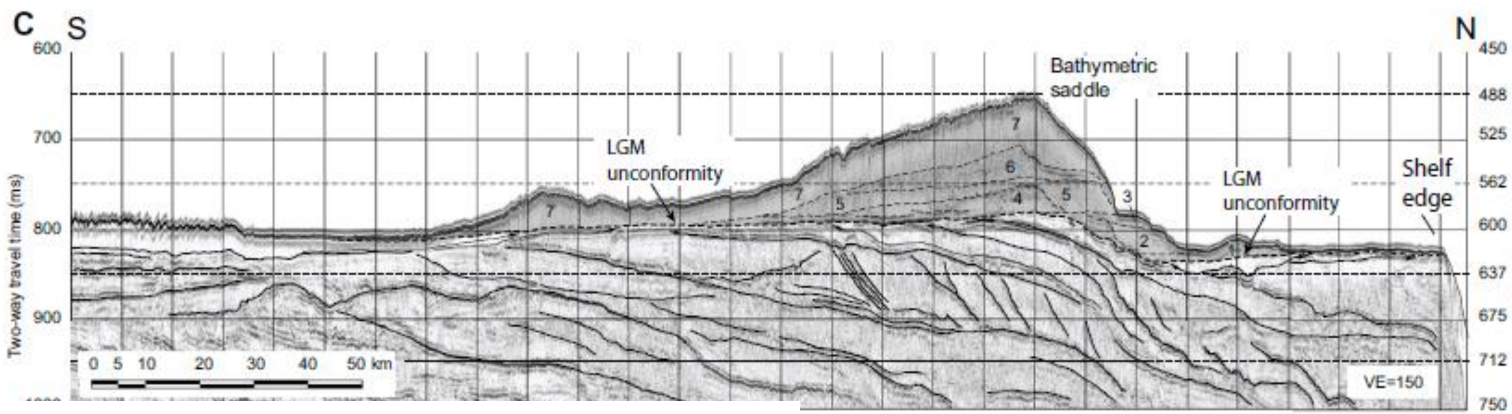
Sauli et al., 2014

paleo–Bindschadler Ice Stream



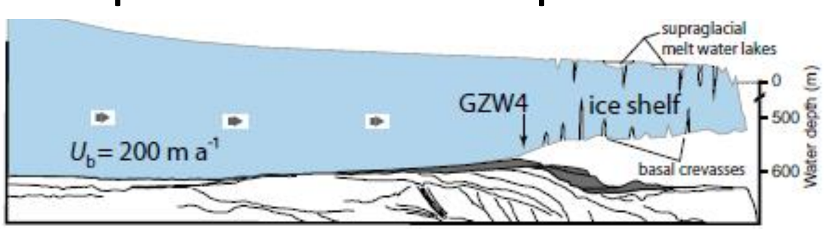


Most of GZW deposited in only 800 ± 300 years after the breakup of the fringing ice shelf

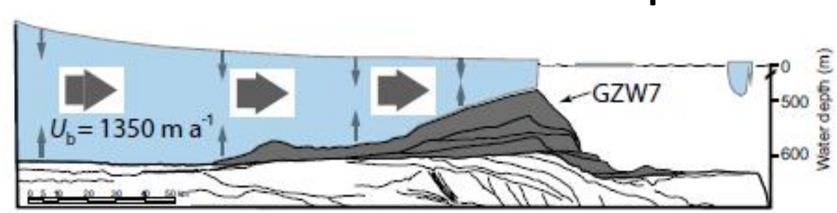


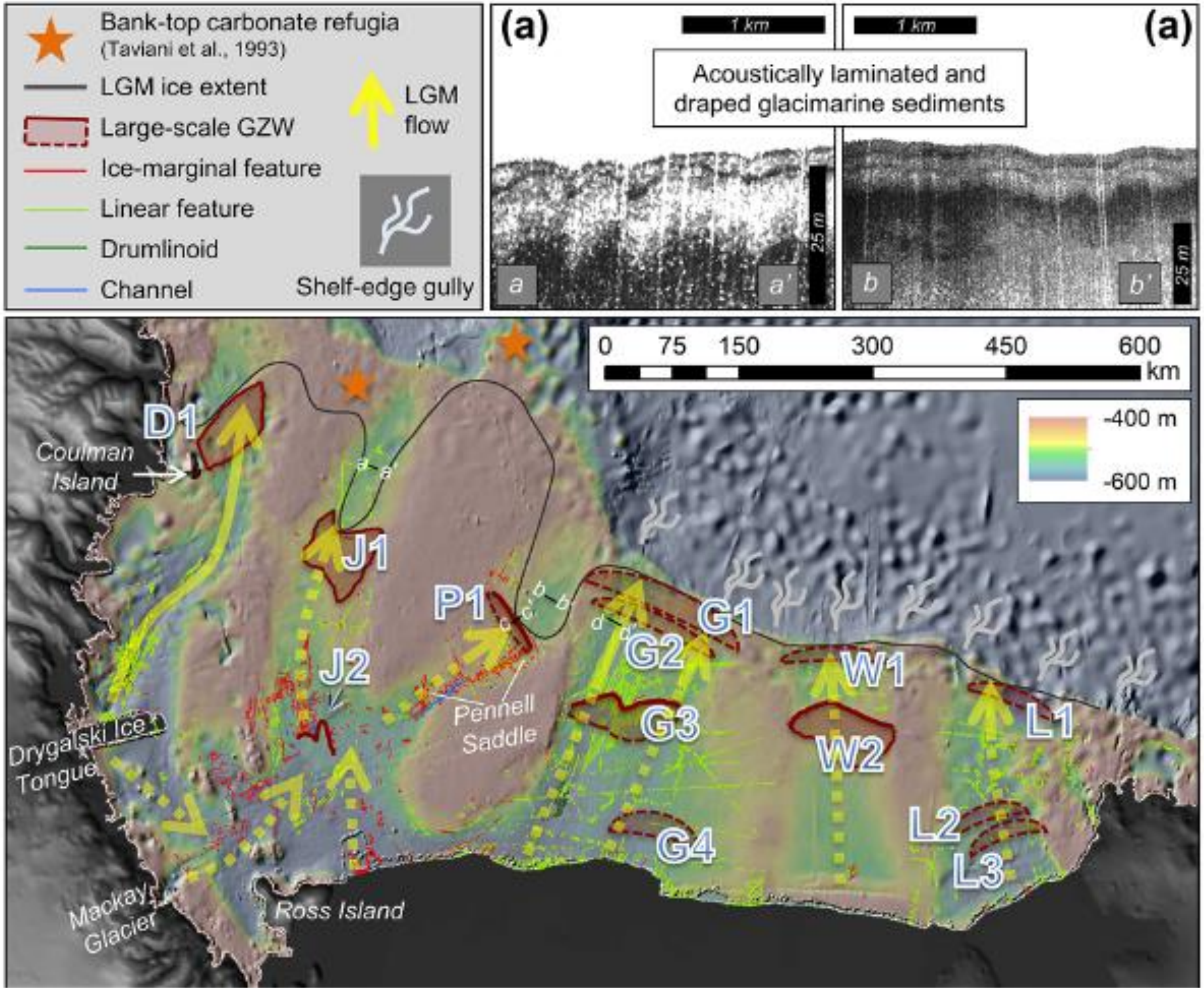
Bart, Tulaczyk, 2020

GZW4 prior to ice-shelf breakup 14.7-12.3 Ka

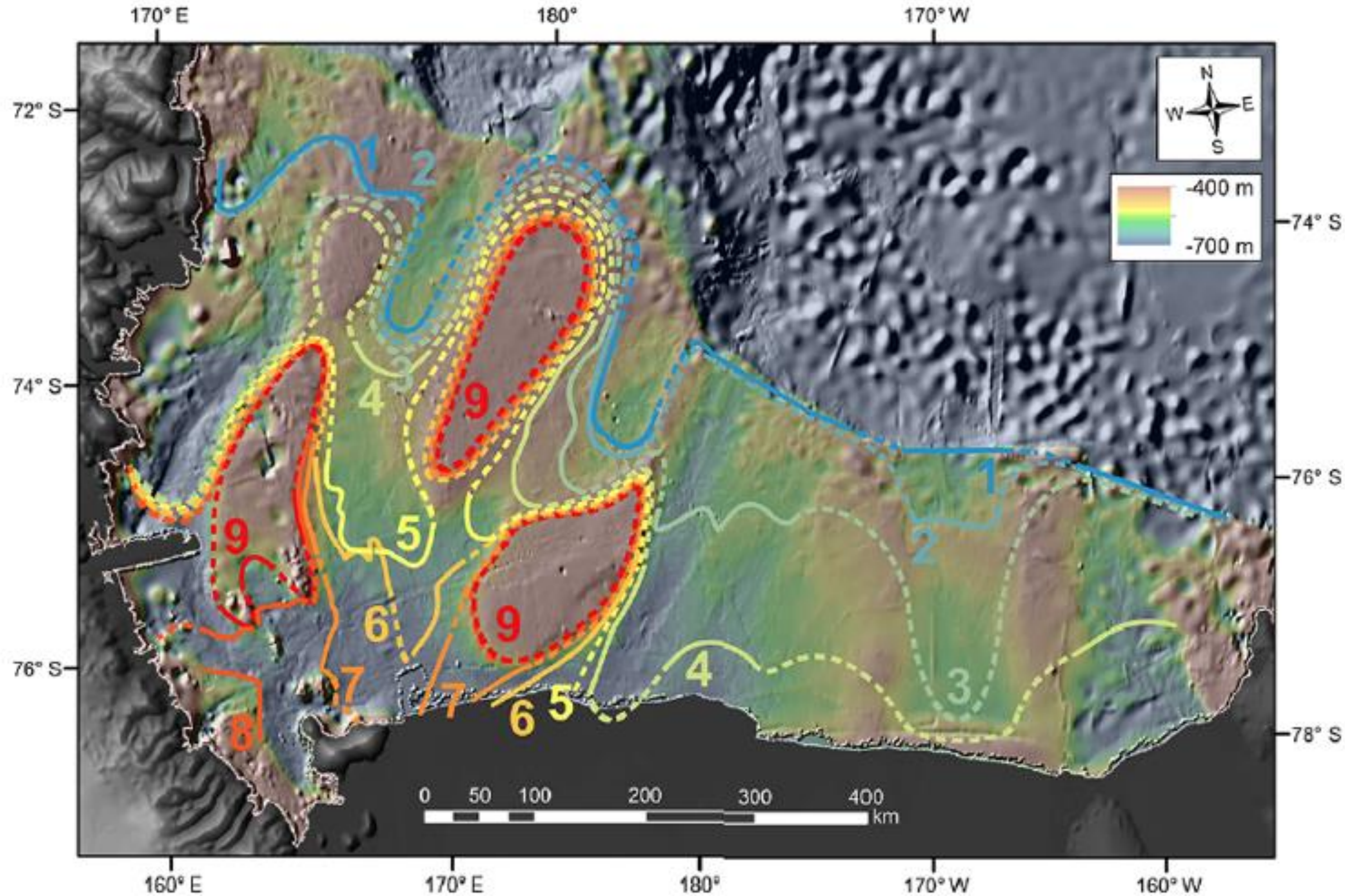


GZW7 after to ice-shelf breakup 12.3-11.5 Ka





Halberstadt et al., 2016

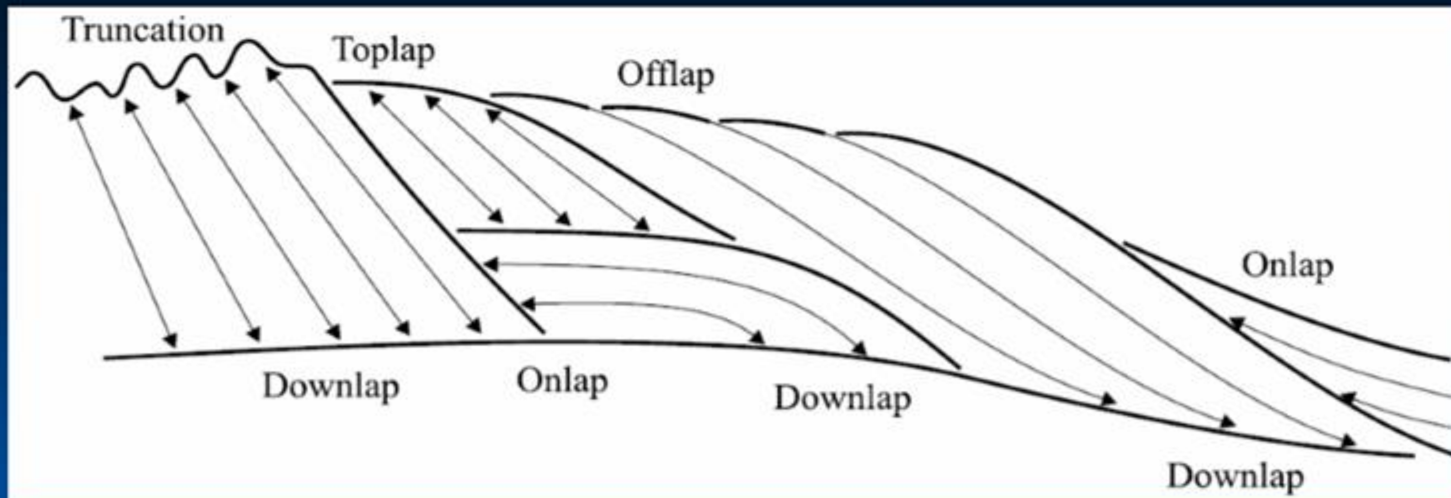


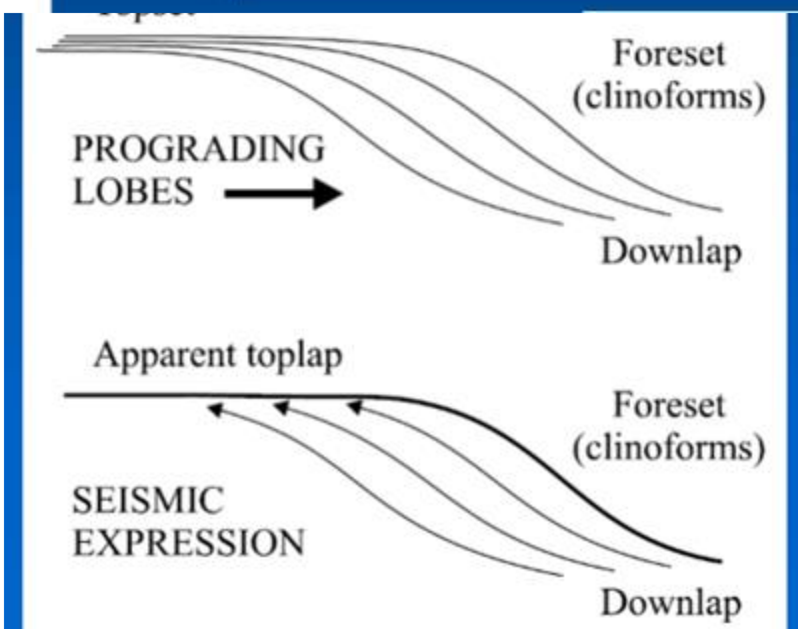
Halberstadt et al., 2016

Figure 7. Reconstructed grounding-line retreat across the Ross Sea based on geomorphic indicators of grounding lines (solid lines) and inferred grounding-line locations (dashed). Each line marks a relative step in grounding-line retreat starting with step 1 at the LGM grounding line and ending with step 9 with ice pinned on banks.

EXERCIZE

Stratal terminations (model-independent)





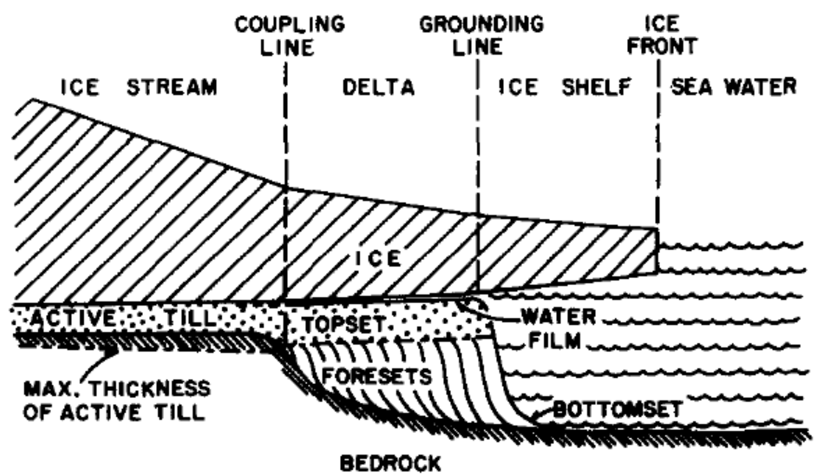
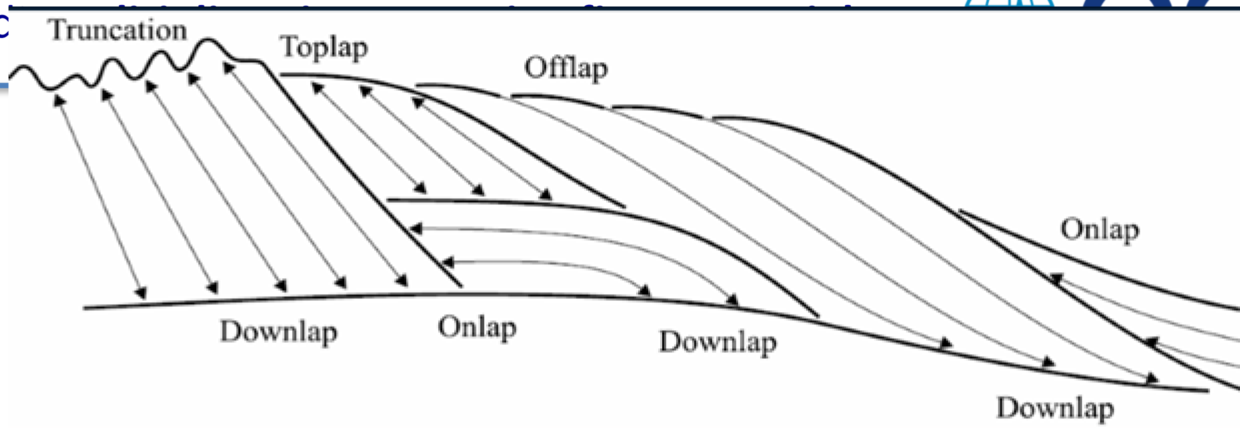
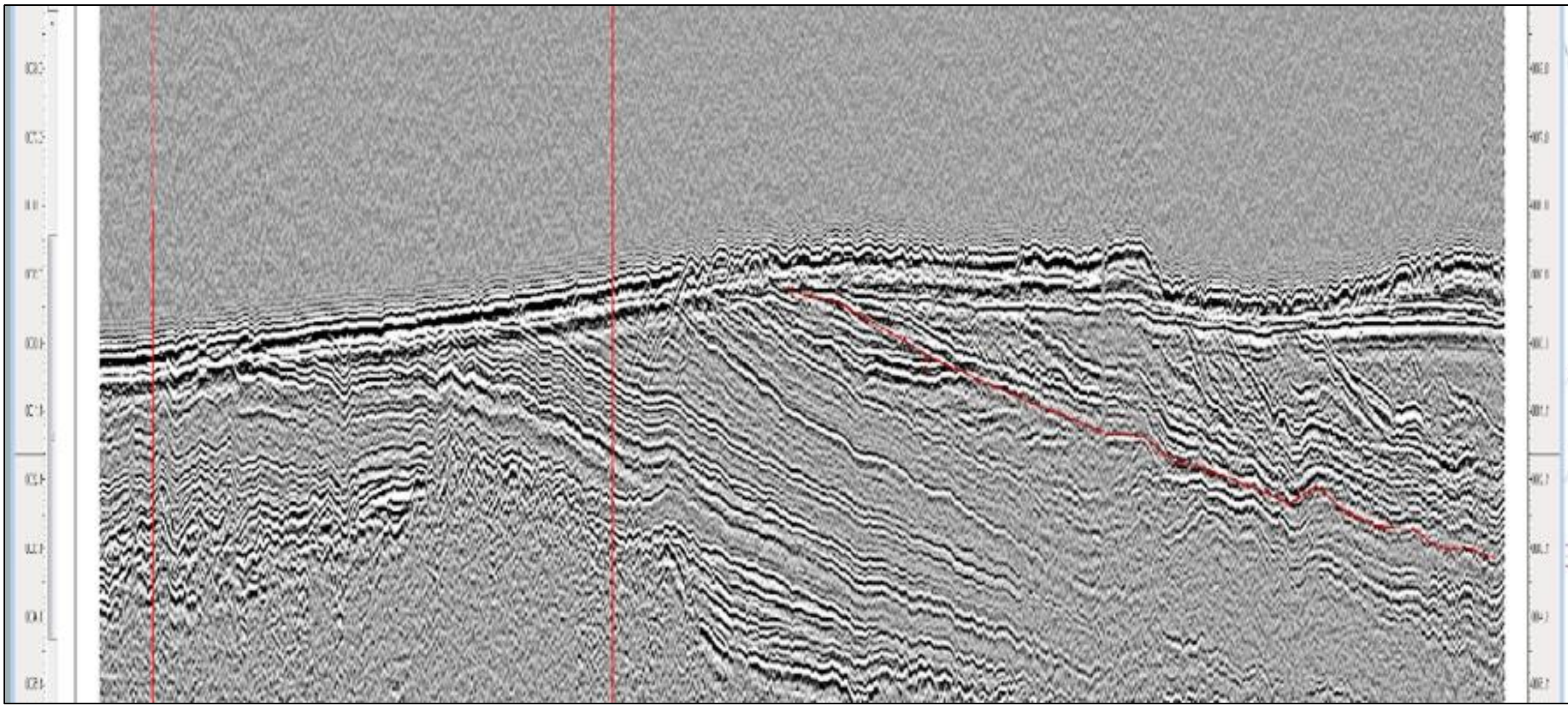
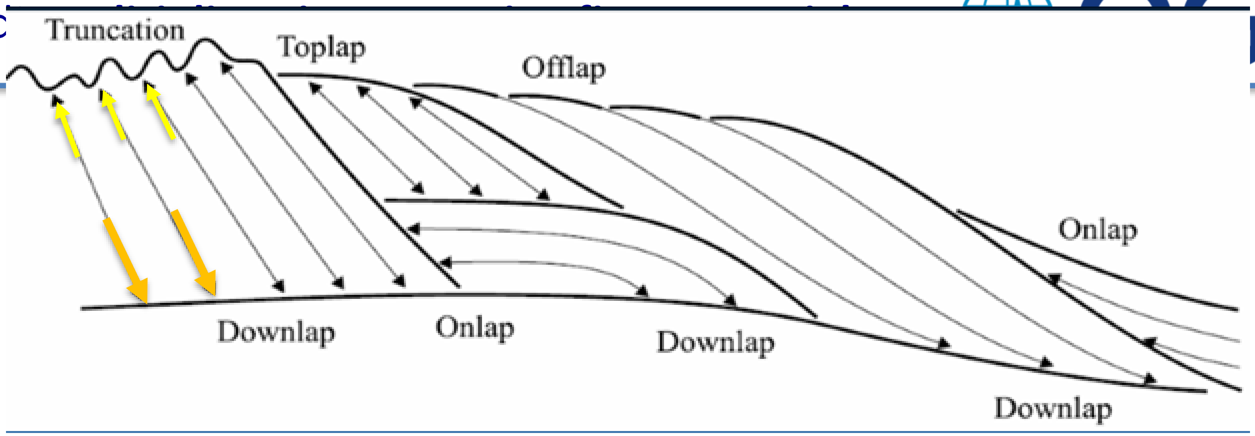


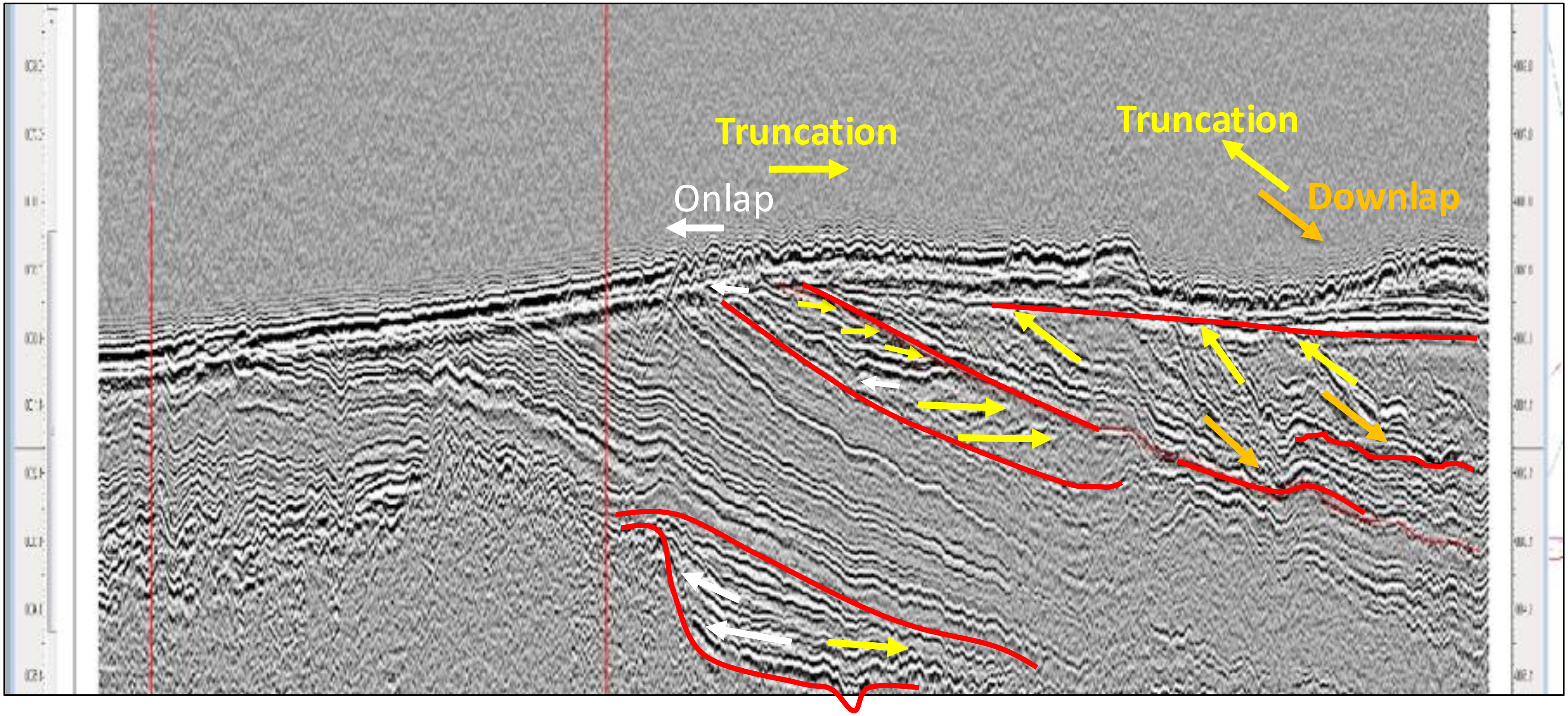
Fig.3. Cartoon of the likely configuration of the ice stream, till delta, and ice shelf.

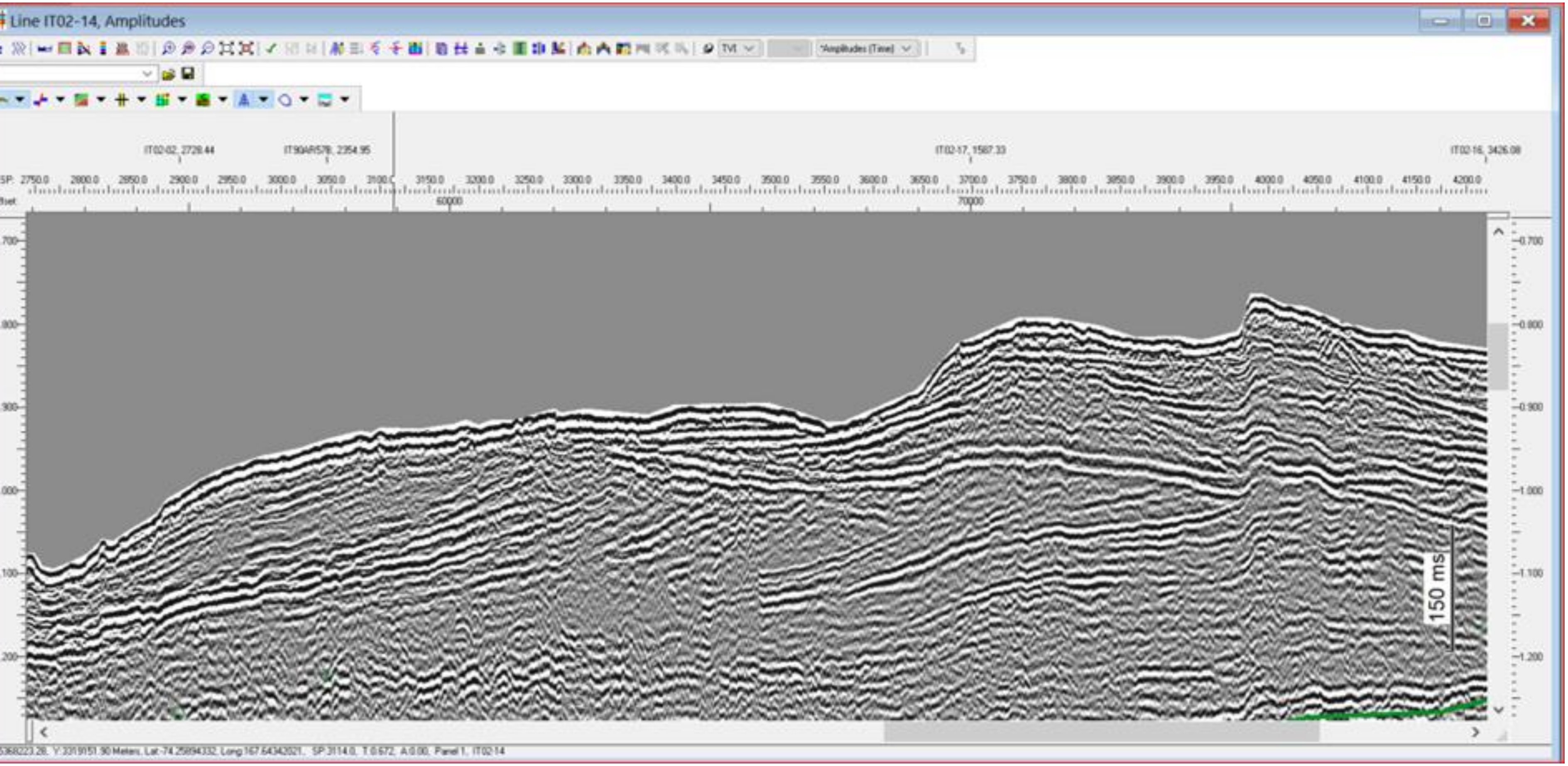

Truncation
Toplap
Offlap
Onlap
Downlap
Onlap
Downlap
Downlap

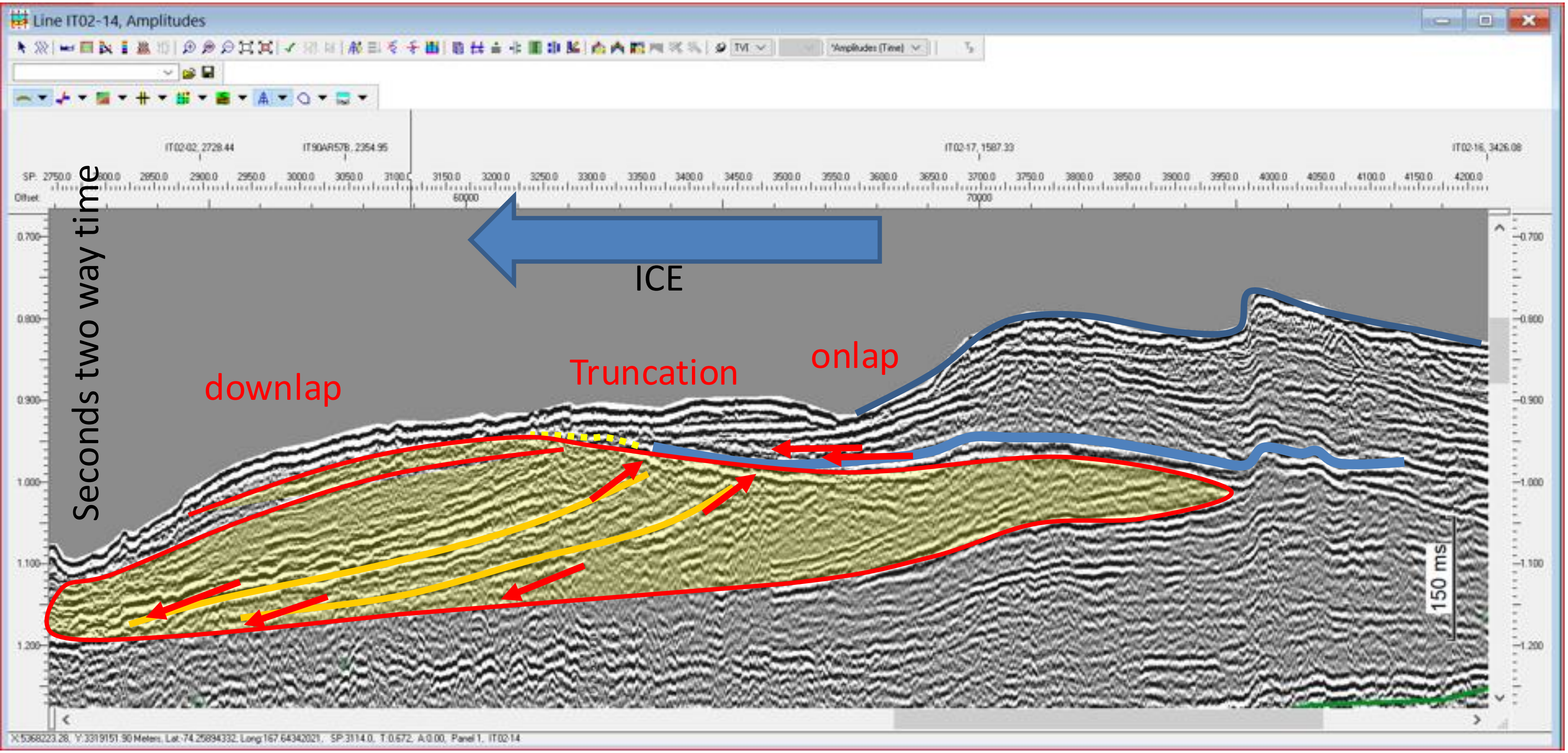


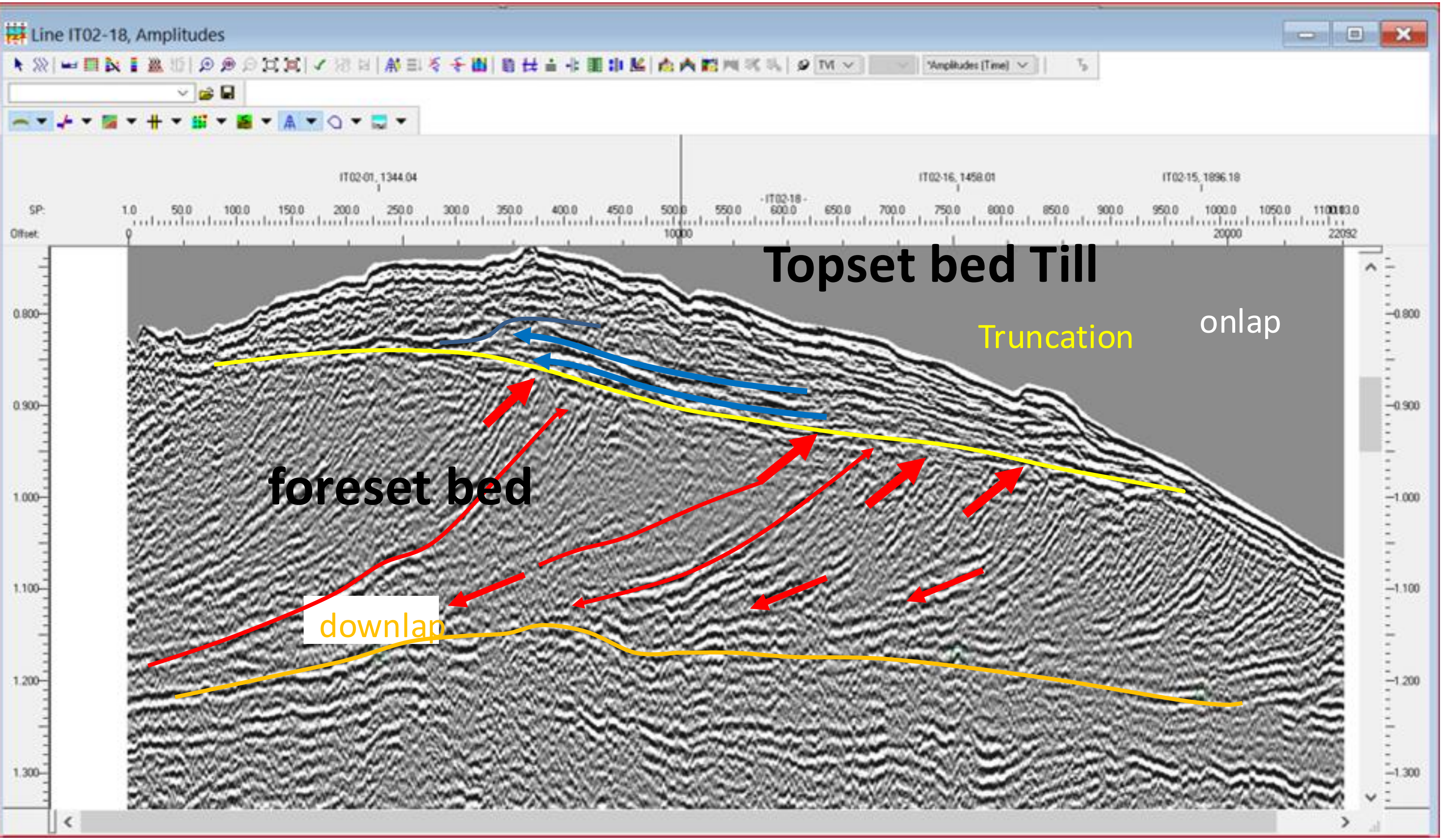
Istituto Nazionale
di Oceanografia
e di Geofisica
Sperimentale

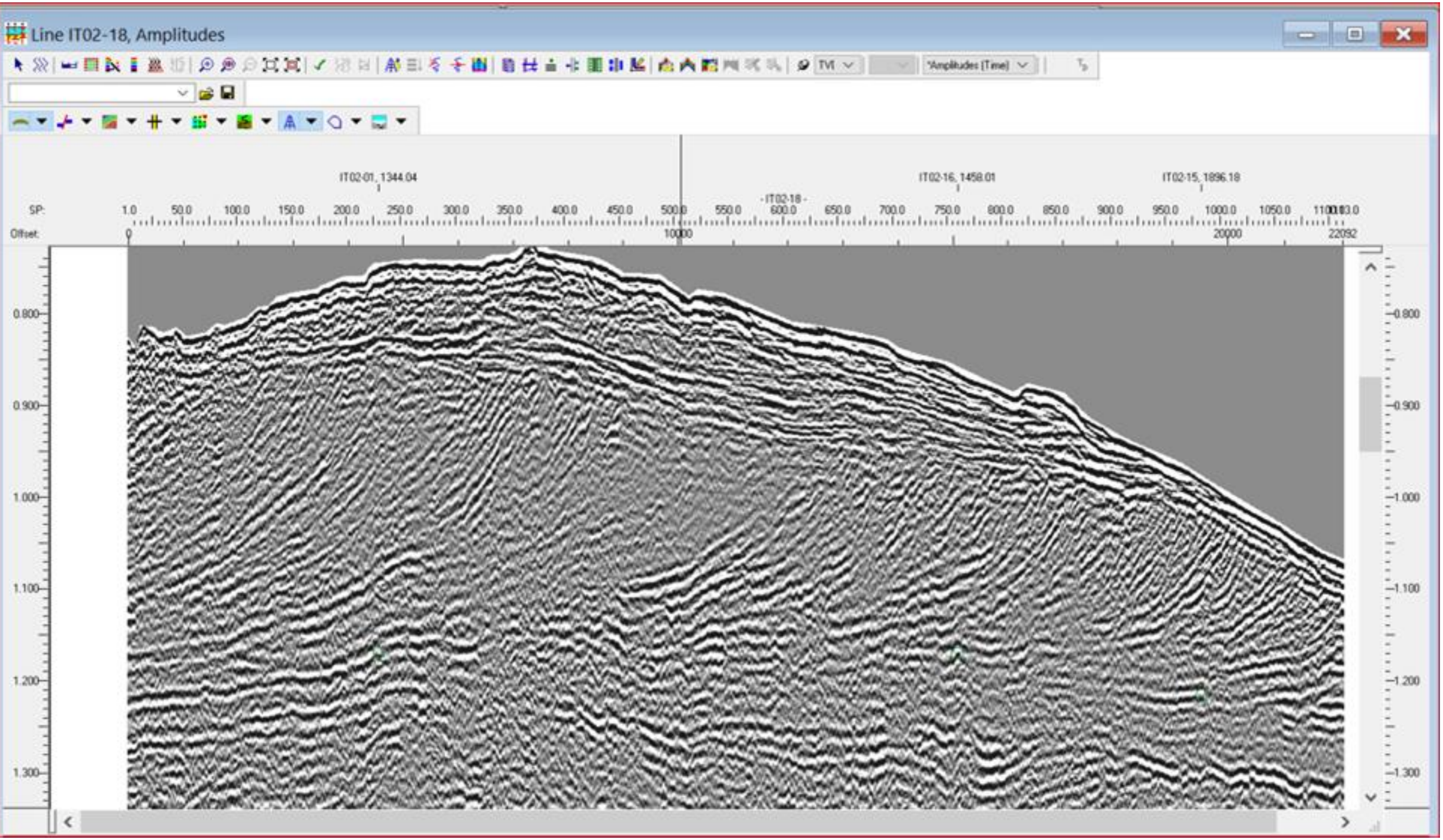


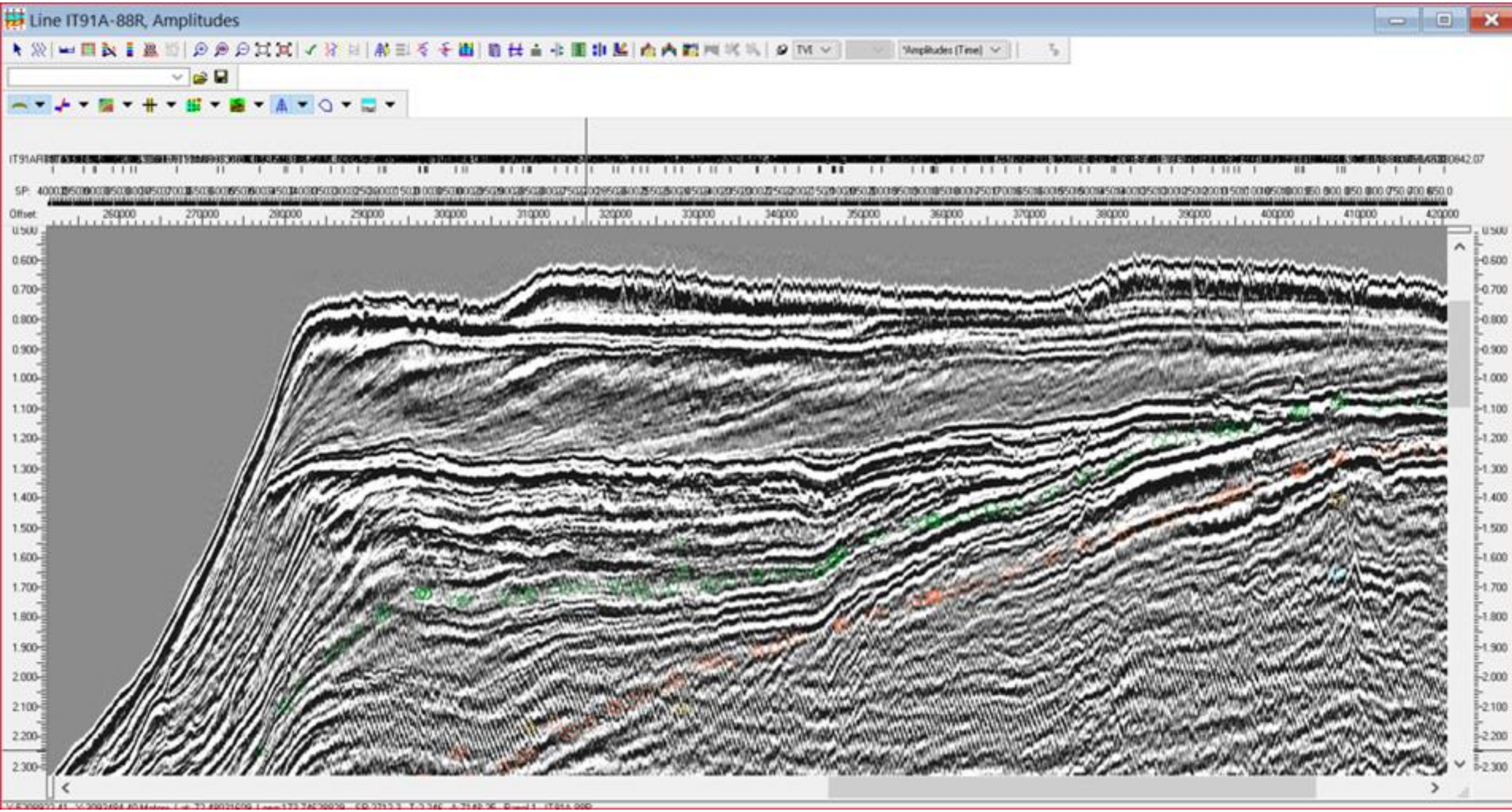



Line IT02-14, Amplitudes
150 ms

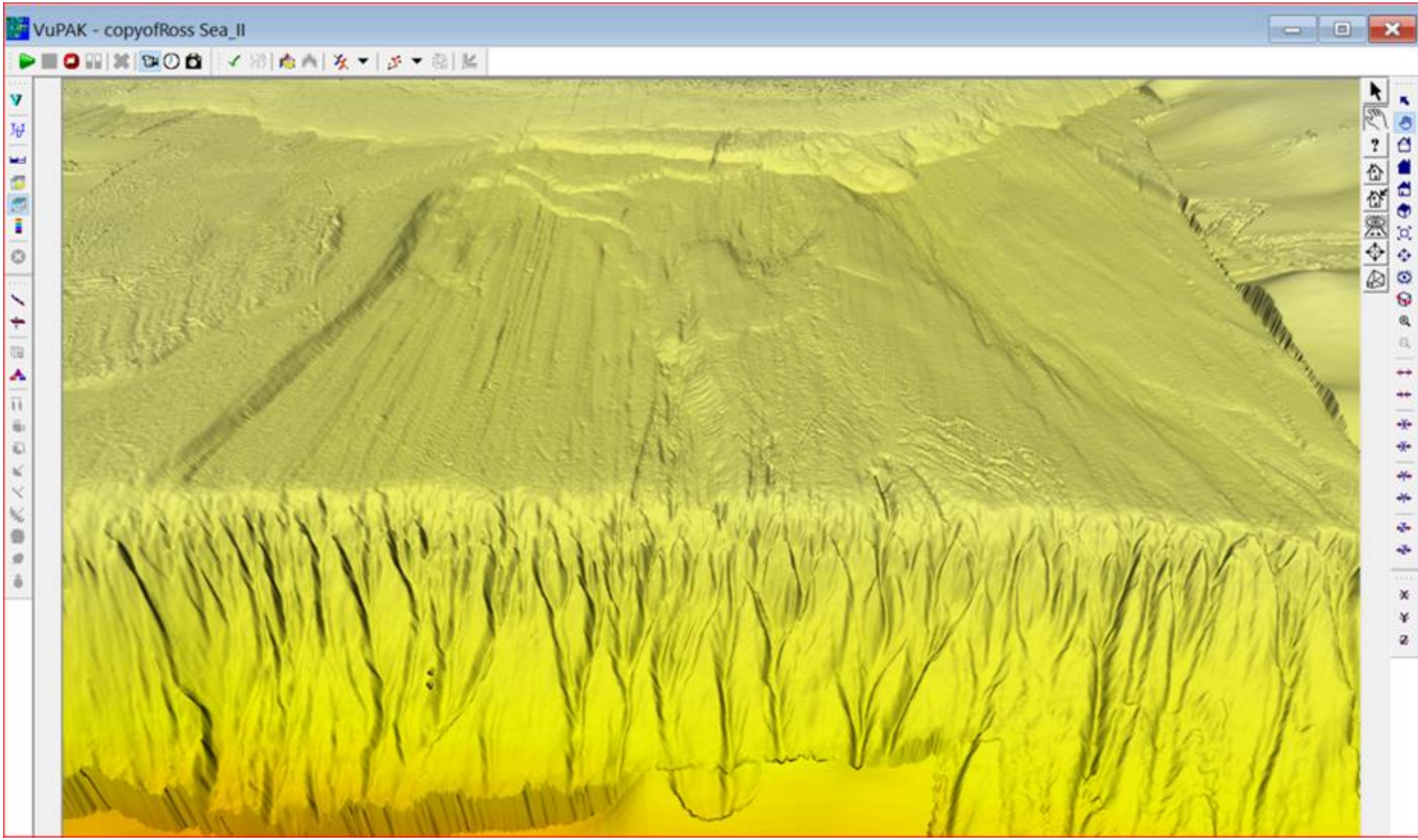

Line IT02-14, Amplitudes
Seconds two way time
ICE
downlap
Truncation
onlap
150 ms


Line IT02-18, Amplitudes
Topset bed Till
Truncation
onlap
foreset bed
downlap

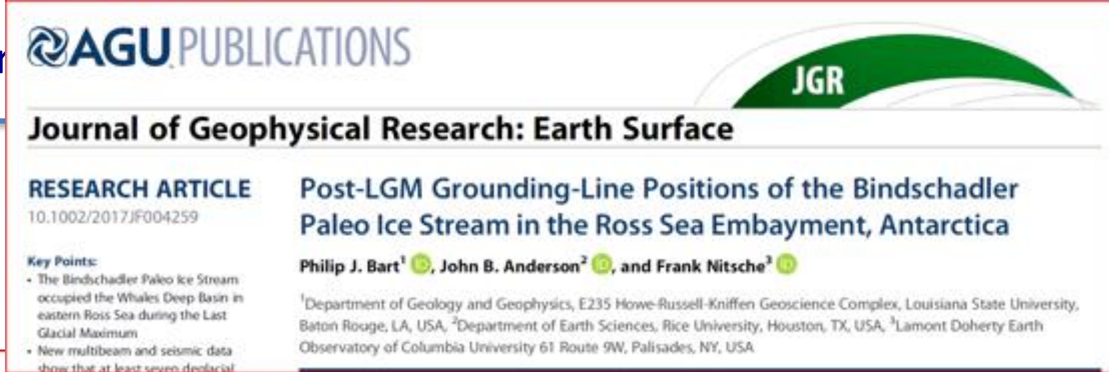

Line IT02-18, Amplitudes
IT02-01, 1344.04
IT02-16, 1458.01
IT02-15, 1896.18
- IT02-18 -
SP:
Offset:
0.800
0.900
1.000
1.100
1.200
1.300


Line IT91A-88R, Amplitudes
Amplitudes (Time)
SP
Offset
260000
270000
280000
290000
300000
310000
320000
330000
340000
350000
360000
370000
380000
390000
400000
410000
420000
0.600
0.700
0.800
0.900
1.000
1.100
1.200
1.300
1.400
1.500
1.600
1.700
1.800
1.900
2.000
2.100
2.200
2.300

EXERCIZE


VuPAK - copyofRoss Sea_II

Cor



AGU PUBLICATIONS

JGR

Journal of Geophysical Research: Earth Surface

RESEARCH ARTICLE

10.1002/2017JF004259

Key Points:

- The Bindschadler Paleo Ice Stream occupied the Whales Deep Basin in eastern Ross Sea during the Last Glacial Maximum
- New multibeam and seismic data show that at least seven deglacial

Post-LGM Grounding-Line Positions of the Bindschadler Paleo Ice Stream in the Ross Sea Embayment, Antarctica

Philip J. Bart[1], John B. Anderson[2], and Frank Nitsche[3]

[1]Department of Geology and Geophysics, E235 Howe-Russell-Kniffen Geoscience Complex, Louisiana State University, Baton Rouge, LA, USA, [2]Department of Earth Sciences, Rice University, Houston, TX, USA, [3]Lamont Doherty Earth Observatory of Columbia University 61 Route 9W, Palisades, NY, USA