Università degli studi di Trieste

LAUREA MAGISTRALE IN GEOSCIENZE

Classe Scienze e Tecnologie Geologiche

Curriculum: Esplorazione Geologica

Anno accademico 2022 - 2023

Analisi di Bacino e Stratigrafia Sequenziale (426SM)

Docente: **Michele Rebesco**

Unit	Topic	Teacher	Date
1.1	Introduction to the course	Rebesco	03/10/22
1.2	Methods (geophysics, but not only)	Volpi/Rebesco	06/10/22
6.1	Visit to the icebreaker Laura Bassi (along with Geologia Marina)	Rebesco	10/10/22
1.3	Mechanisms of basin formation (geodynamics, tectonics…)	Lodolo	13/10/22
1.4	Seismic interpretation, facies and primary structures	Rebesco	17/10/22
	No lesson: 20th October		
2.1	Sedimentary processes in river & deltas	Rebesco	24/10/22
	No lesson: 27th		
2.2	Action of tides and waves, wind and ice	Rebesco	31/10/22
	No lesson: 3rd November		
2.3	Density currents, bottom currents and mass transport	Lucchi/Rebesco	07/11/22
1.5	Energy storage & CCUS	Volpi/Donda	10/10/22
3.1	Alluvial deposits, lakes and deserts	Rebesco	11/11/22
	No lesson: 14th November		
3.2	Barrier systems and incised valleys	Rebesco	17/11/22
3.3	Continental shelves (wases, storms, tsunamis)	Rebesco	21/11/22
3.4	Mass transport deposits	Ford	24/11/22
3.5	Abyssal plains (hemipelagic fallout) and continental margins	Rebesco	28/11/22
3.6	Submarine fans (gravity flows on the continental slope)	Lucchi	01/12/22
3.7	Sediment drifts (bottom currents along the continental slope)	Rebesco	05/12/22
	No lesson on Thursday 8 th December		
3.8	Glacial depositional systems	De Santis	12/12/22
3.9	Carbonatic environments, faults, volcans	Rebesco	15/12/22
4.1	Sequence stratigraphy: introduction	Rebesco	19/12/22
4.2	Sequence stratigraphy: closer view	Rebesco	22/12/??
	No lessons from 23 rd December to 8 th January		
4.2	Sequence stratigraphy: closer view	Rebesco	09/01/??
4.3	Sequence stratigraphy: applications (e.g. hydrocarbon reservoirs)	Rebesco	12/01/23
5	Excercise	Rebesco	13/01/23
6.2	Visit to OGS and SEISLAB (along with Geologia Marina)	Rebesco	20/01/23
6.3	Visit to CoreLoggingLAB (along with Geologia Marina)	Rebesco	24/02/??

Istituto Nazionale di Oceanografia e di Geofisica Sperimentale

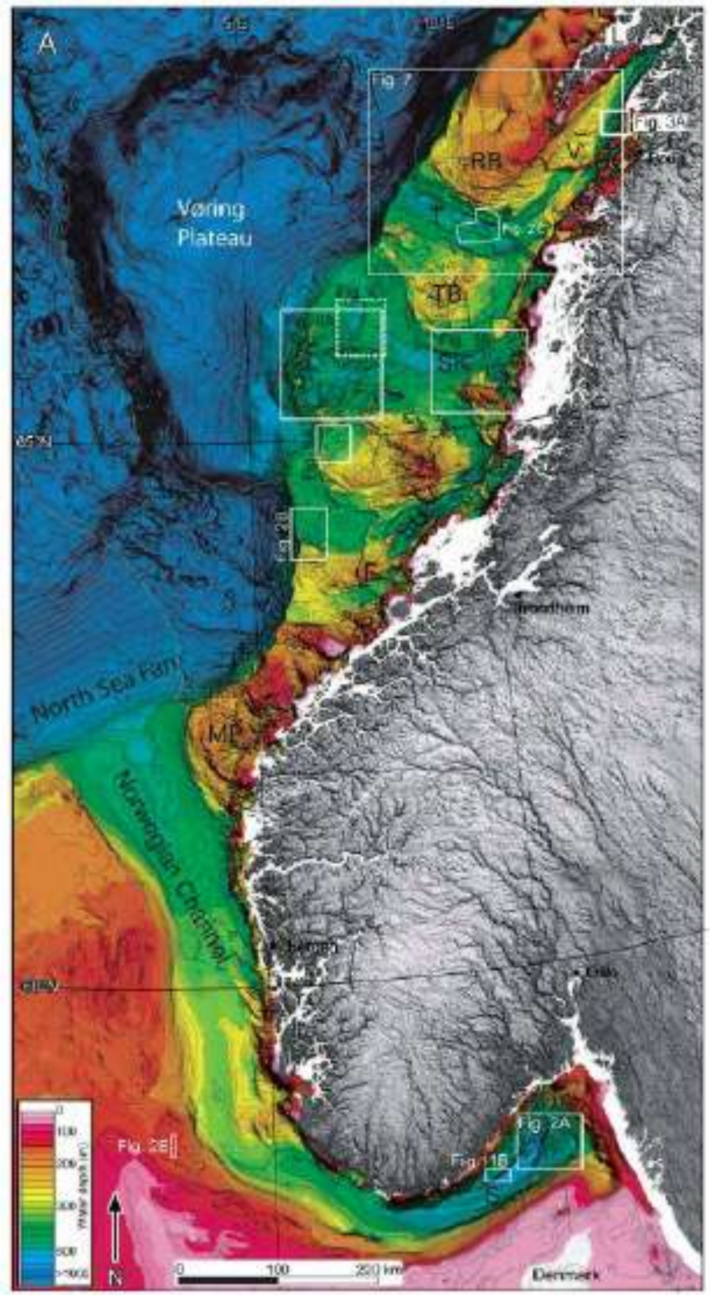
Modulo 3.8
Typical facies of depositional-erosional system in polar environment

Docente: **Laura De Santis**

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

Docente: Laura De Santis

OUTLINE



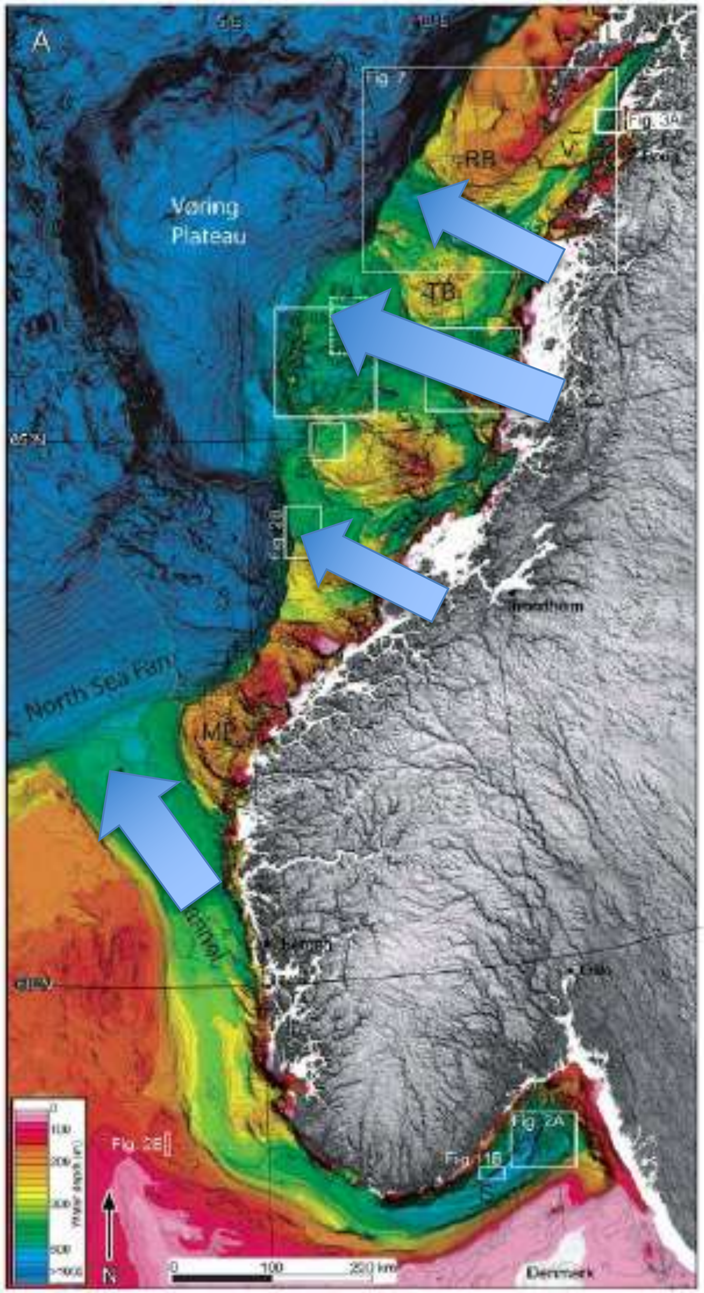
Diagnostic features

- Glacial valleys and foredeepened surfaces
- Trough/bank topography
- Trough mouth fans
- 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



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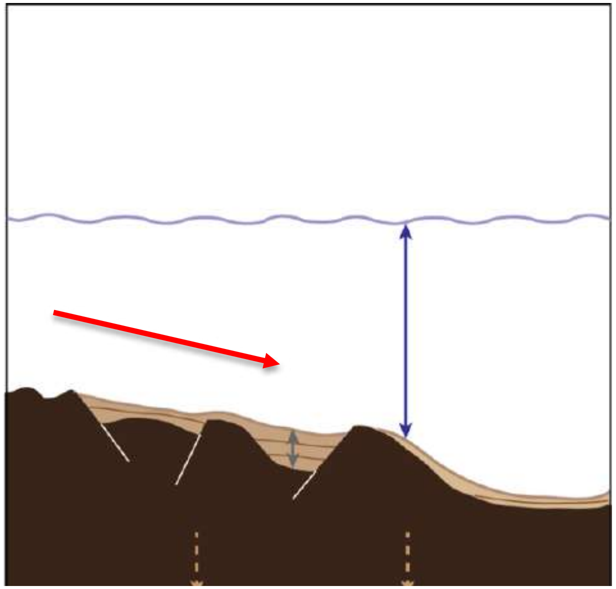
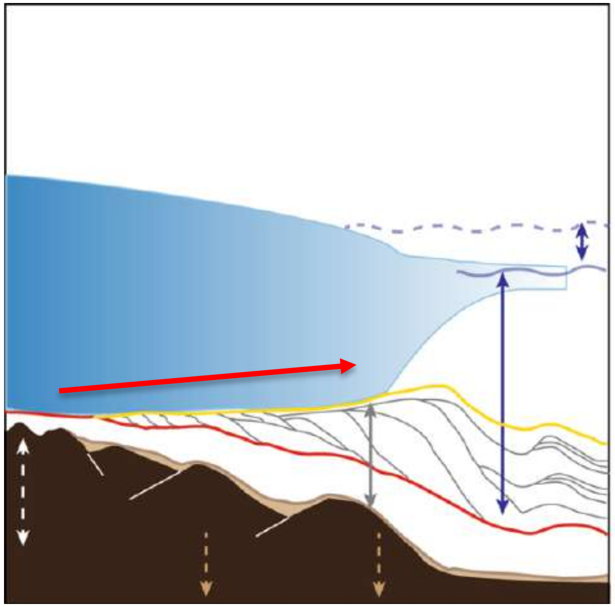
Glacial erosion and deposition => foredeepened and wide continental shelf



Typical low latitude
Seaward dipping profile



Landward dipping profile

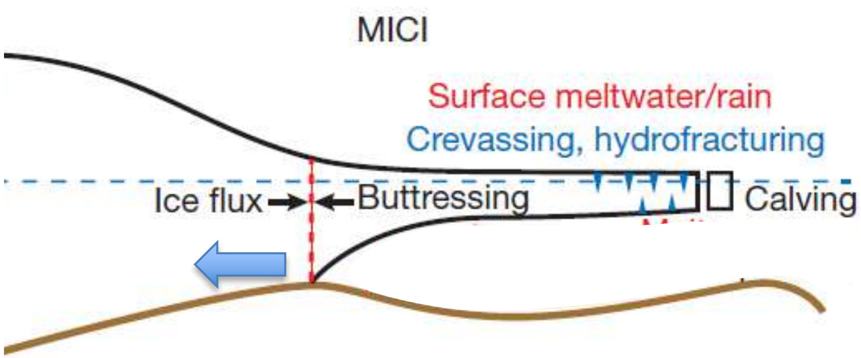
Colleoni et al., 2018

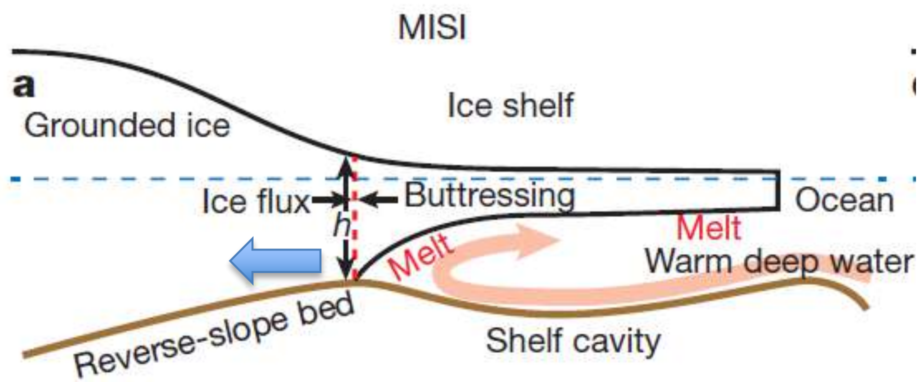
Marine Ice Cliff Instability (MICI)

Ice-shelf surfaces melting due to atmospheric warming causes thinning, crevassing and calving rates

Marine Ice Sheet Instability (MISI)

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



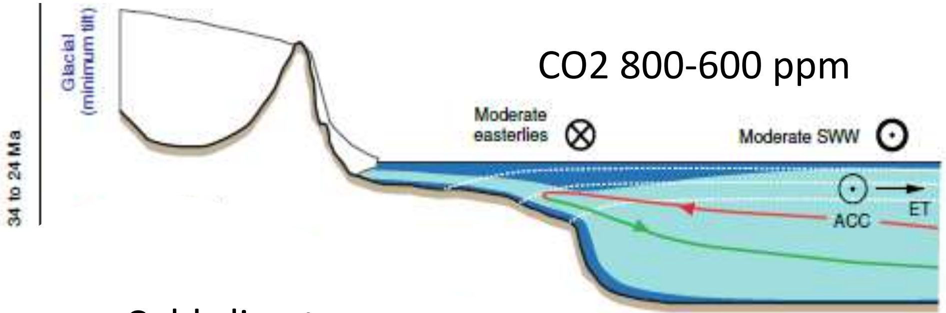


Including these processes was found to increase the previous model's contribution to Pliocene Global Mean Sea Level from +7 m to +17 m

DeConto and Pollard 2016

AIS sensitivity to ocean and climate dynamics

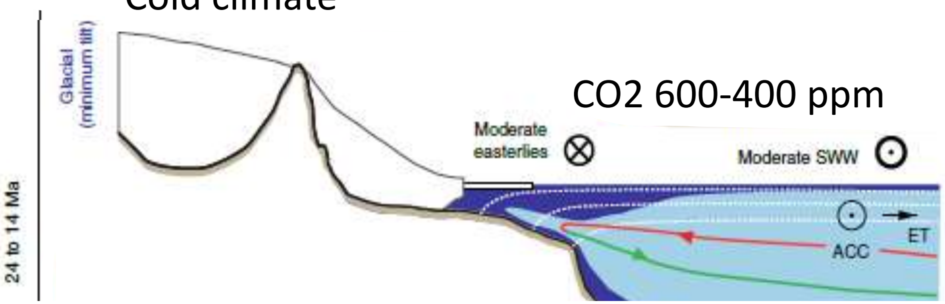
Cool climate



Levy et al., 2019

Terrestrial ice → low sensitivity to ocean warming

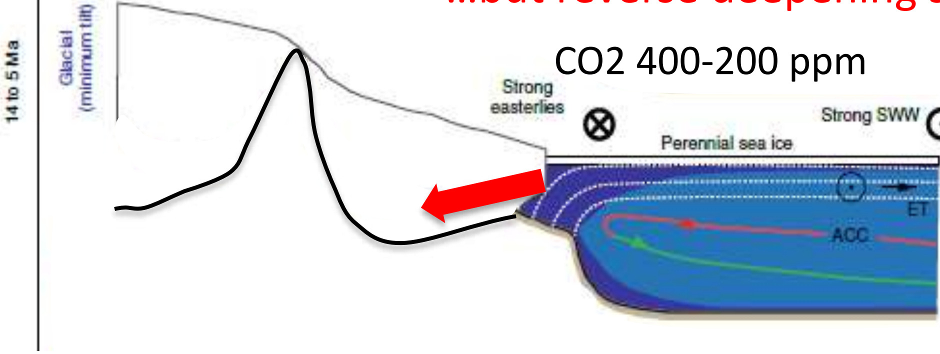
Cold climate



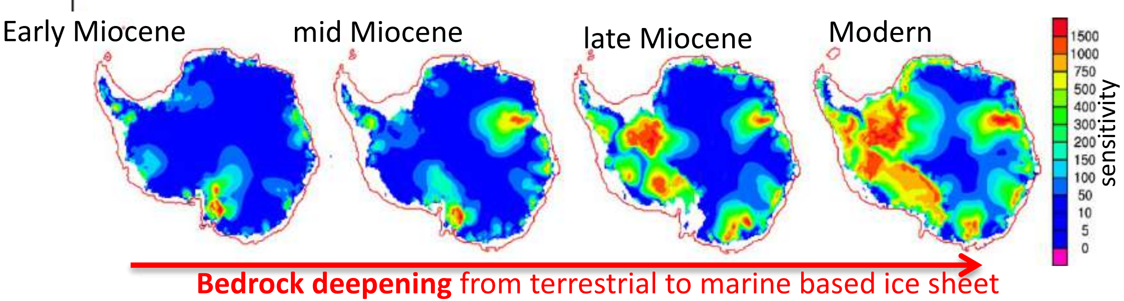
Marine ice-sheet extent → high sensitivity to ocean warming

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



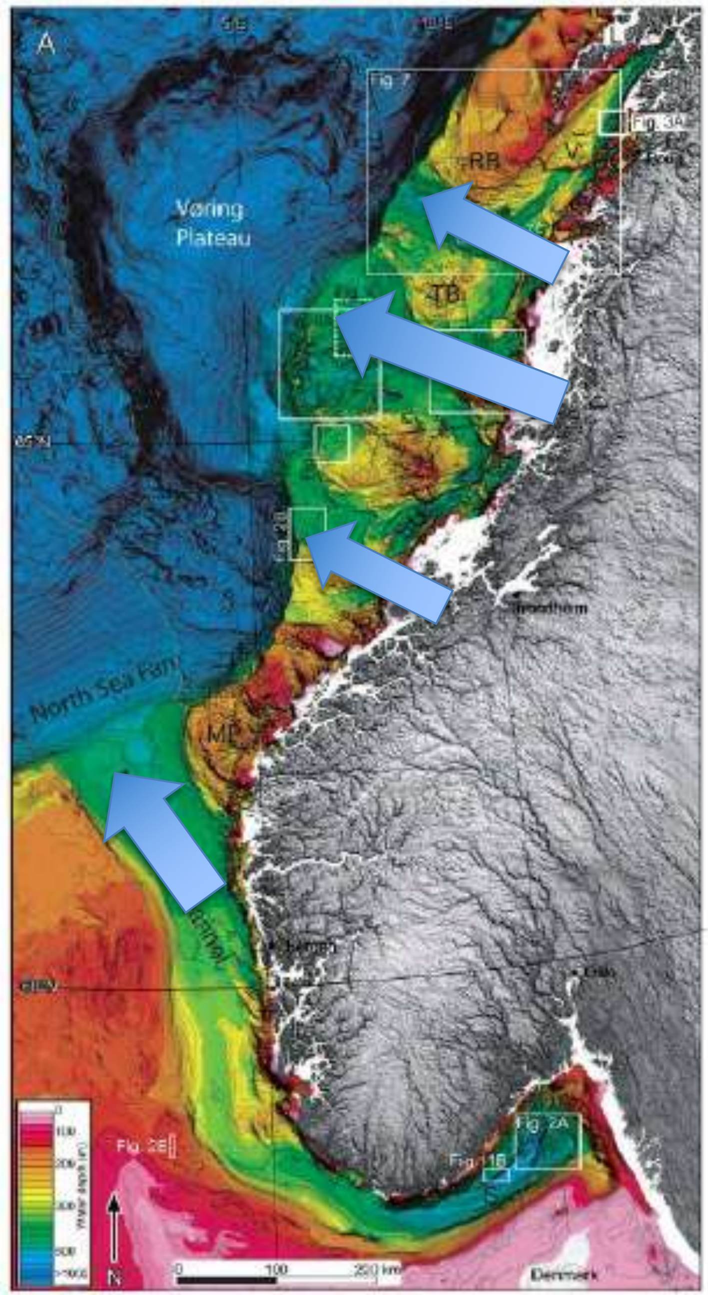
Colleoni, F., et al. 2018

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

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

Docente: Laura De Santis

OUTLINE



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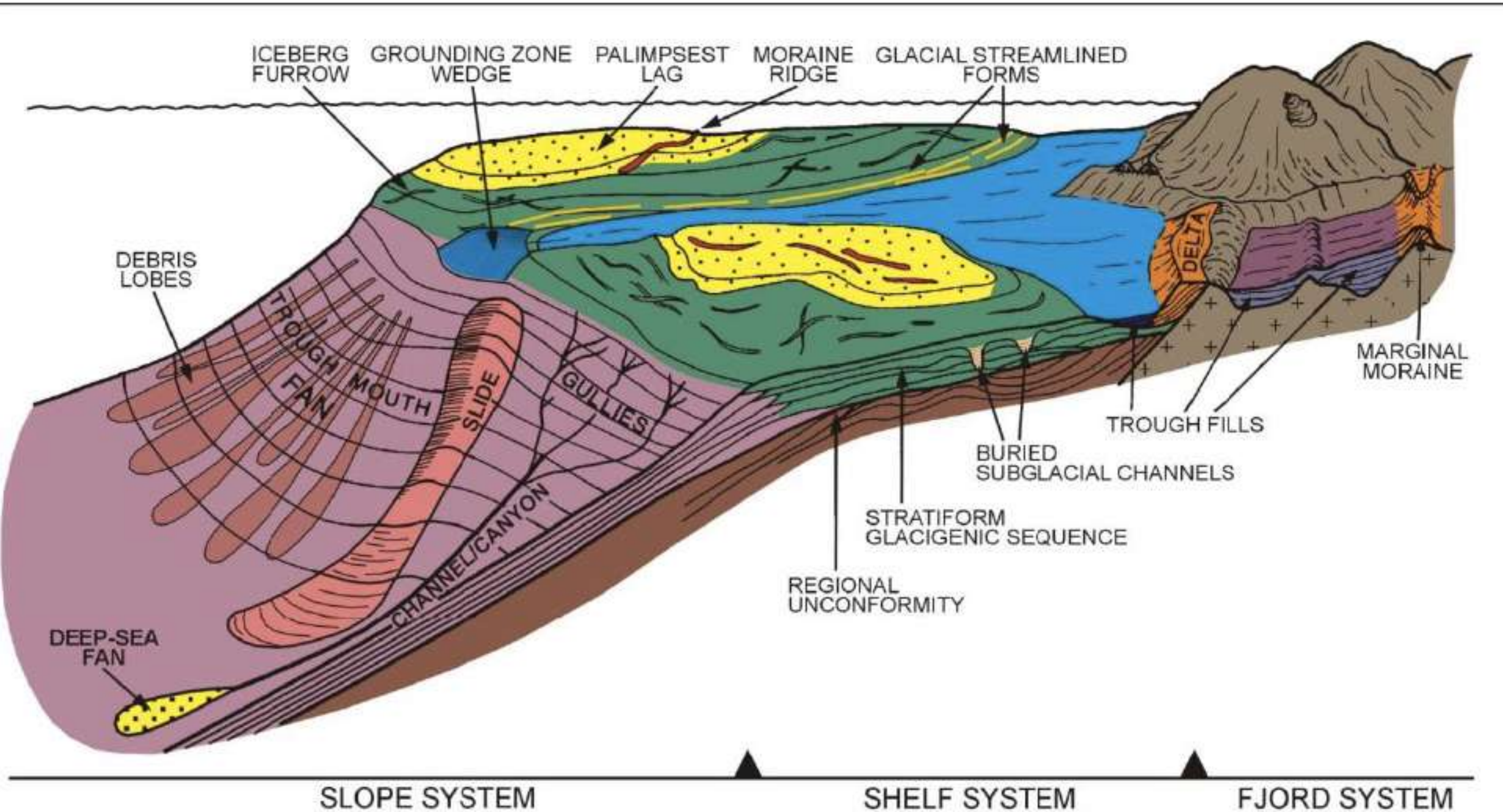
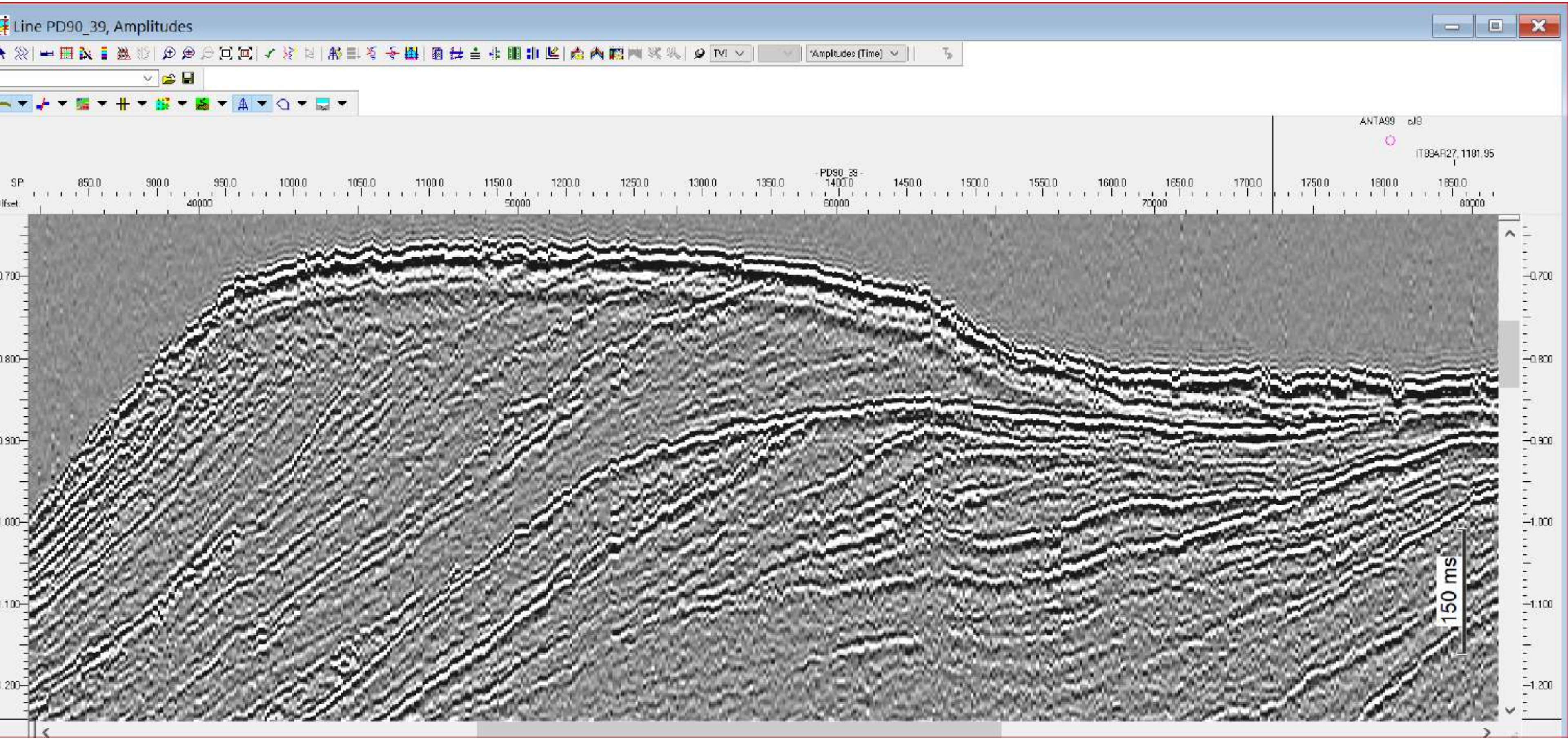
- Trough mouth fans
- Ice grounding zone wedge
- Glacial lineations, outwash channels

Trough/bank topography Trough mouth fans

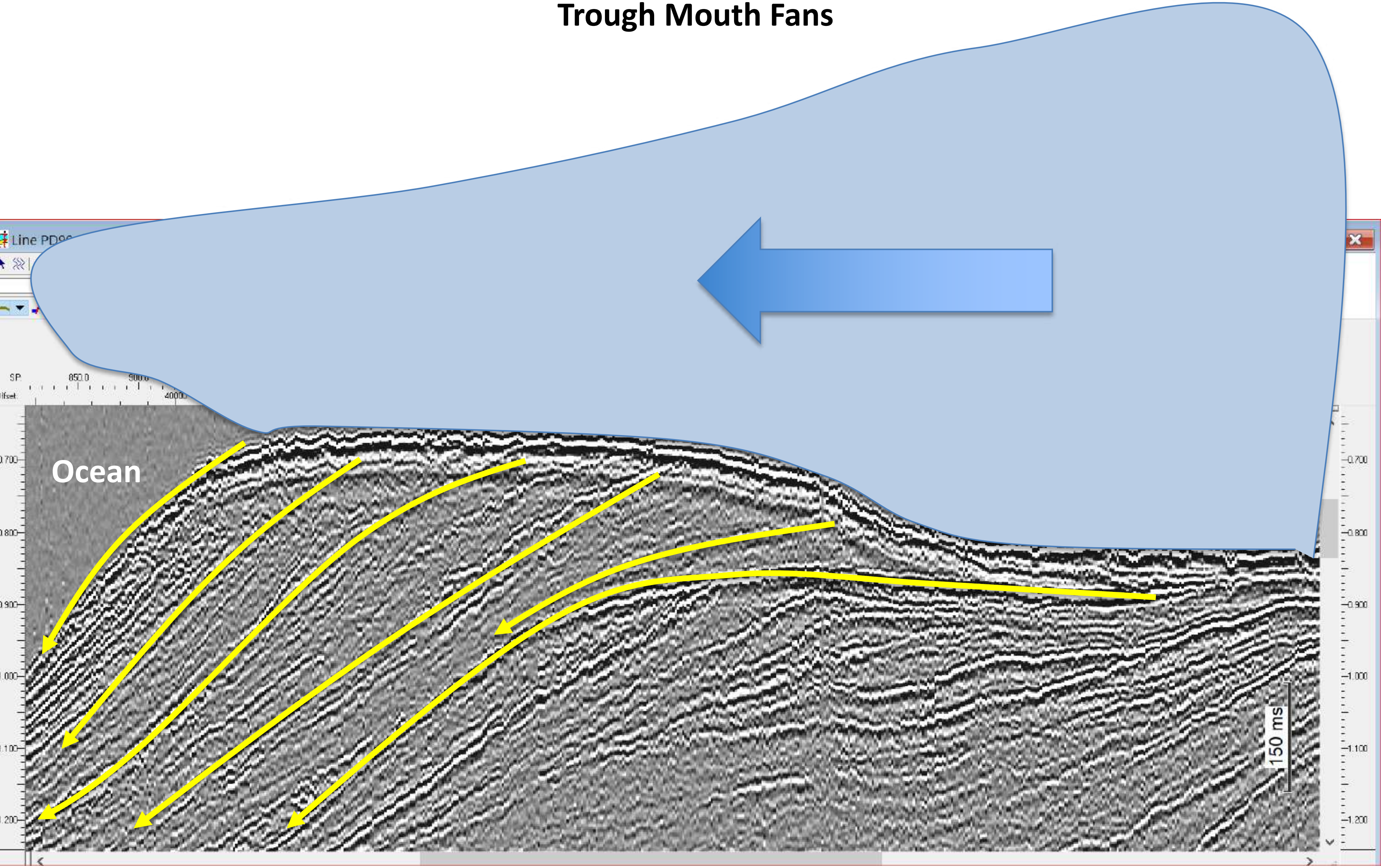


Vorren, 2003

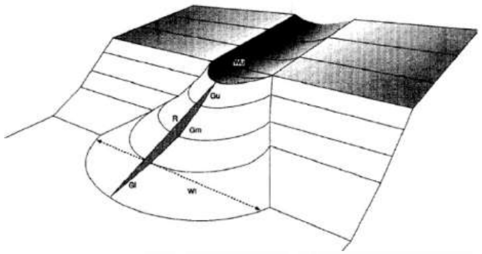
Trough Mouth Fans



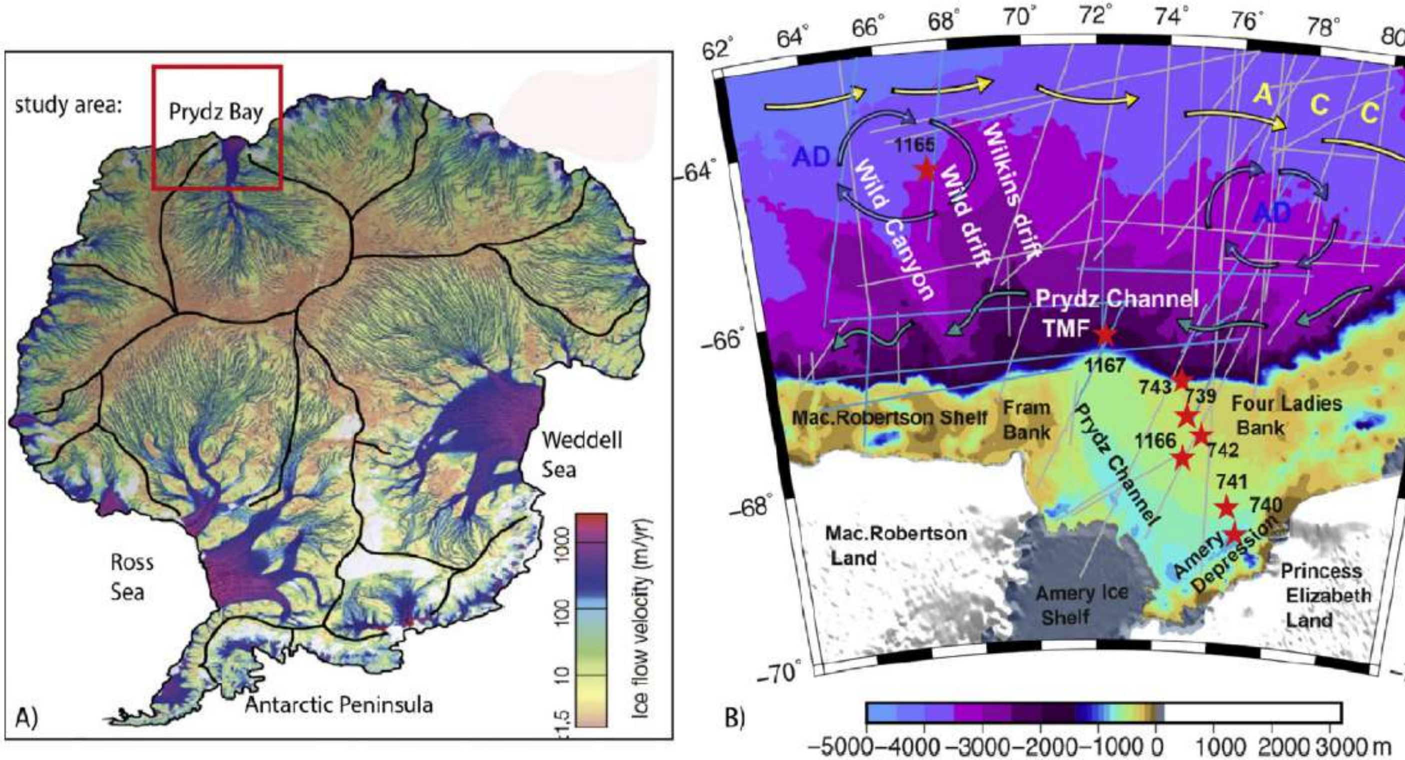
Trough Mouth Fans



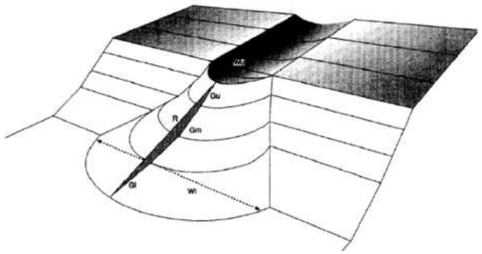
Trough/bank topography
Trough mouth fans

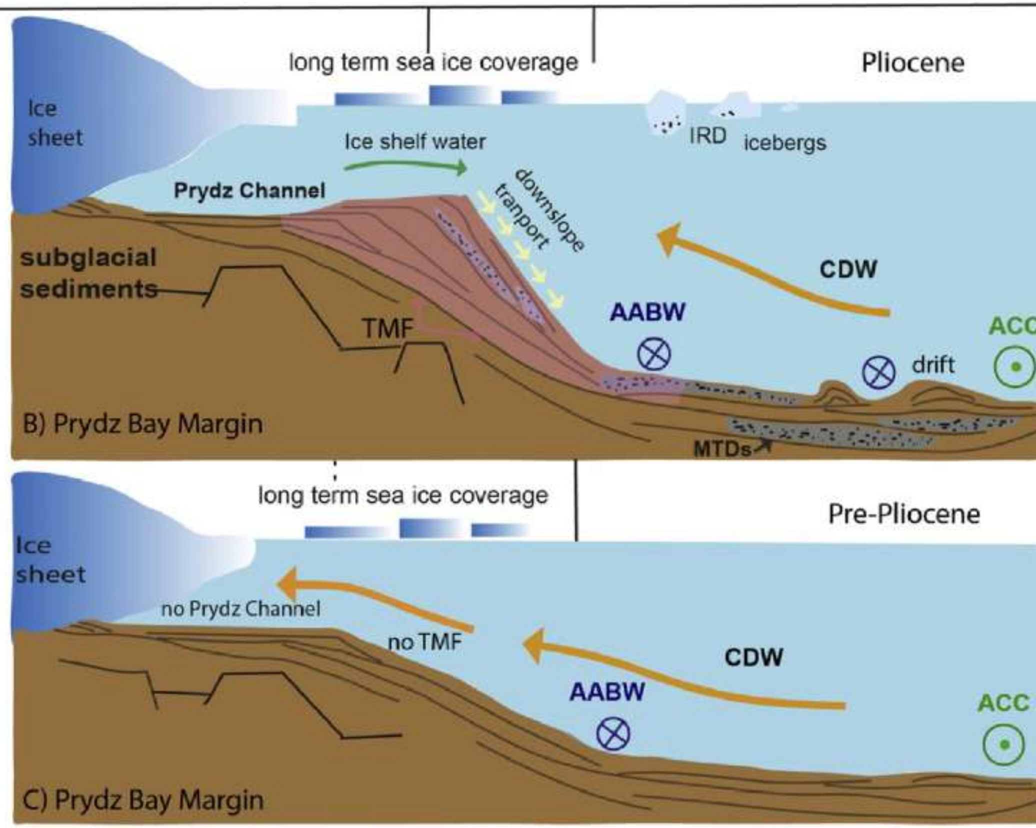


X. Huang, et al. Marine Geology 430 (2020) 106339

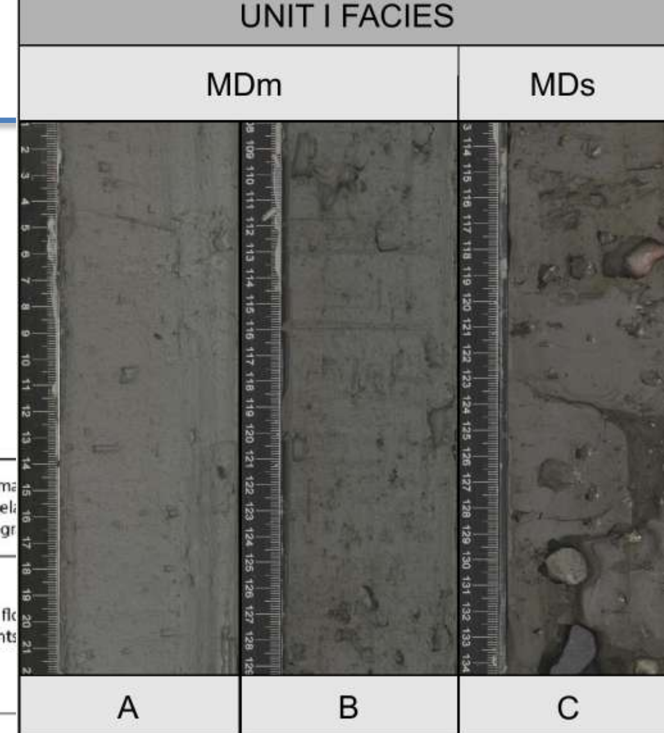


Trough/bank topography
Trough mouth fans



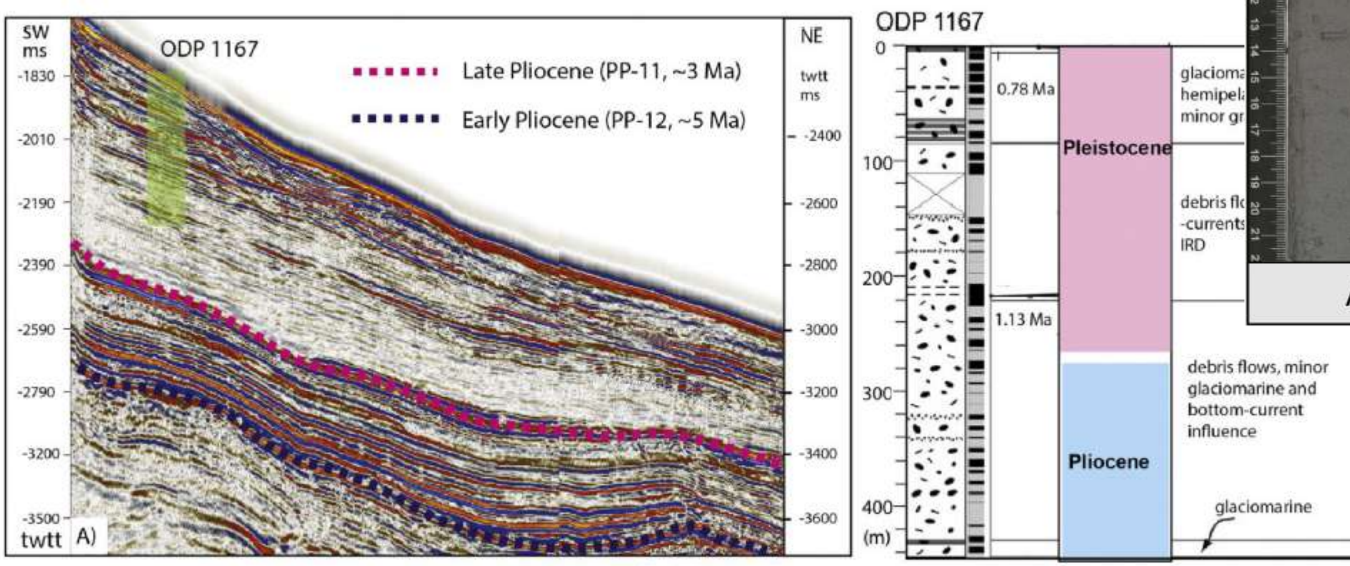
Prydz Bay Margin		Late Pliocene to present
Prydz Bay Margin: Shelf width: ~250 km (wide), the shelf edge prograded ~27 km from the early Pliocene to the present; Slope gradient: < 2°; Prydz Channel formed during the Early Pliocene; Large glacial system advances and retreats during Pliocene.		Late Pliocene to present: On the continental rise, the presence of drifts formed by AABW and CDW (Fig. 8) Early to Late Pliocene: On the slope, episodic MTDs and other gravity flow dominated (Fig. 6); TMF grew during the Pliocene (Fig. 5); The onset of Prydz Channel TMF occurred in the Early Pliocene.
Pre-Pliocene: Shelf width: (~ 223 km) No Prydz Channel exist		No TMF and Prydz Channel

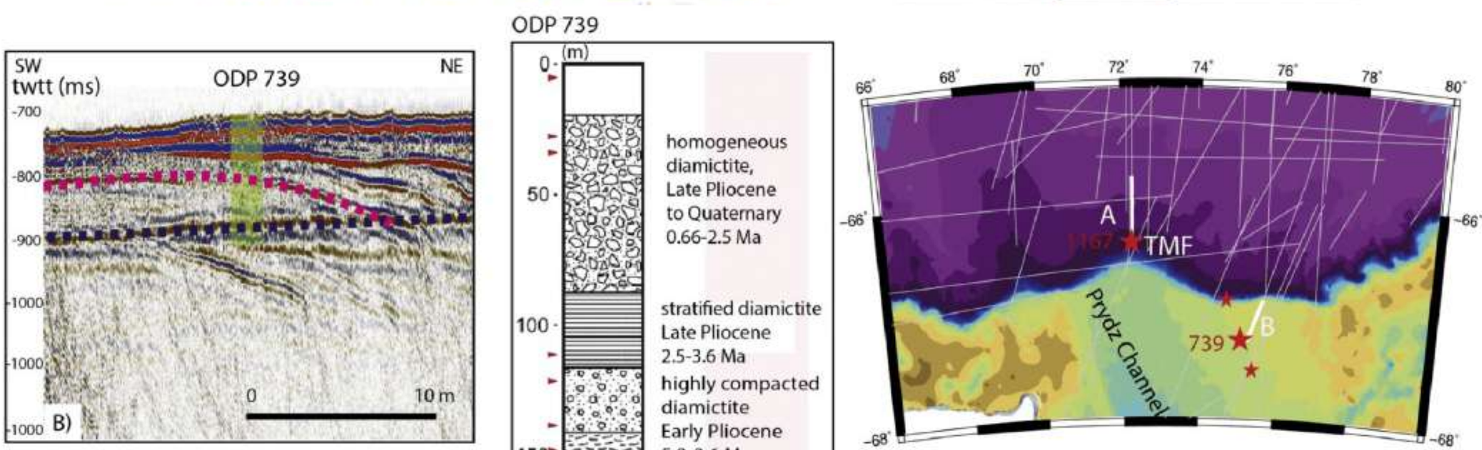
Huang et al., 2020



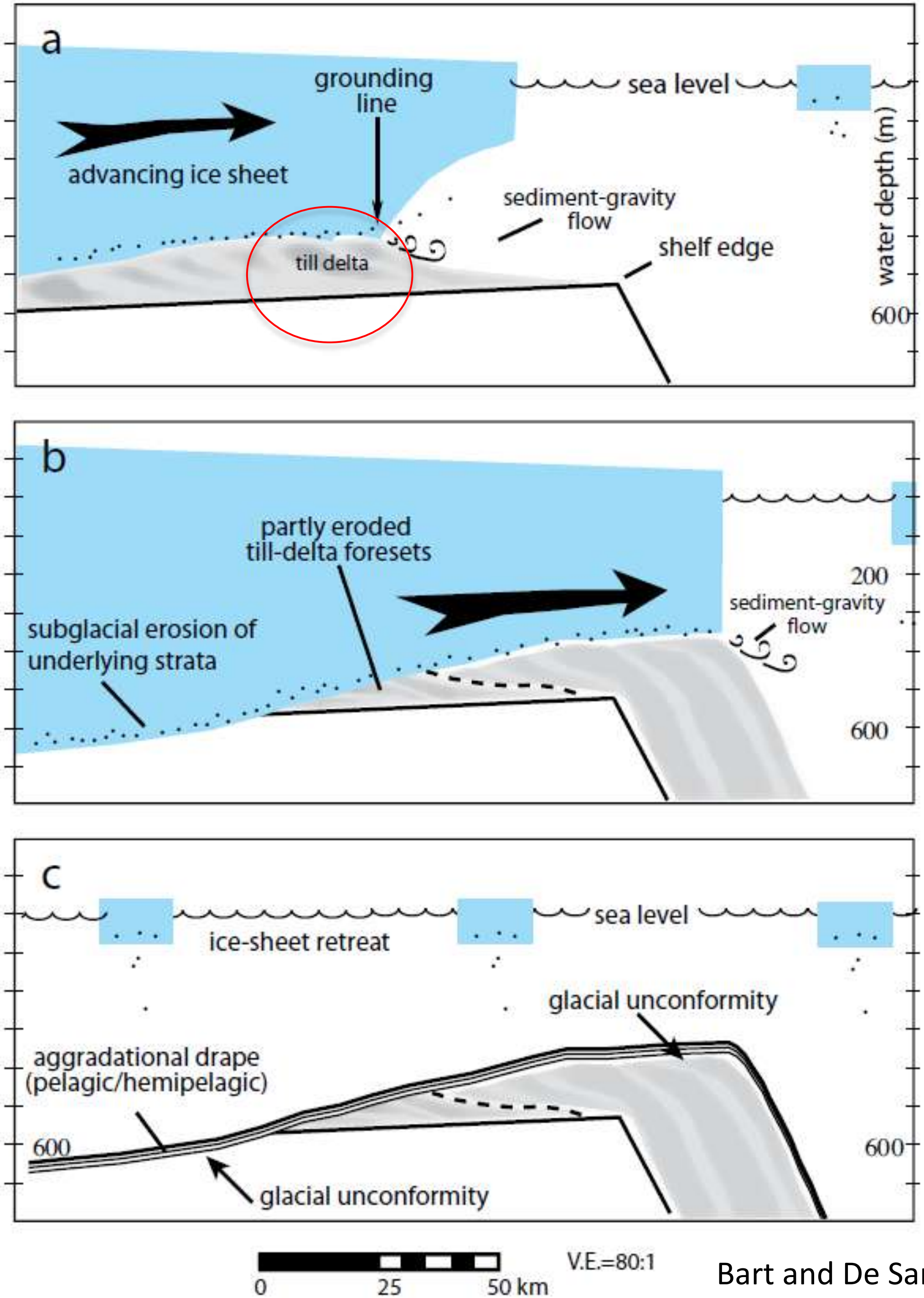
mud (55%) sand (32%) gravel (13%)
Ross Sea IODP U1525 unit I (King et al., 2021)

Huang et al., 2020

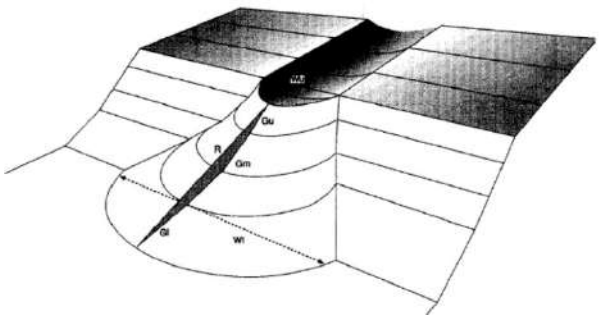




Ross Sea AND-2 (Mckay et al. 2009 GSA Bull.)



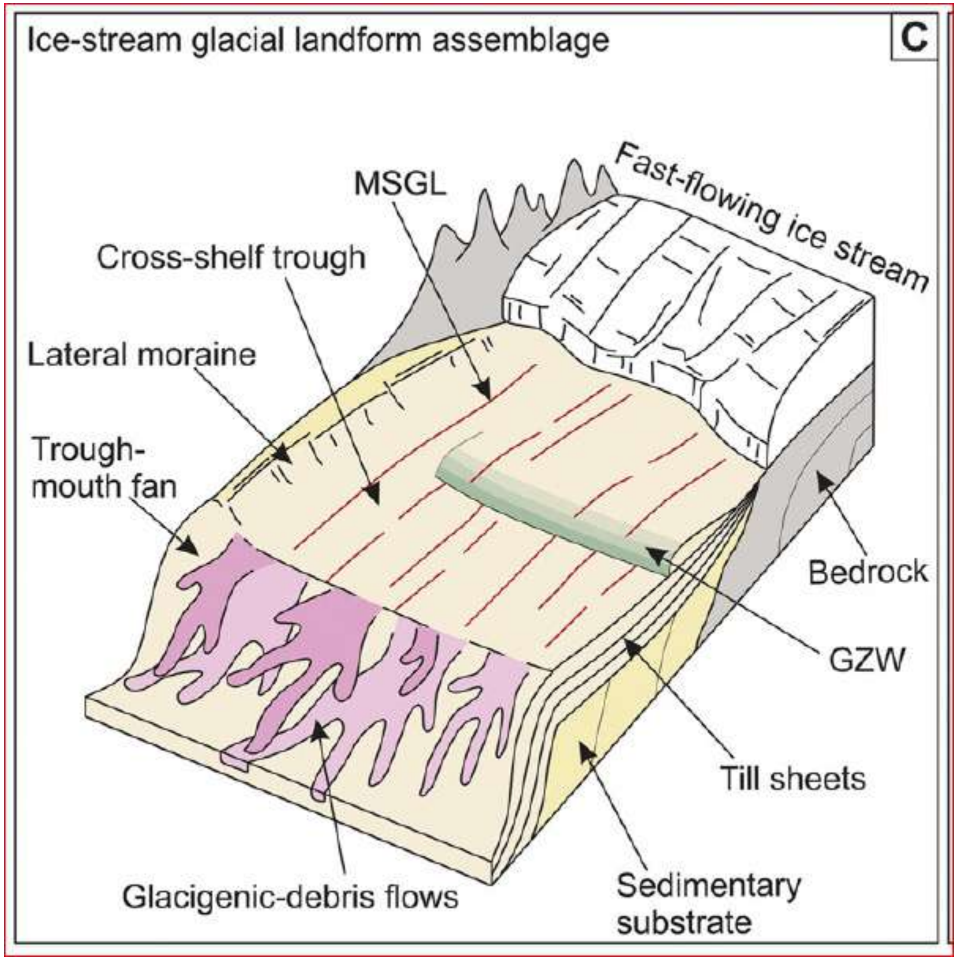
- Trough-mouth fans
- Till delta



Bart and De Santis 2012

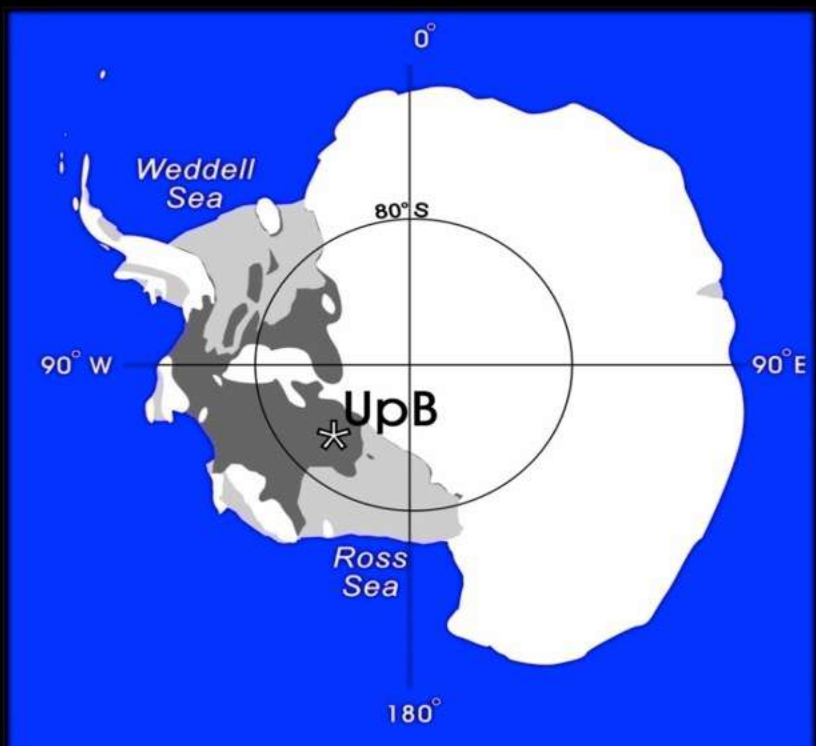
Diagnostic features

- Glacial valleys and foredeepened surfaces
- Trough/bank topography
- Trough mouth fans
- Ice grounding zone wedge (GZW)
- Glacial lineations
- Outwash channels



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.

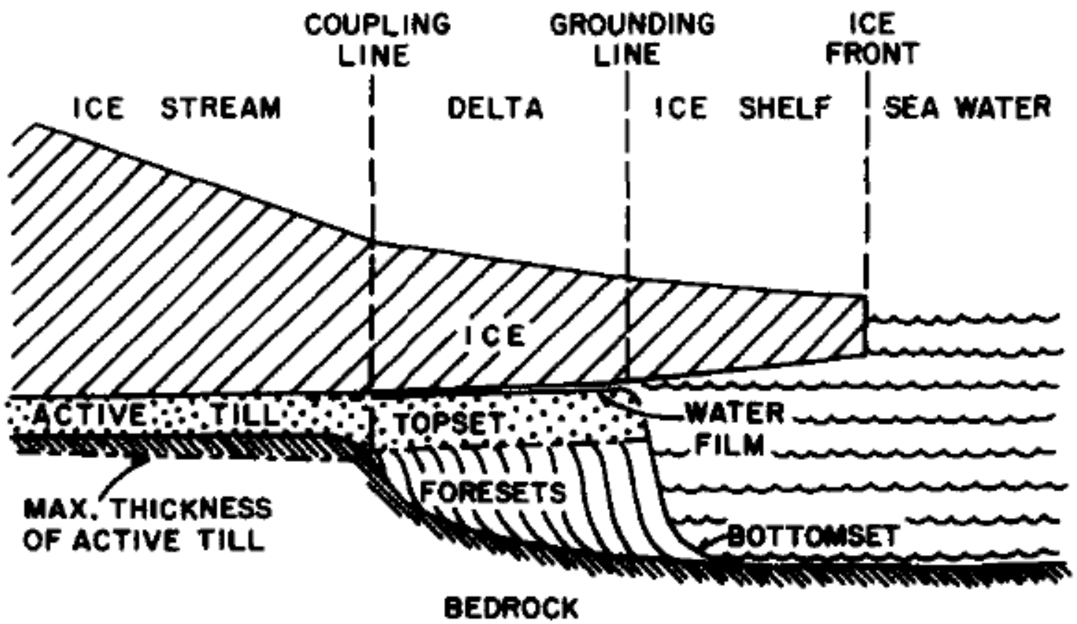


Fig.3. Cartoon of the likely configuration of the ice stream, till delta, and ice shelf.

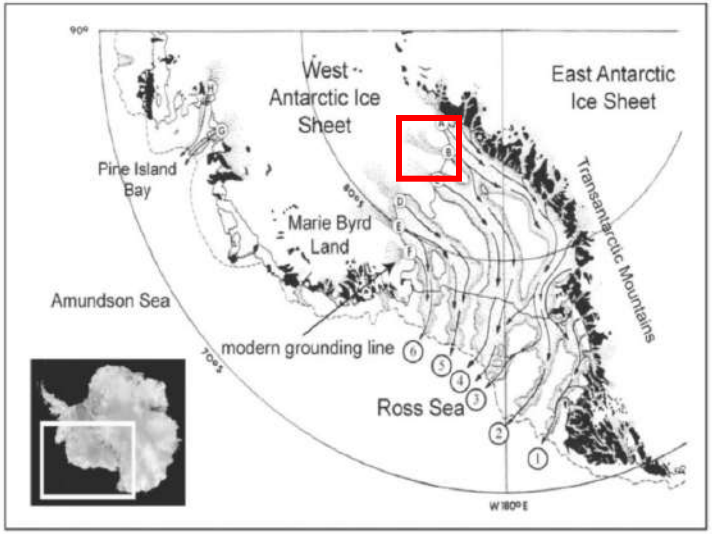
Discovery of a 6 m-thick layer of deforming till beneath the Whillans Ice Stream

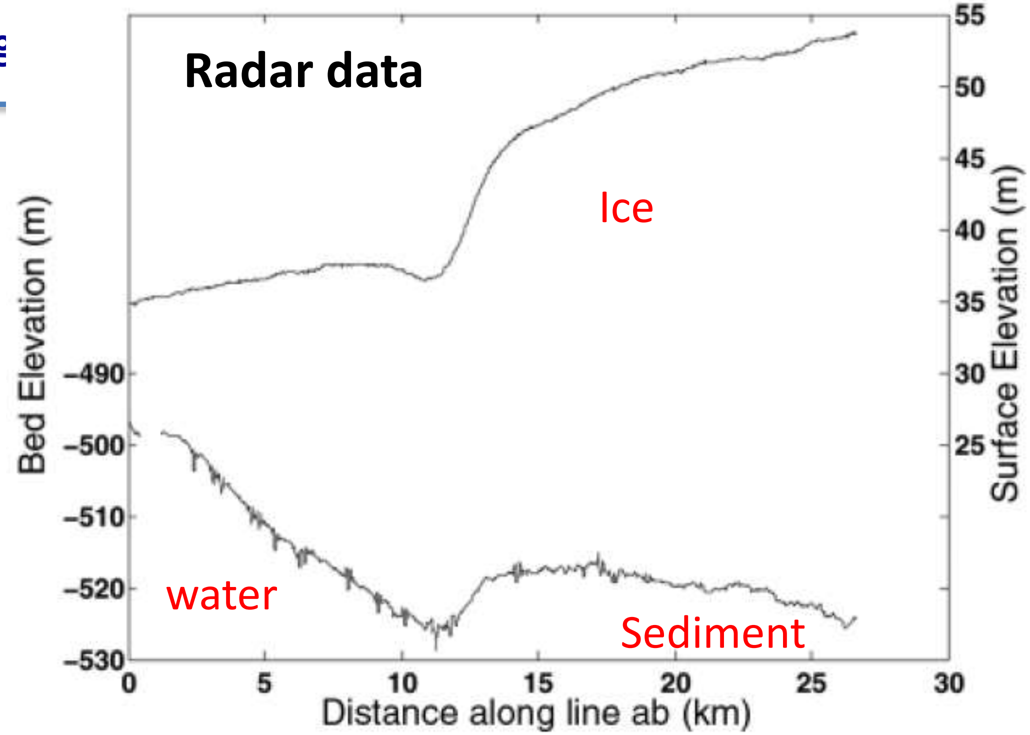
If the grounding line has been near its present position for the last 5-10 ka

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

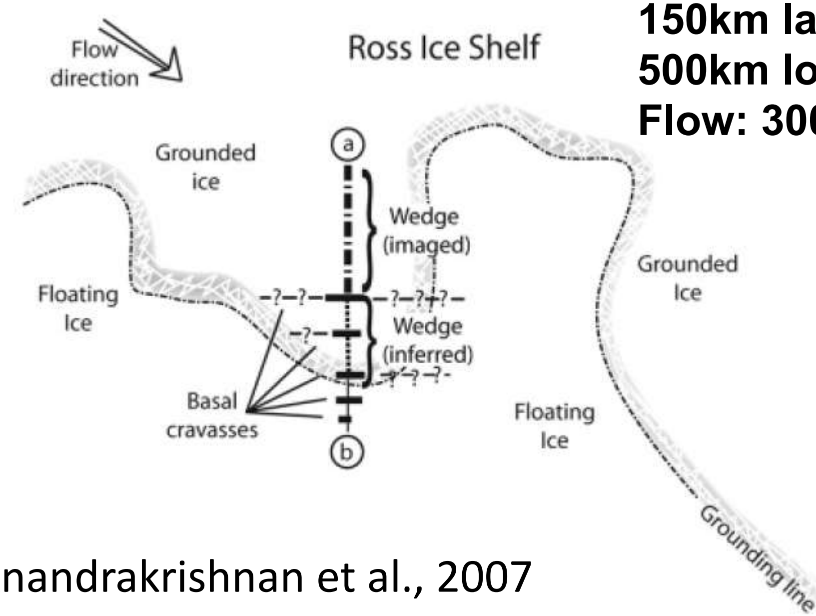
assuming a constant rock flux of hundreds of cubic meters/year at the grounding line

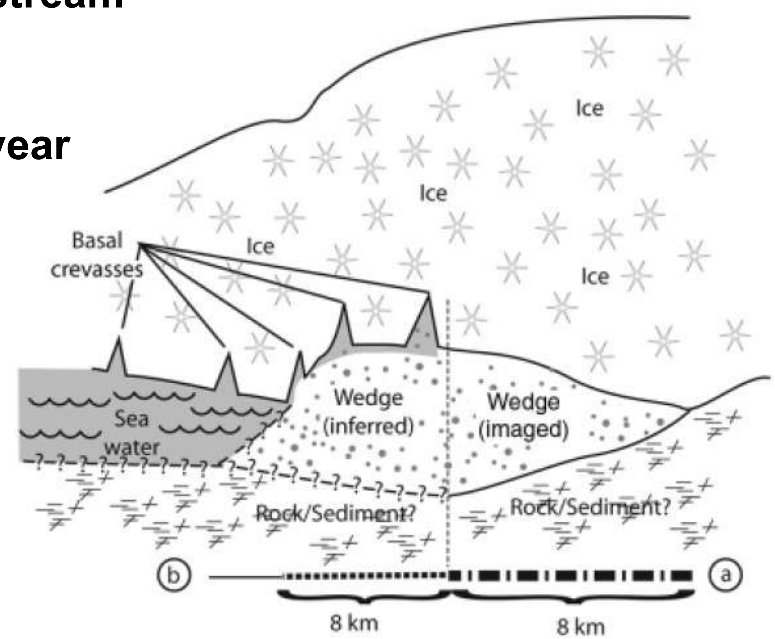
Alley et al., 1987; 1989





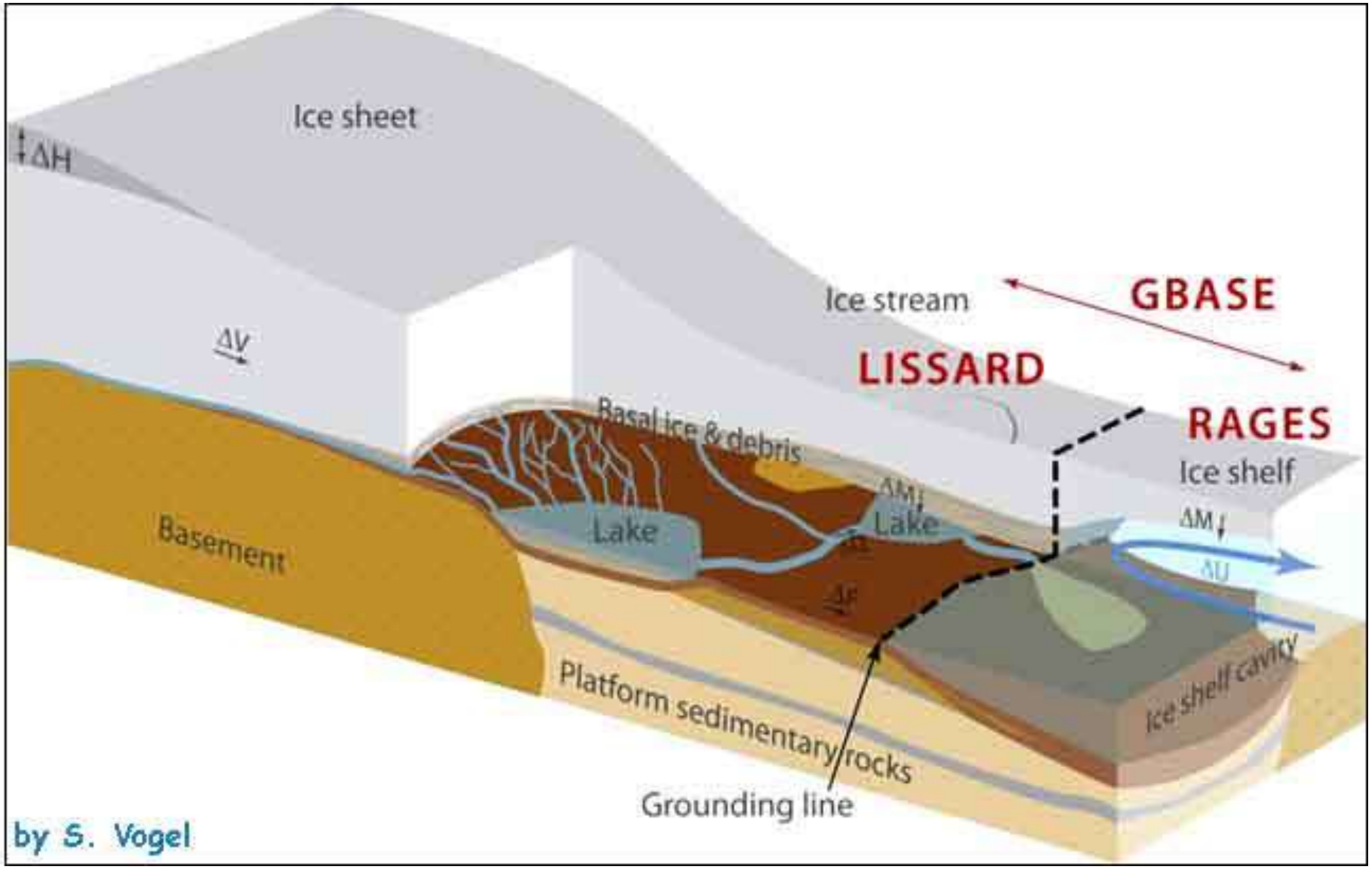
Whillans ice stream
150km large
500km long
Flow: 300 m/year





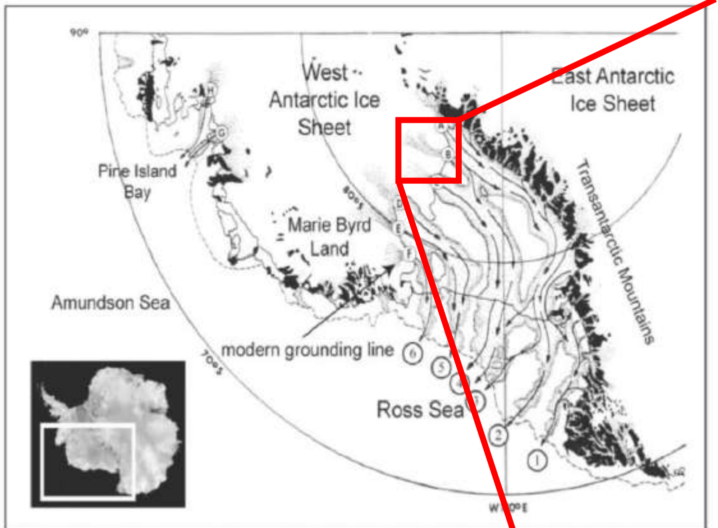
Anandrakrishnan et al., 2007

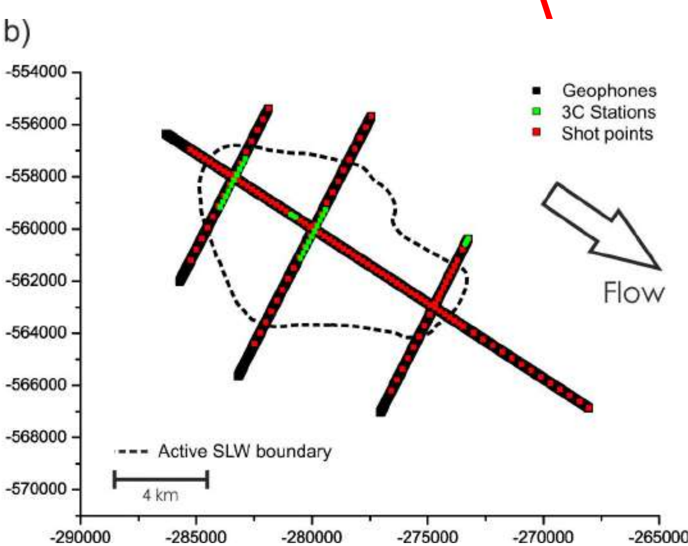
location of ice-sheet grounding is affected by short-term variations (e.g tides) and climatically-induced variations in thinning and rates of mass loss. The grounding zone is a key site for meltwater transfer from the ice sheet to the marine environment

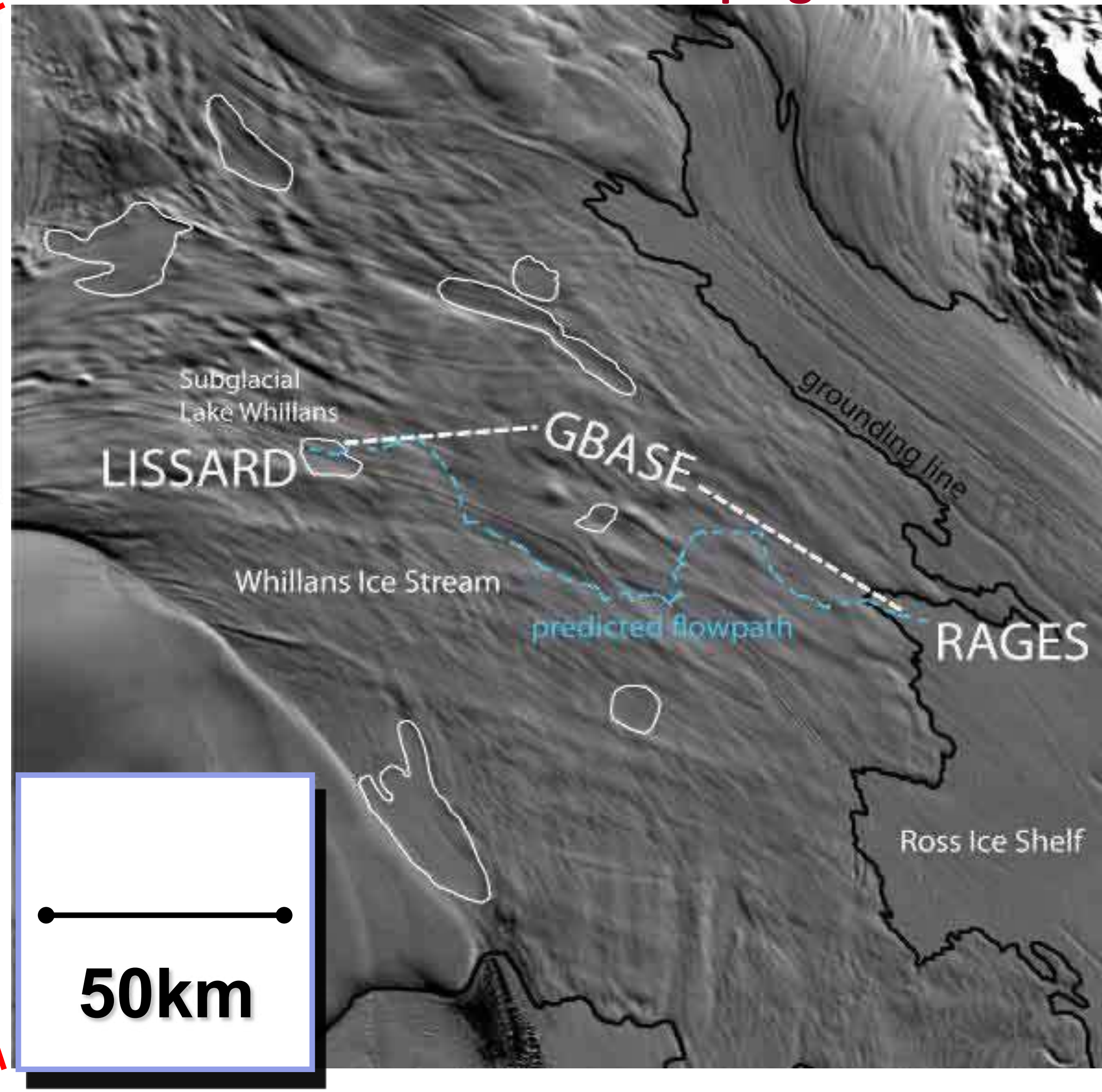


Subglacial and grounding-zone sedimentation aggradation may act as a negative feedback that counters dynamic thinning of the ice stream and stabilizes the ice-stream grounding zones (e.g., Alley et al., 2007).

Whillans Ice Stream – 2010-2011 Antarctic Campaign

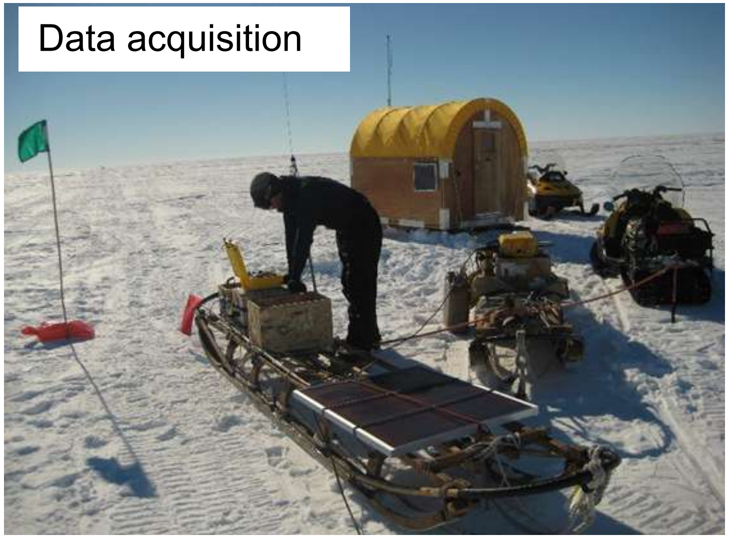






Whillans Ice Stream – 2010-2011 Antarctic Campaign

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



Whillans Ice Stream – 2010-2011 Antarctic Campaign

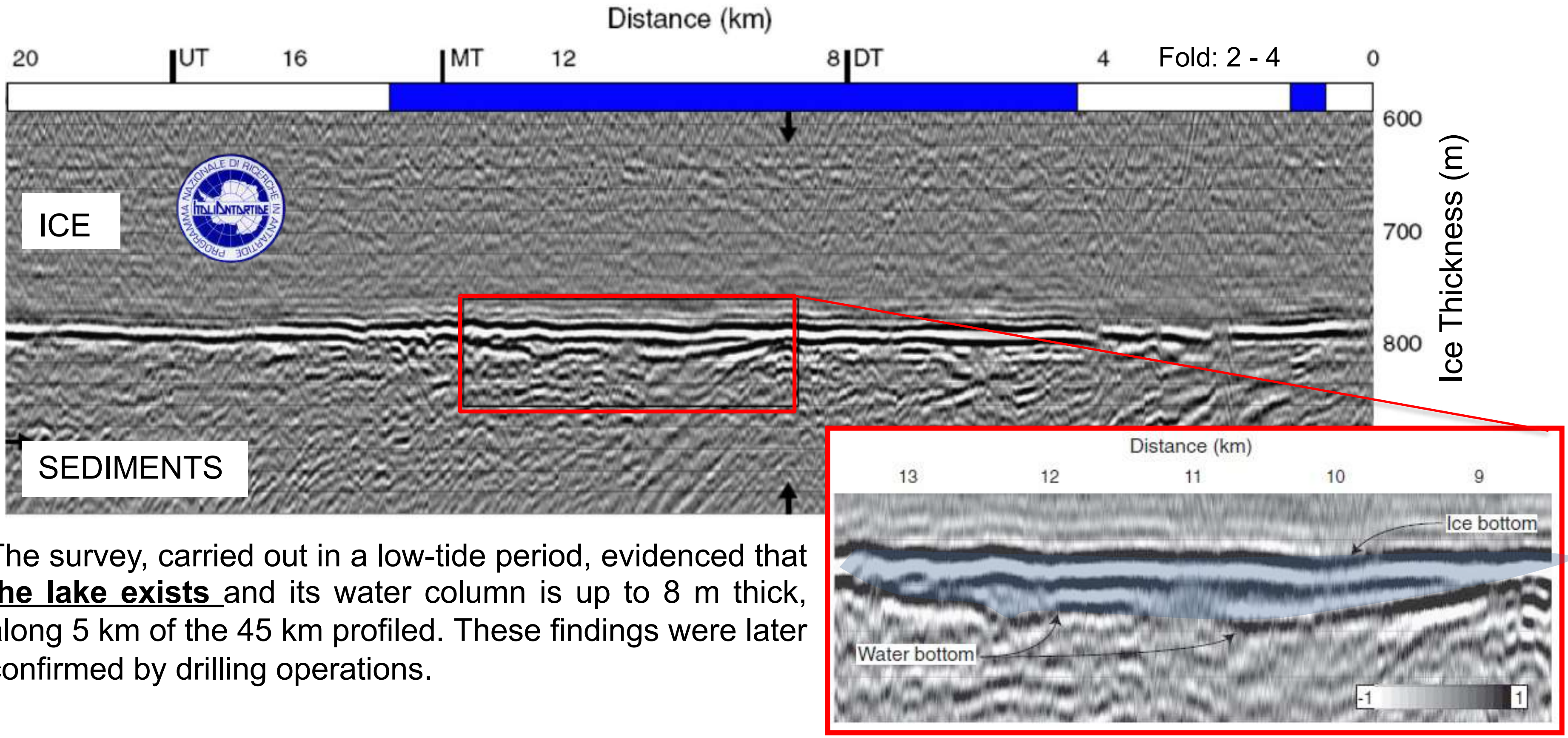

While drilling the holes for the explosive


A hole in the ice for the explosive


Digging after the wind....!


3C Stations deployment

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

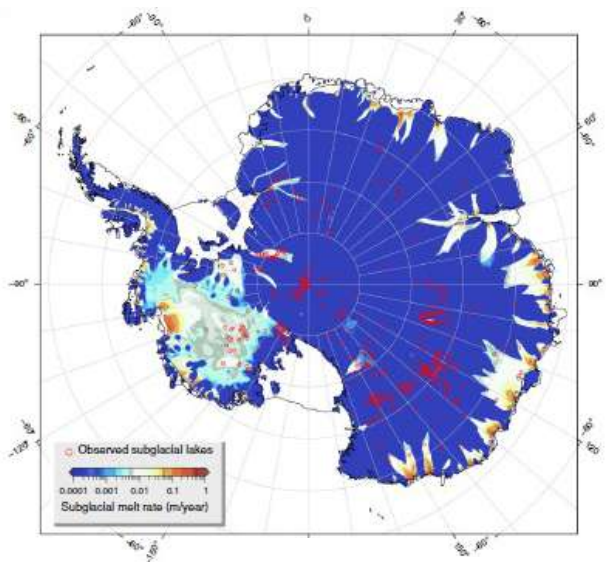


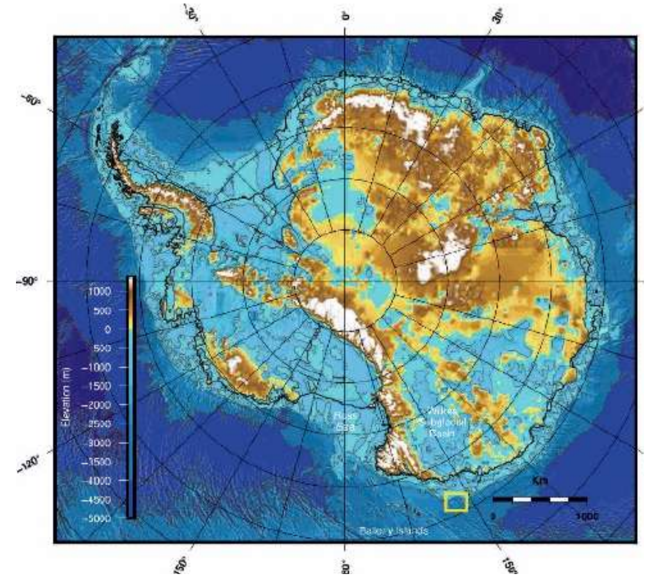
The survey, carried out in a low-tide period, evidenced that **the lake exists** and its water column is up to 8 m thick, along 5 km of the 45 km profiled. These findings were later confirmed by drilling operations.

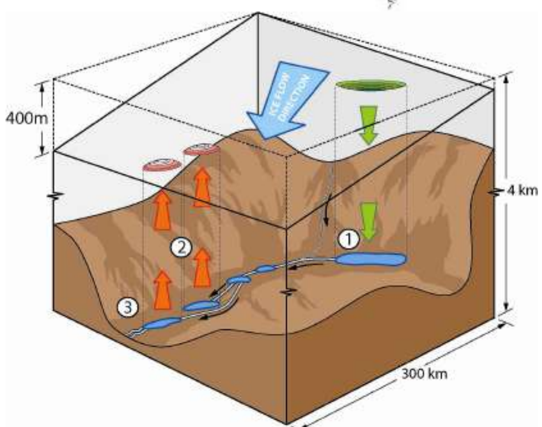
AVO (Amplitude Versus Offset) analysis shows that the major part of the bed around the lake consists of soft sediments and thin water lenses.

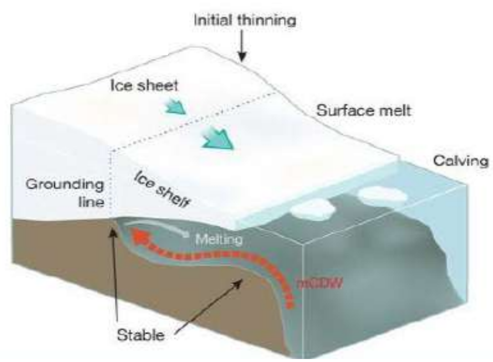
Picotti et. al 2011; 2015

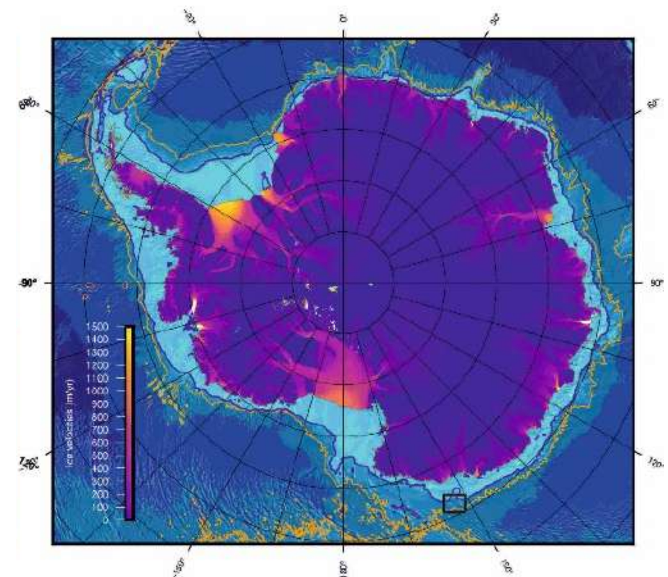
Duncan et al., 2006
Colleoni et al., 2018

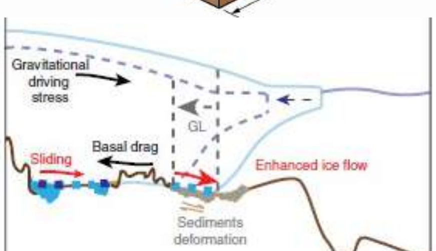




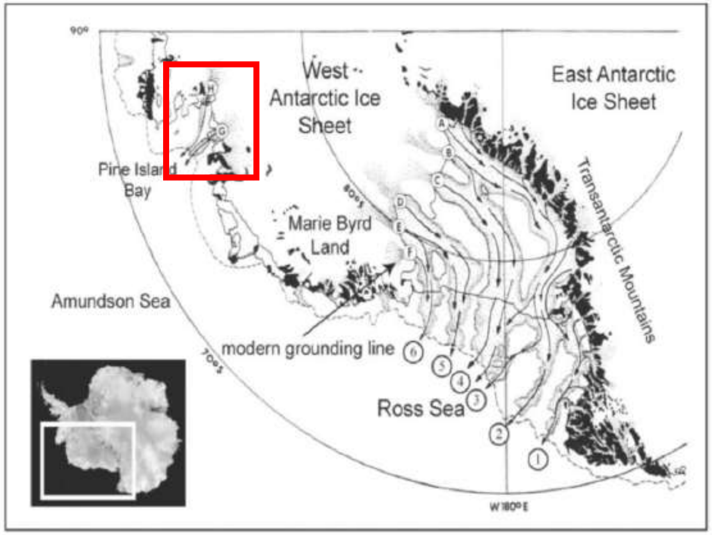




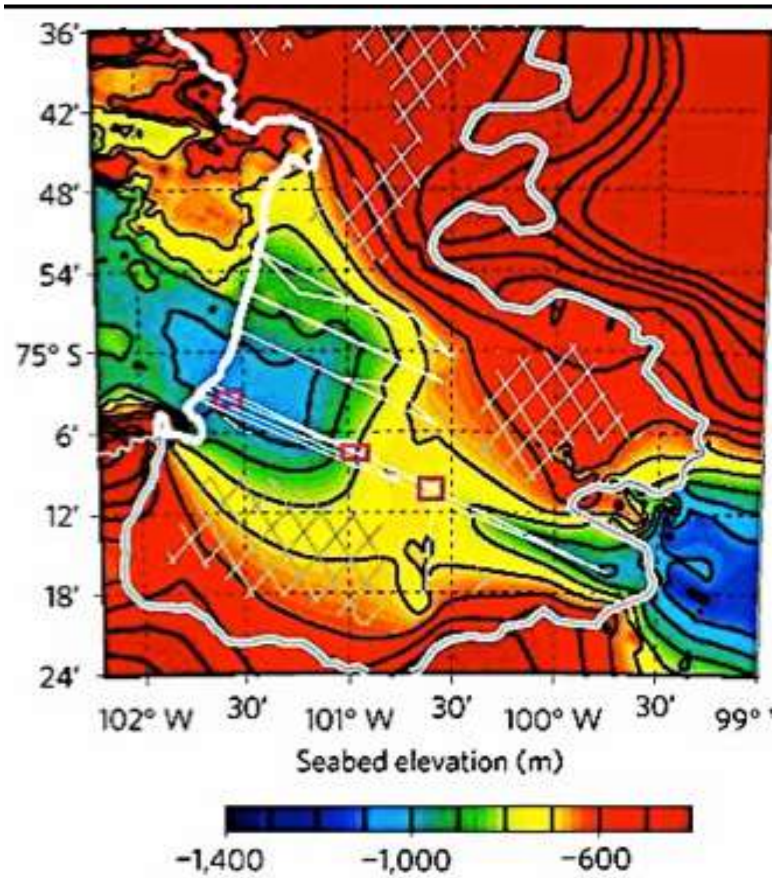


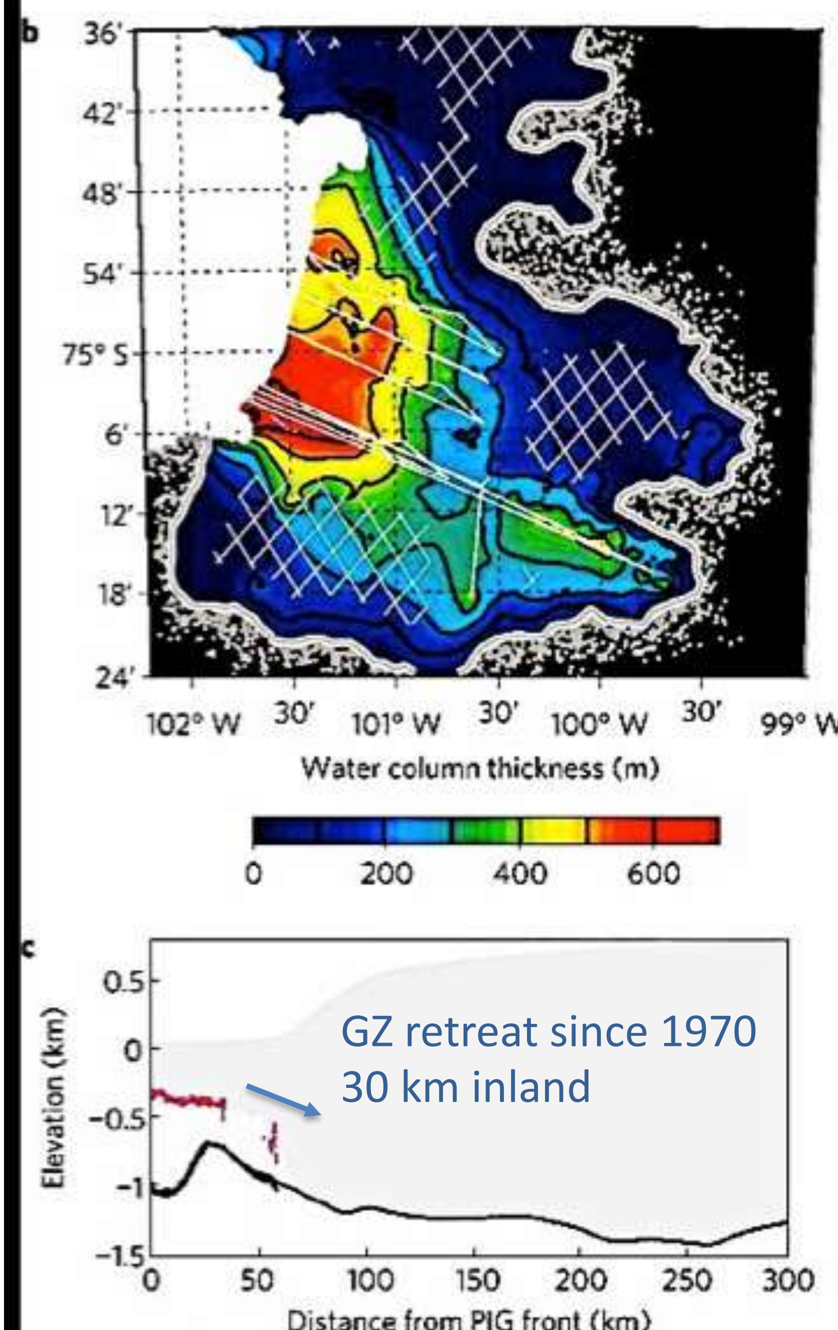


Pine Island Glacier



autonomous underwater vehicle





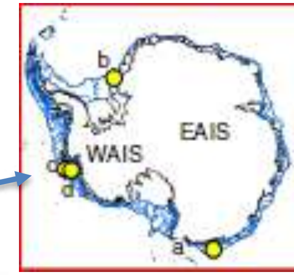
PIG - Jenkins et al. 2010

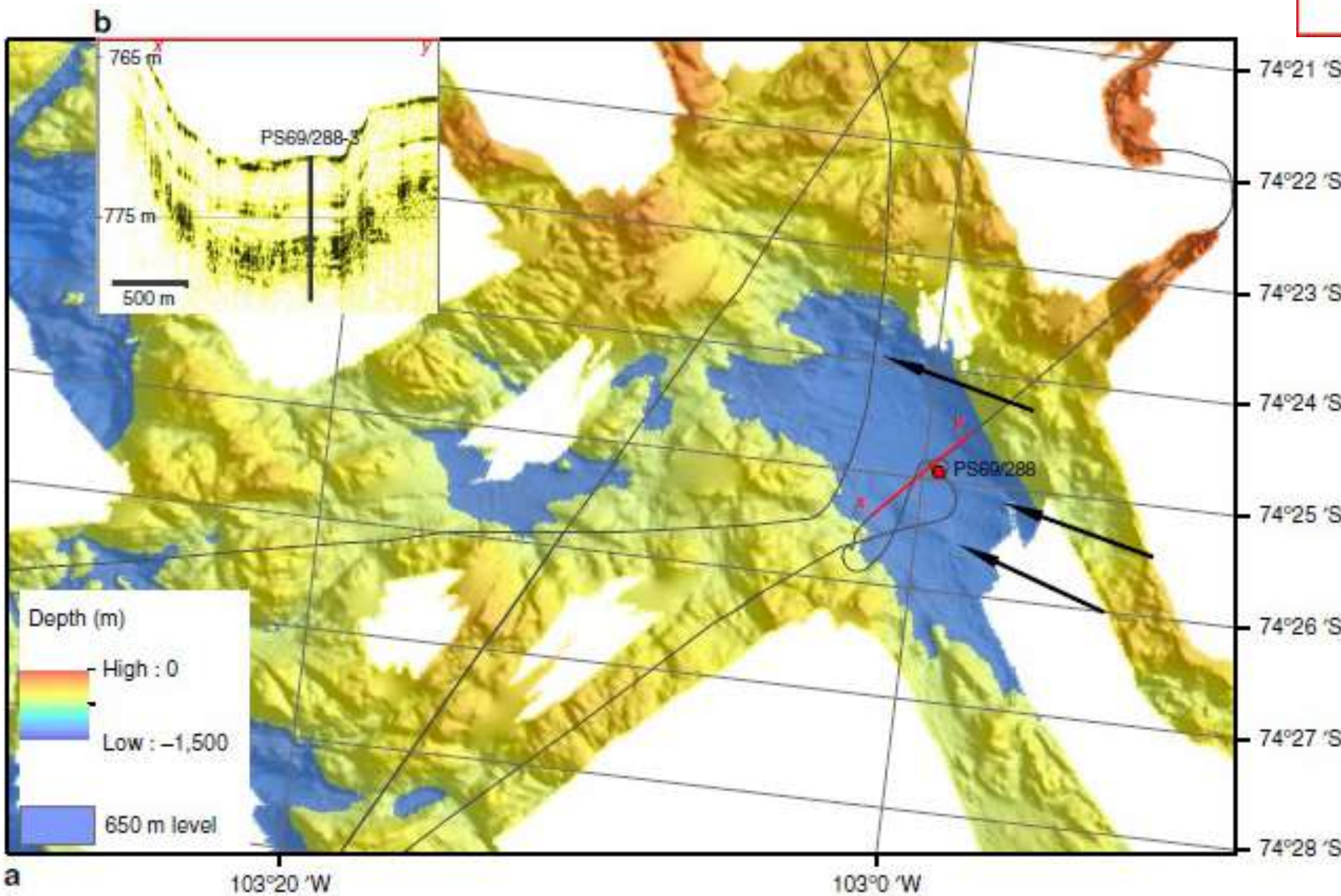
ARTICLE

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]





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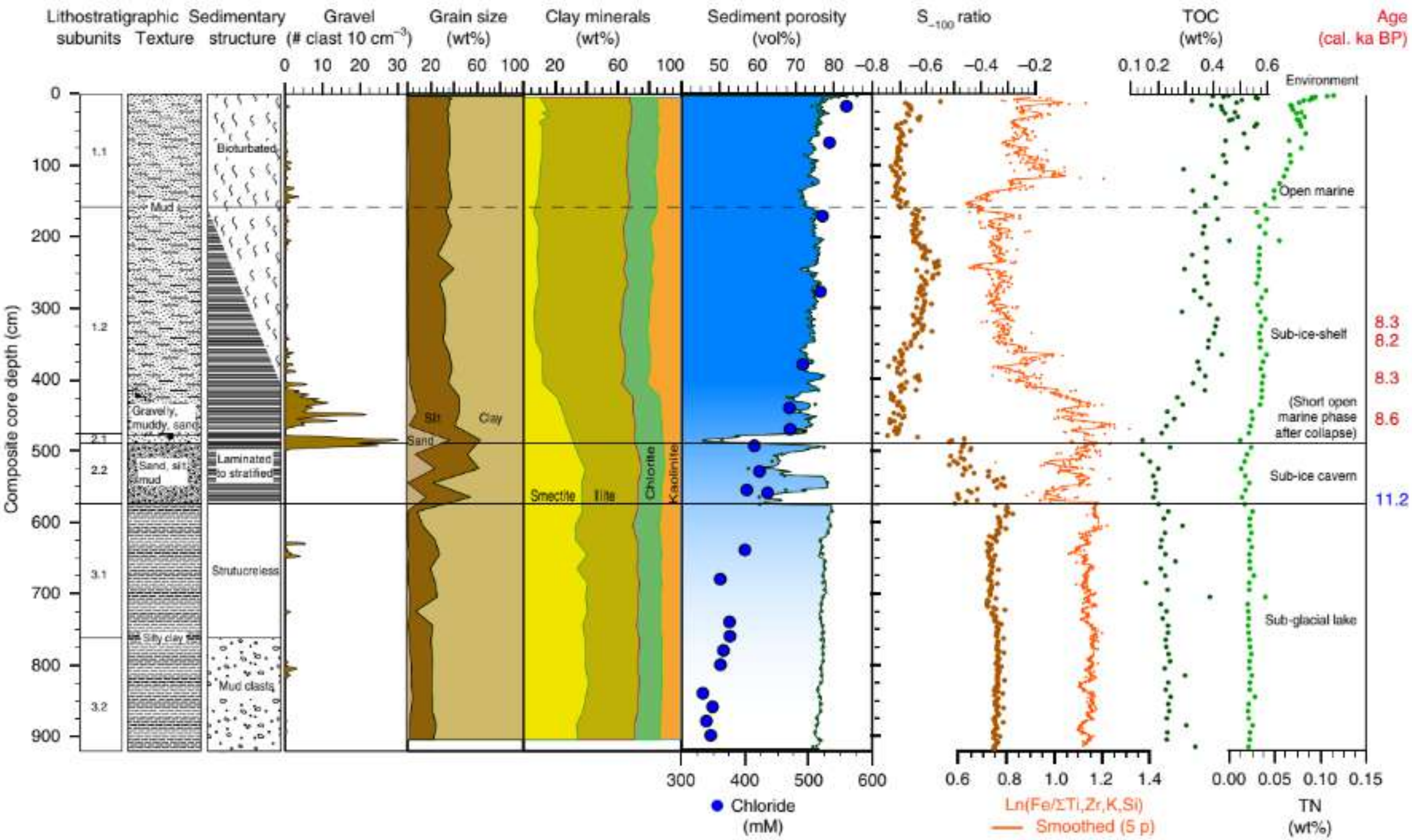
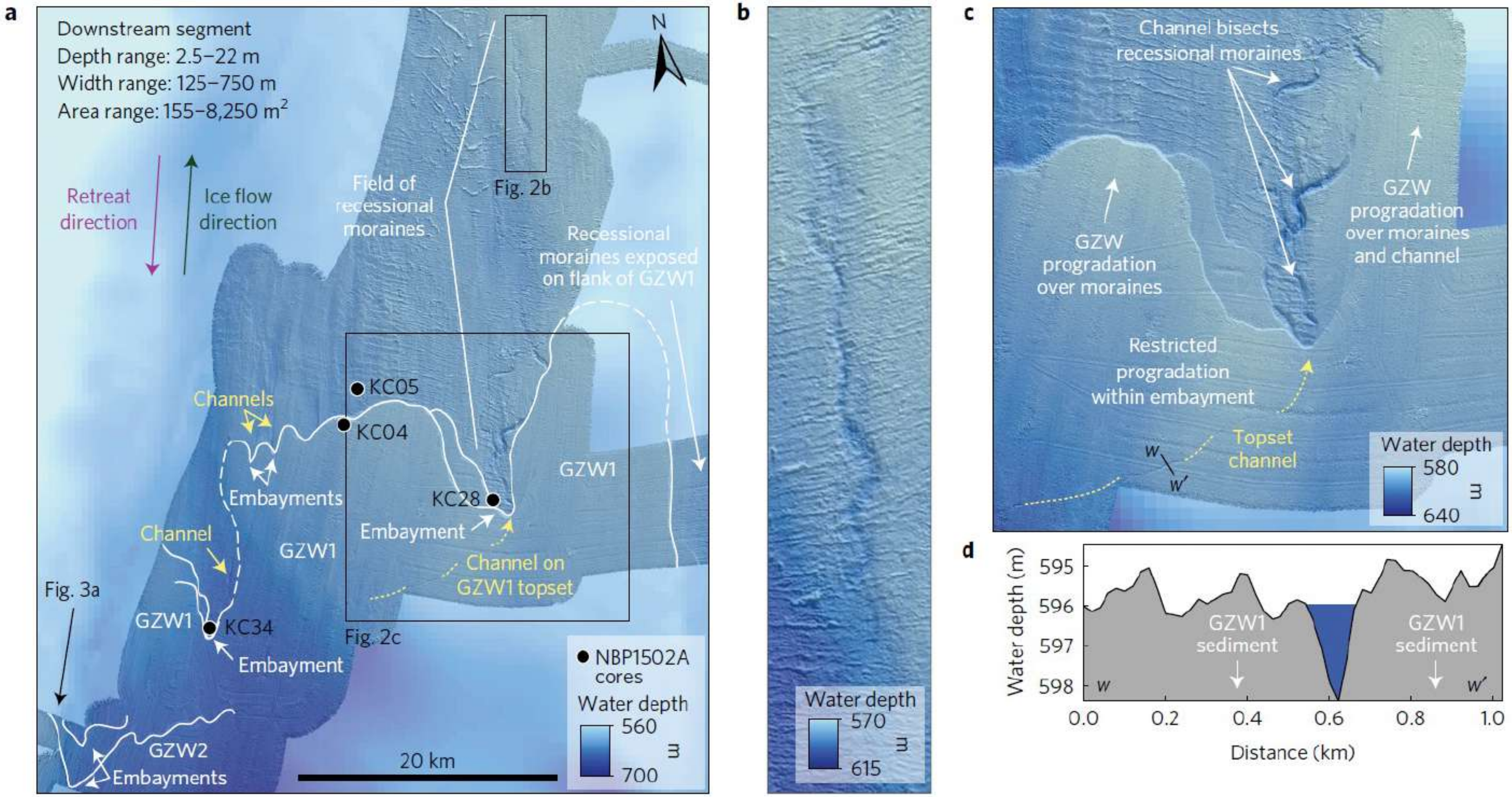
NATURE COMMUNICATIONS | DOI: 10.1038/ncomms15591

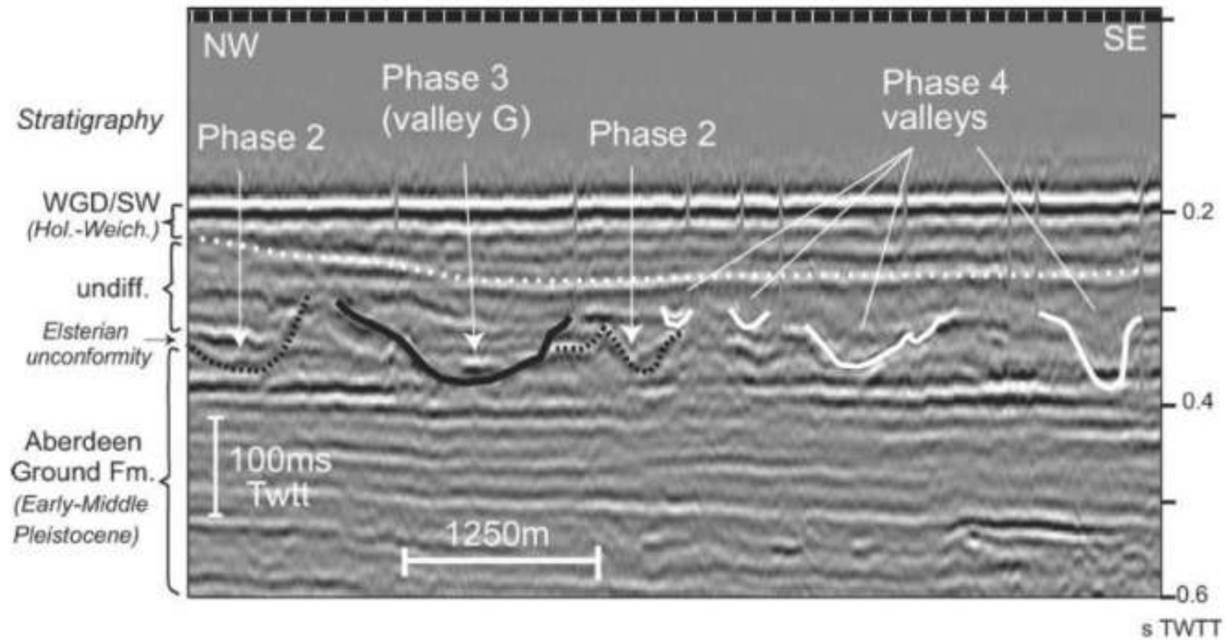


Outwash channels

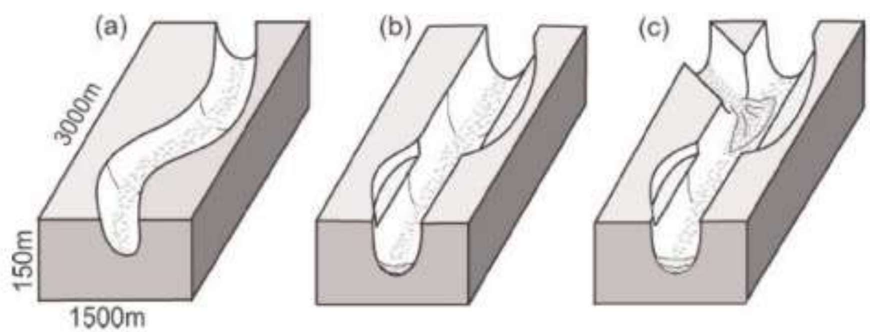


Simkins et al., 2017

Outwash channels

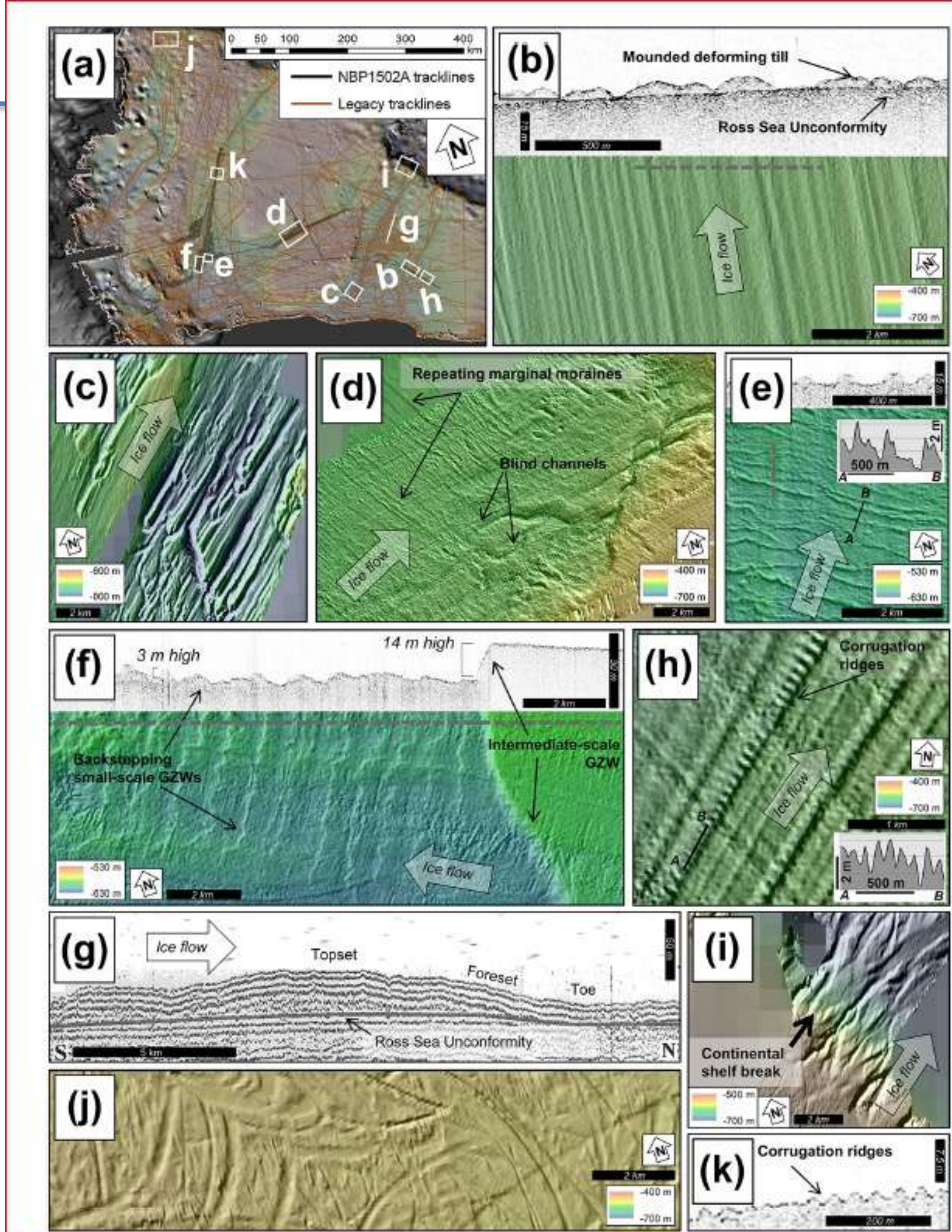


Sand fill

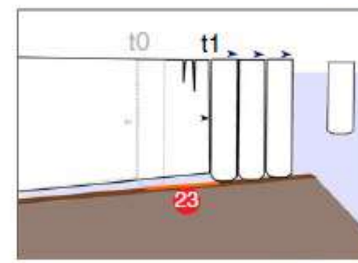


Bojer Kristensen et al., 2008, *Earth Surf. Process. Landforms*

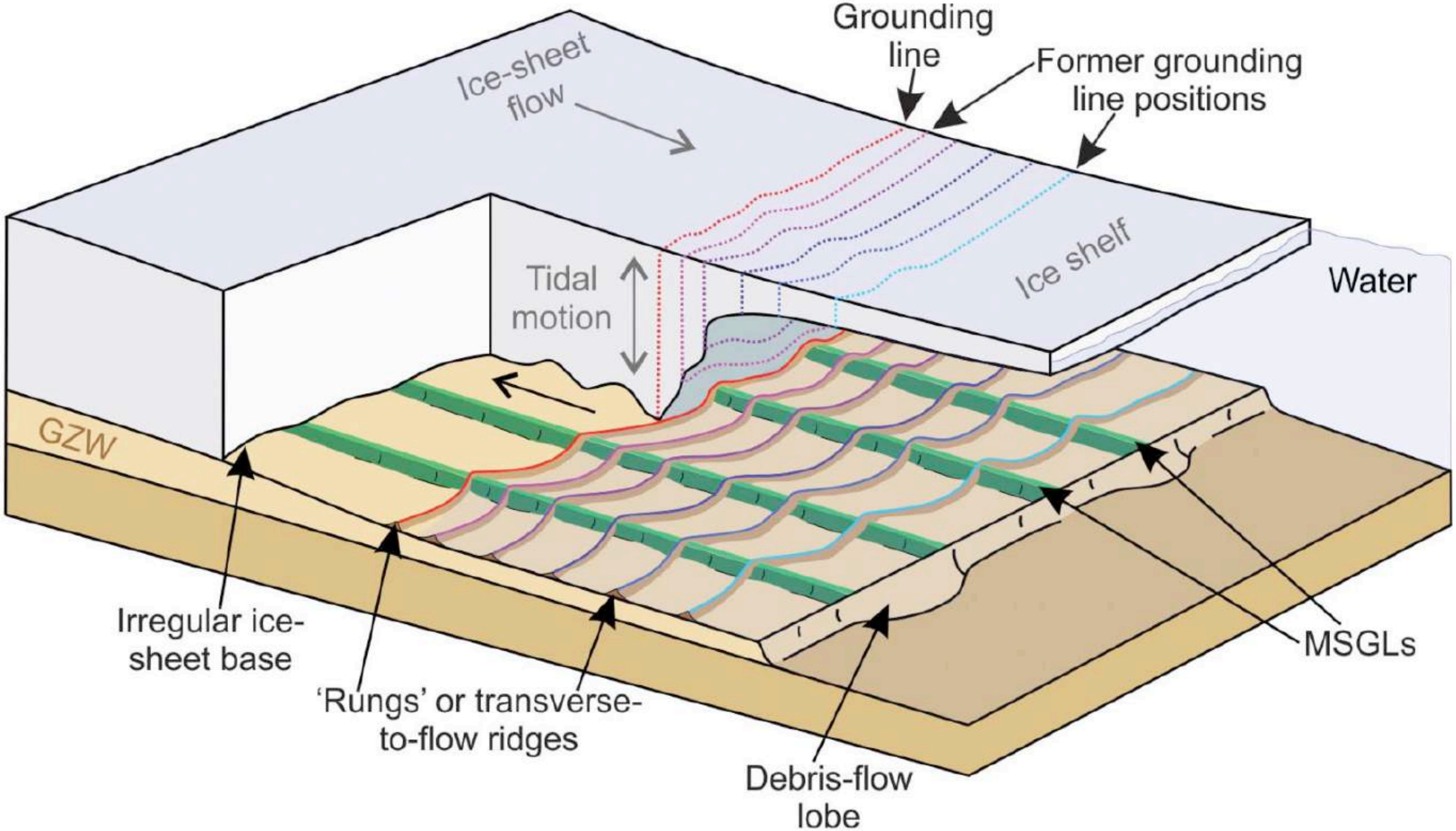
drumlins,
crag and
tails, and
megaflutes



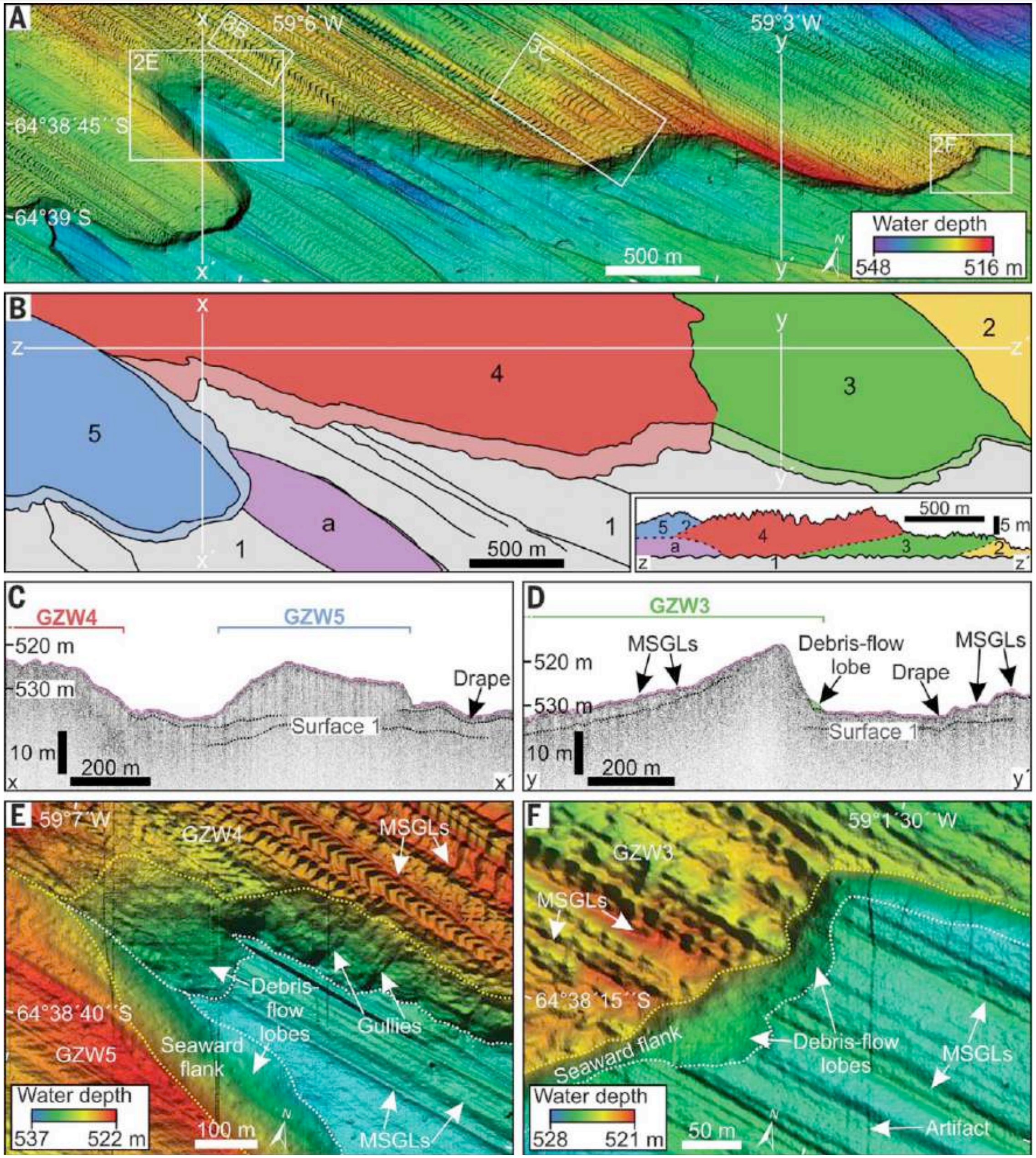
Megascale
glacial
lineations



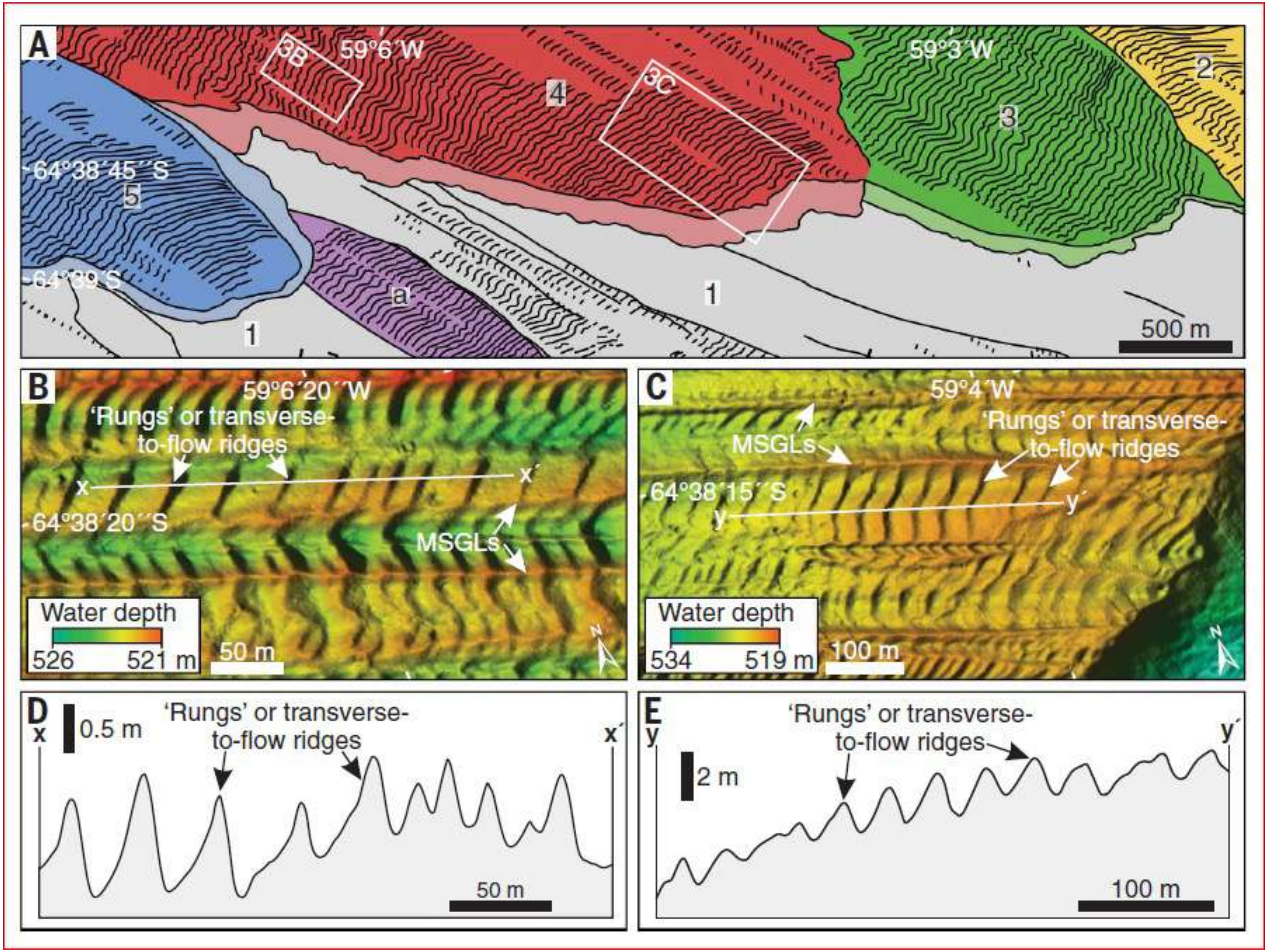
Halberstadt et
al., 2016



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
2
3
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.

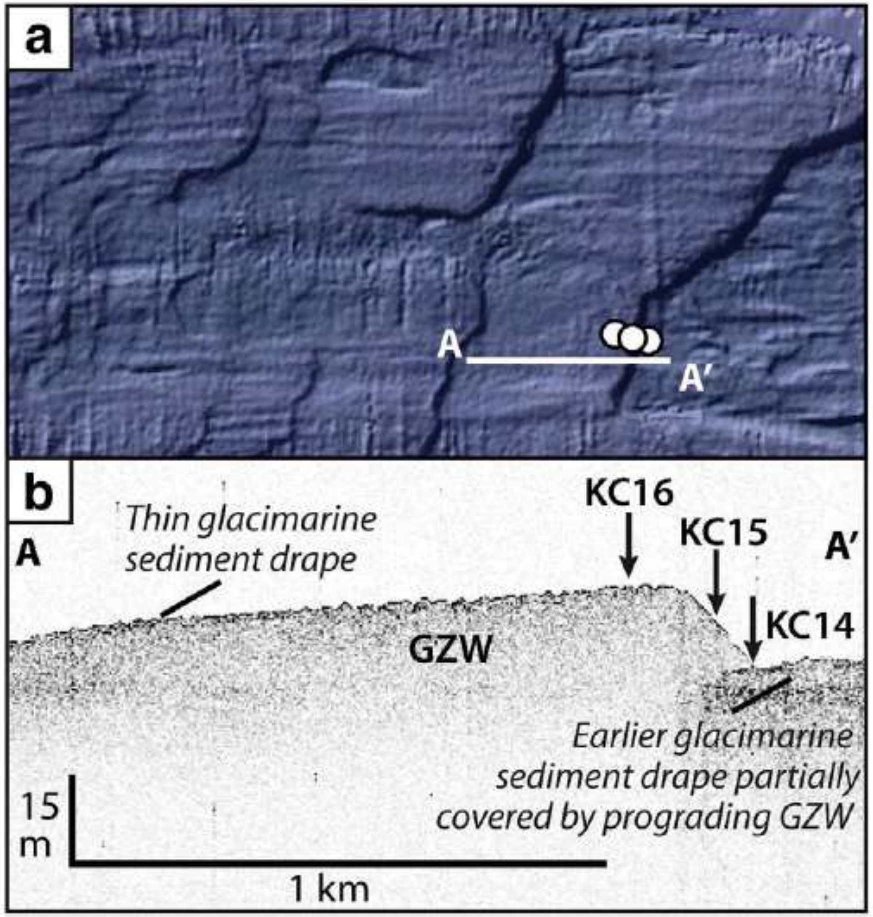
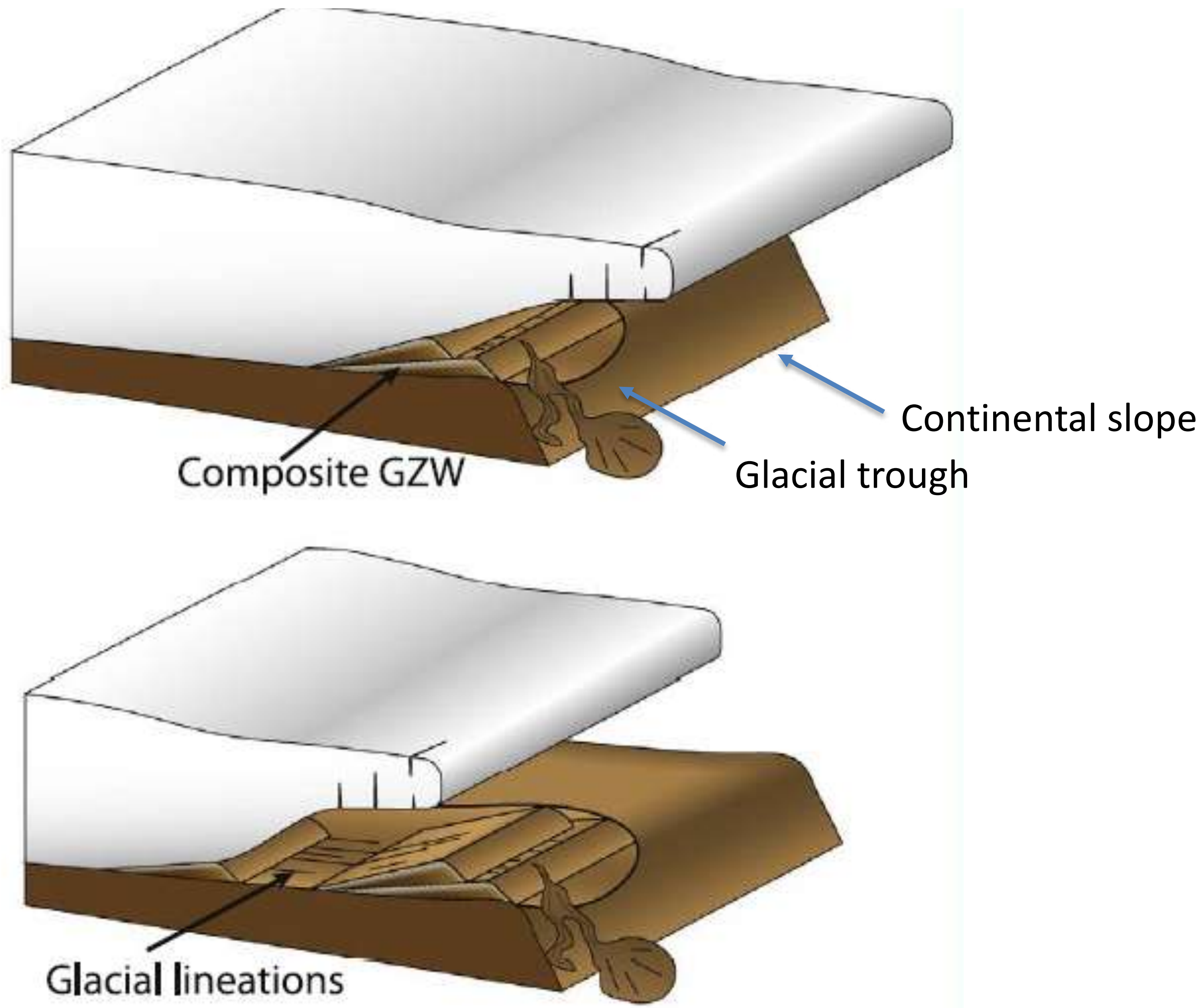


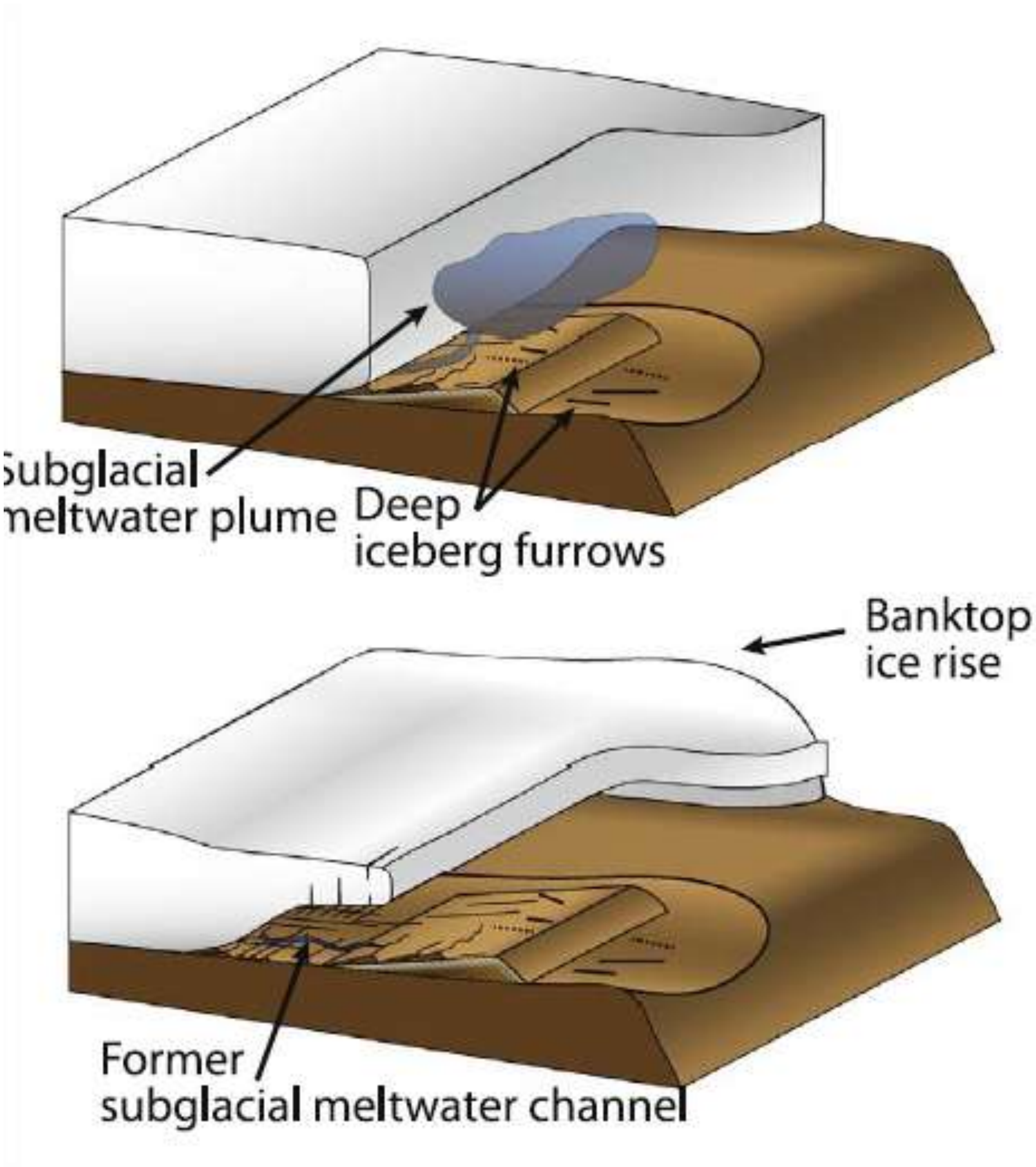
Fig. 3. Example of coring transect demonstrating targeted coring along a grounding-zone wedge using both (a) multibeam swath bathymetry and (b) CHIRP data. Core locations are shown in multibeam context in Fig. 3a, seismic context in Fig. 3b, and regional context in Fig. 1.

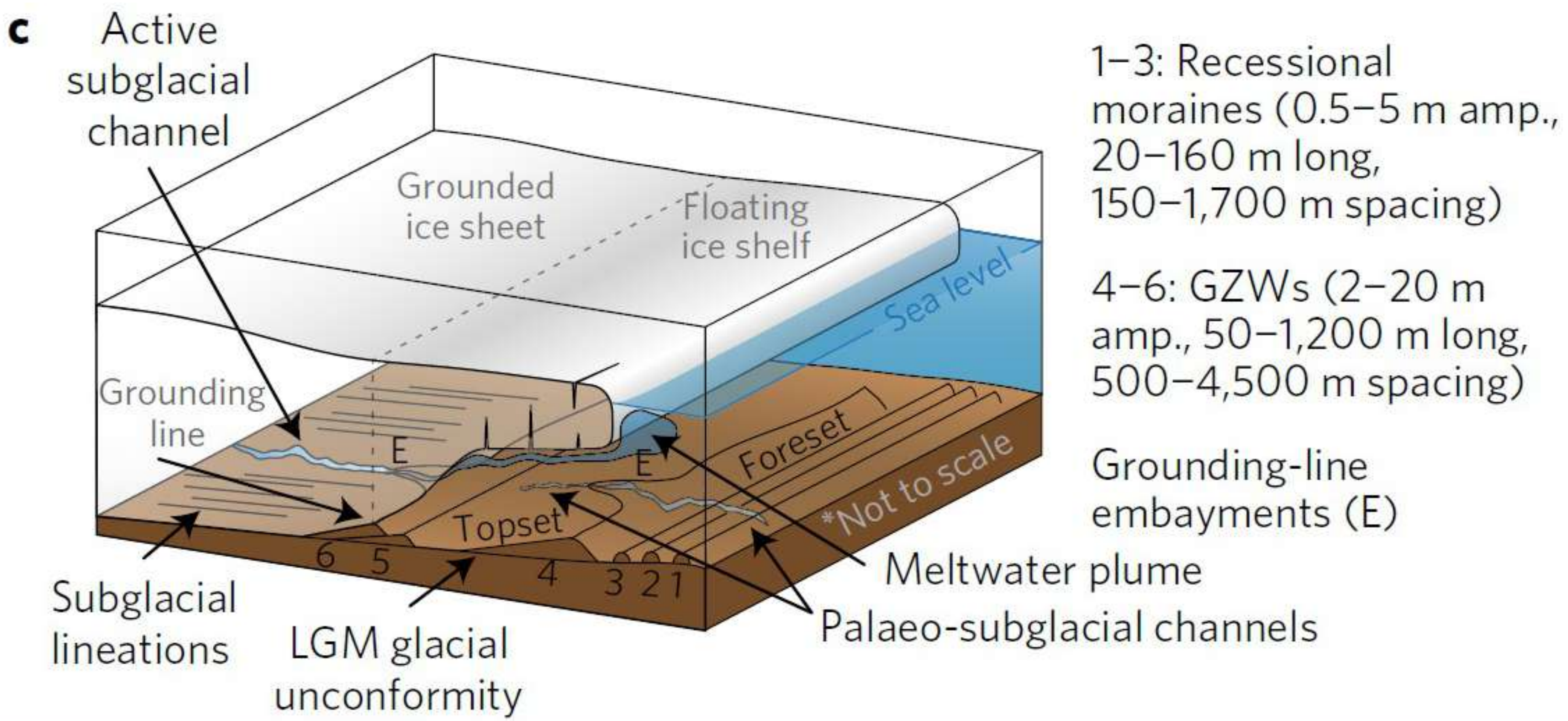
Prothro et al., 2018

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

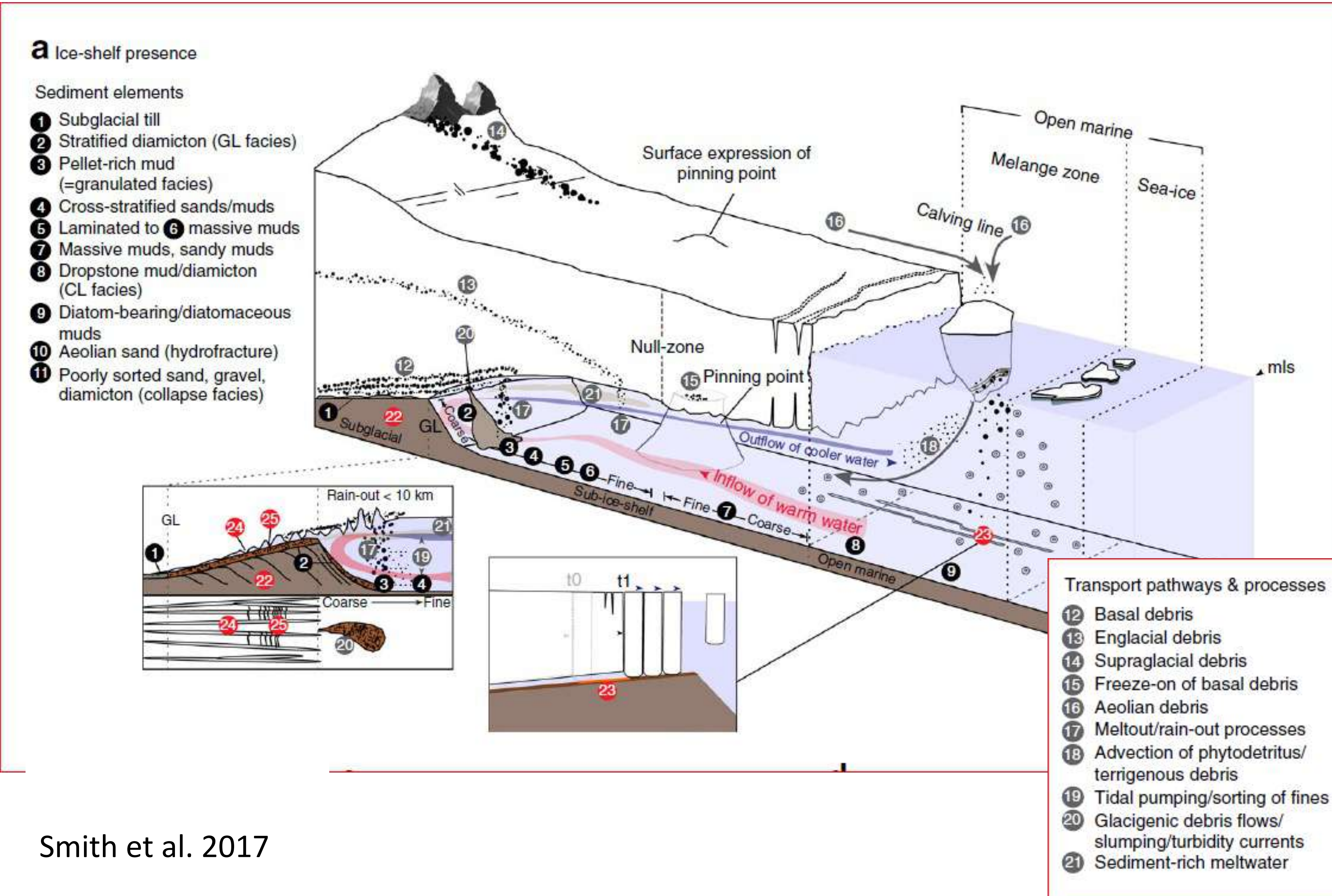


Prothro et al., 2018

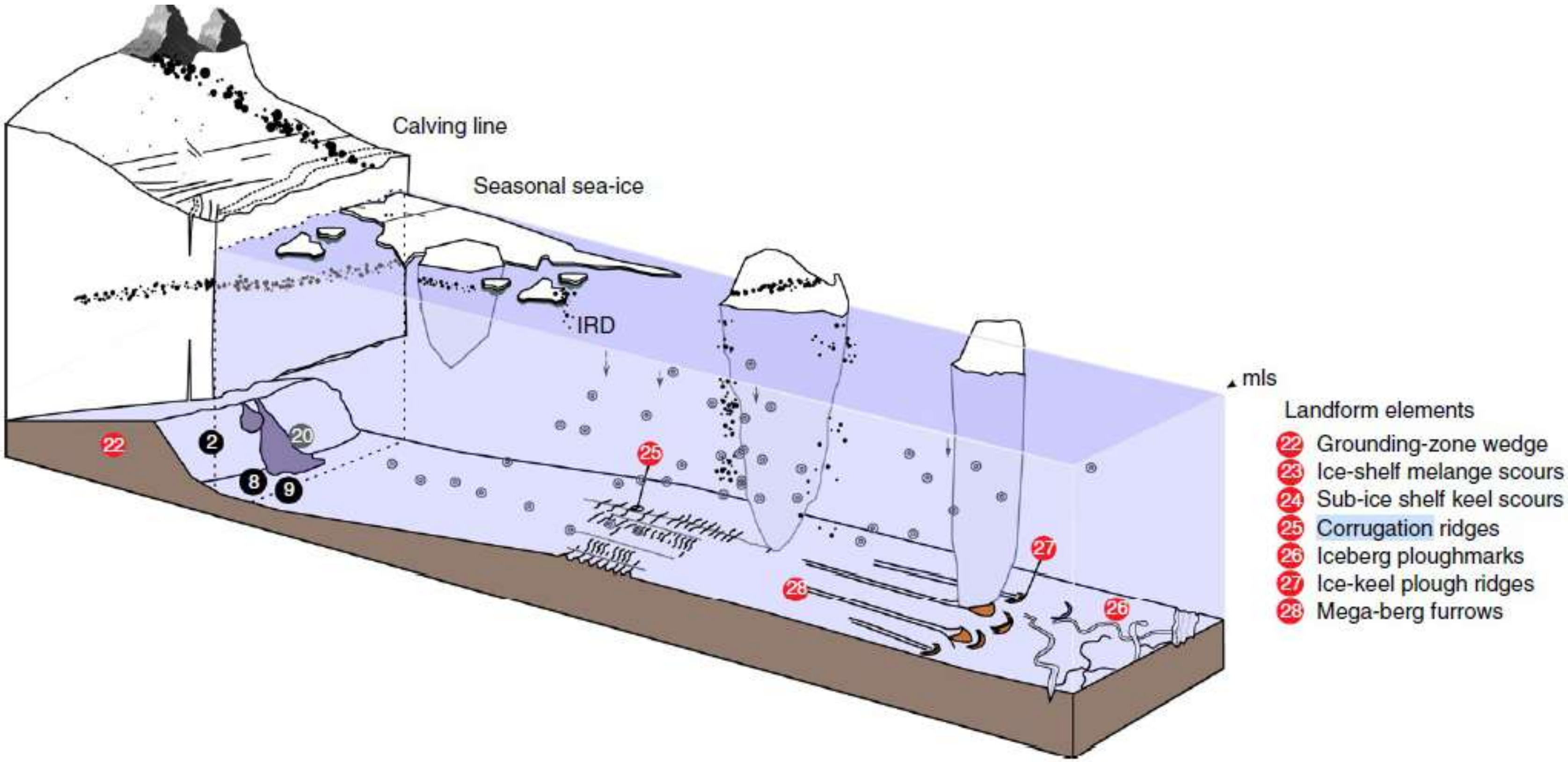

Subglacial meltwater plume
Deep iceberg furrows
Banktop ice rise
Former subglacial meltwater channel



Simkins et al., 2017



Smith et al. 2017



Smith et al. 2017

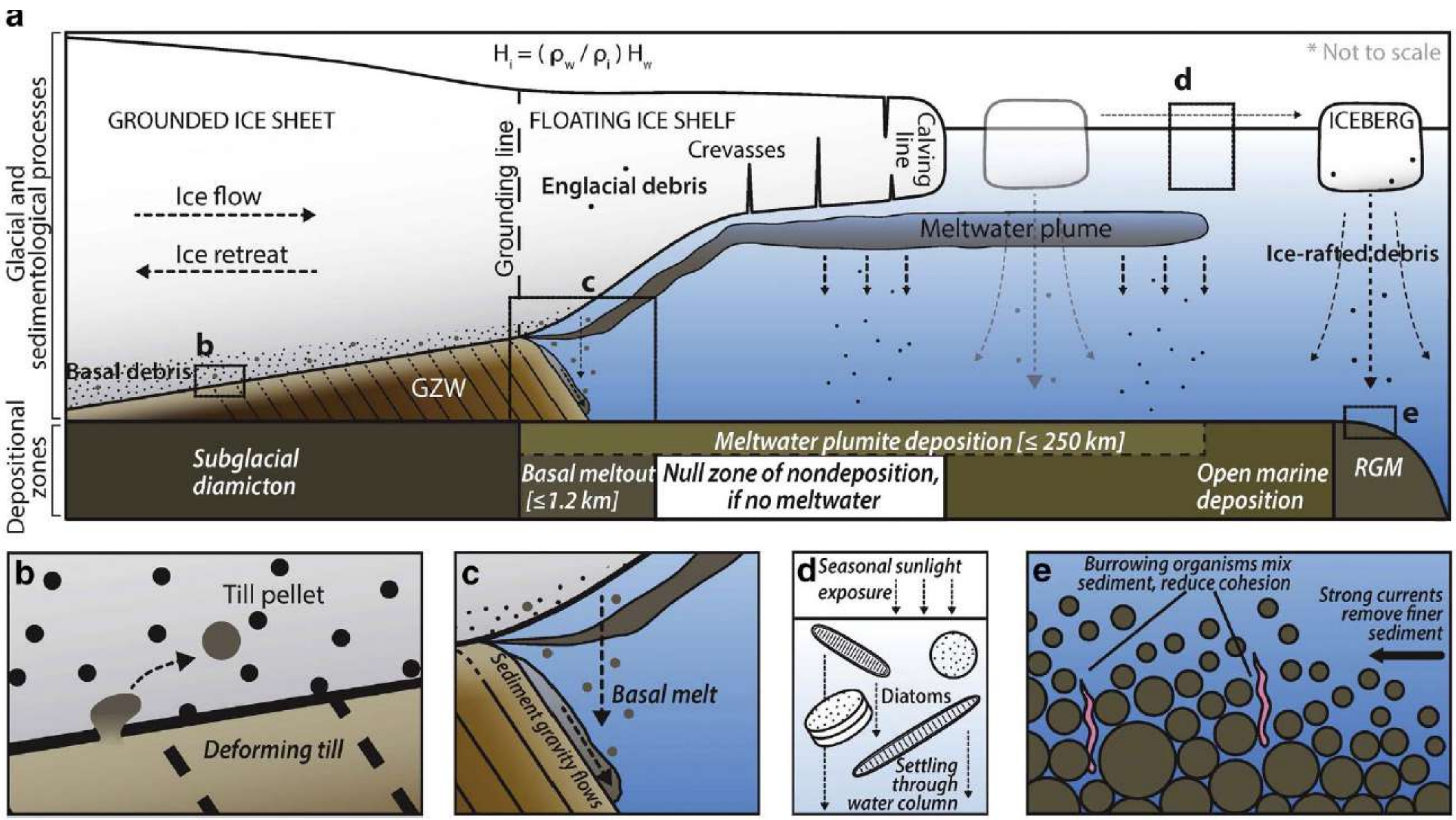
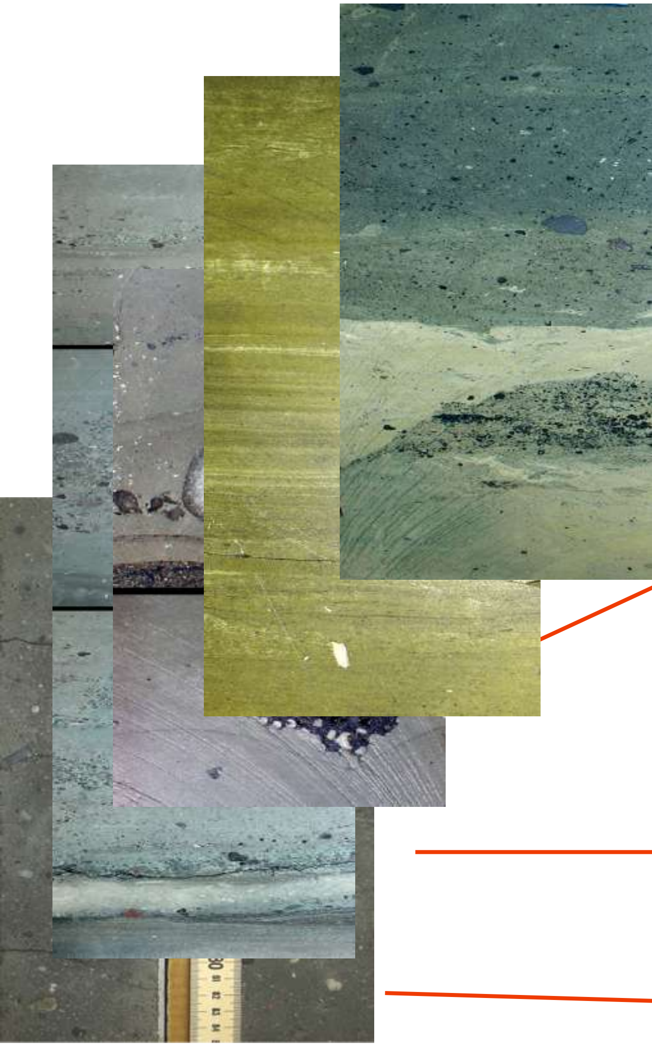


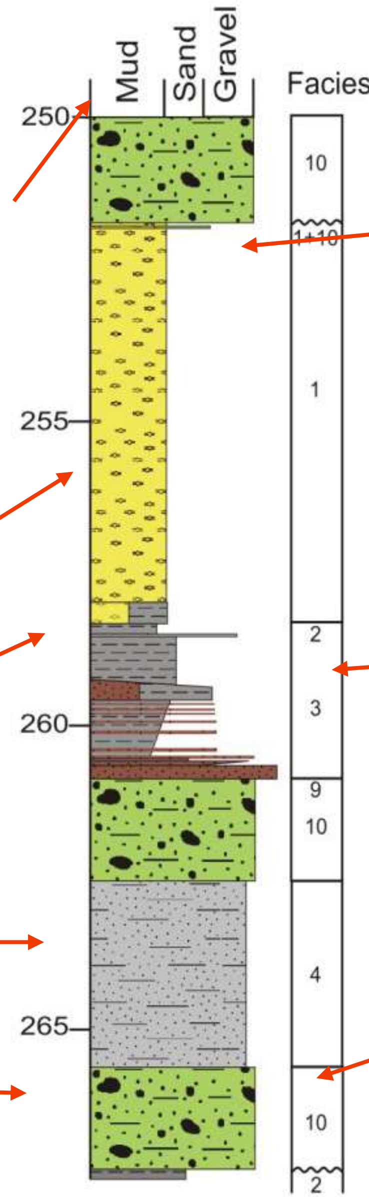
Fig. 2. (a) Conceptual diagram of a grounding-zone wedge (GZW) and proglacial environment, with associated glacial and sedimentary processes. Definitions of terms for buoyancy equation: H_i = ice thickness, Hw = water depth, ρ_i = density of ice (917 kg m^{-3}), ρ_w = density of seawater (~1025 kg m^{-3}—may 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.

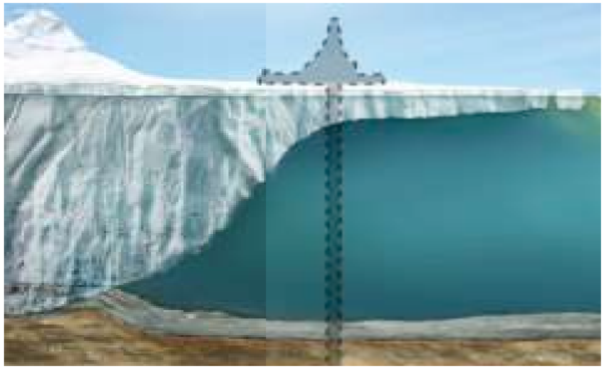
Prothro et al., 2018

Glacial-Interglacial glacimarine cycles

From Mckay et al. 2009 GSA Bull.

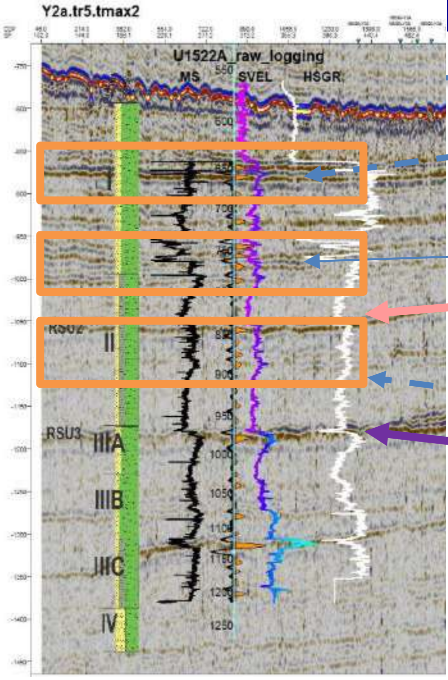


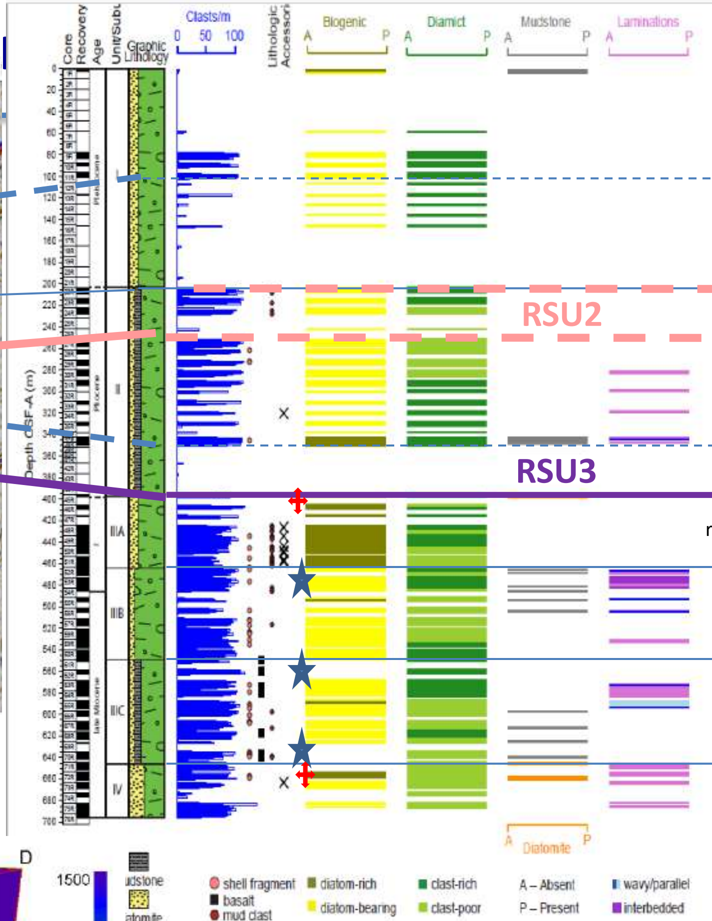


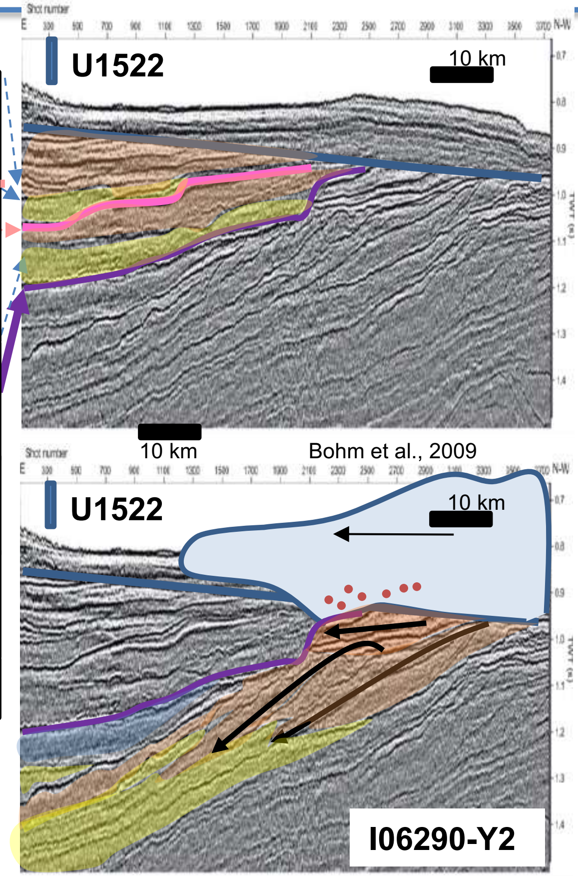


Hole U1522

Istituto Nazionale di Oceanografia e di Geofisica Sperimentale







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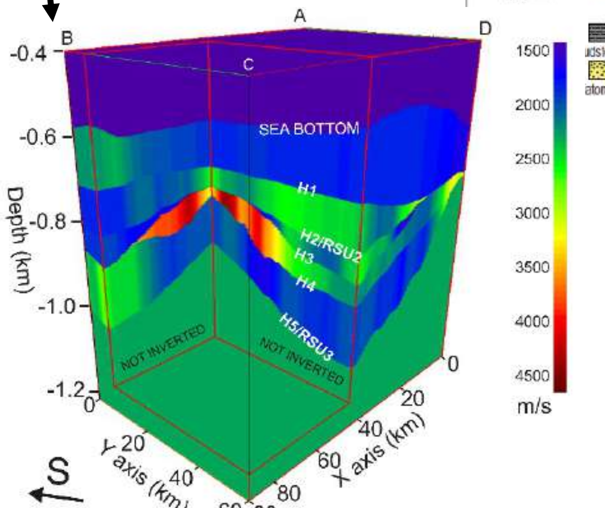
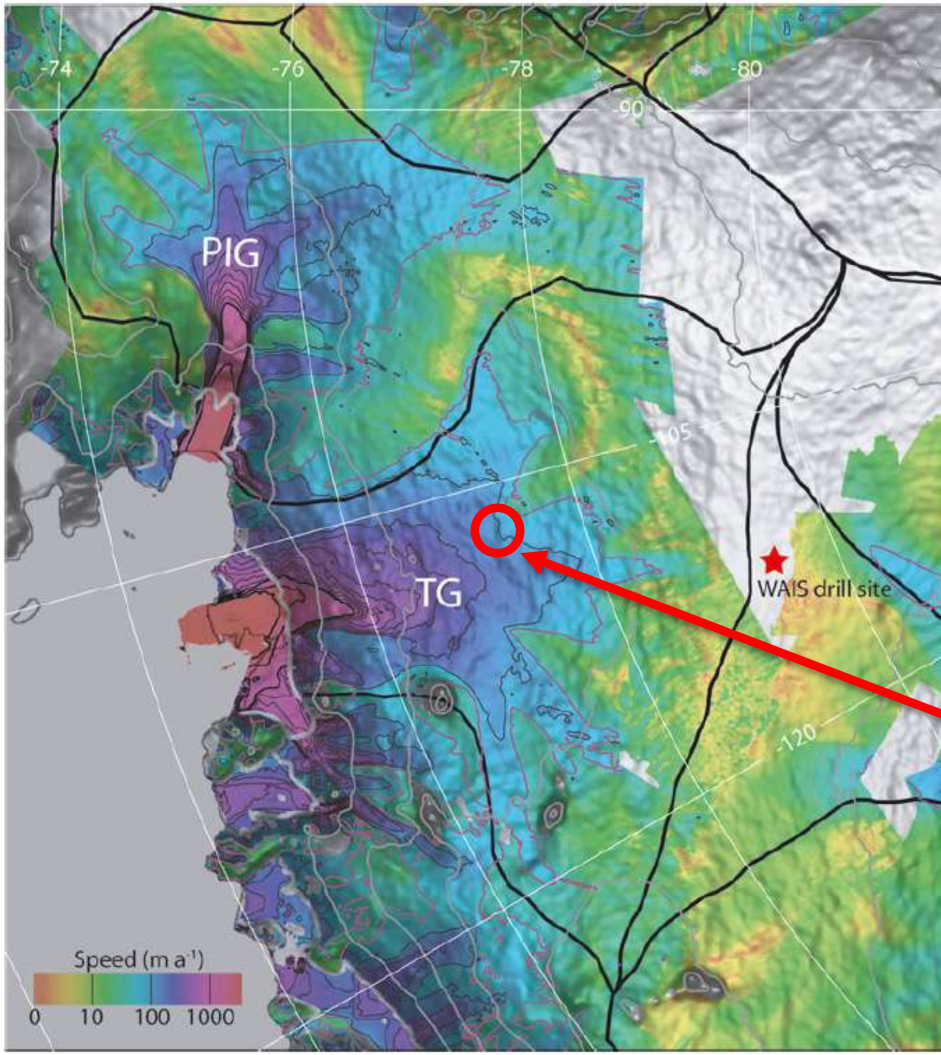


Boehm et al., 2009

IODP
INTERNATIONAL OCEAN DISCOVERY PROGRAM

Thwaites Glacier (Amundsen-Scott coast - WAIS)



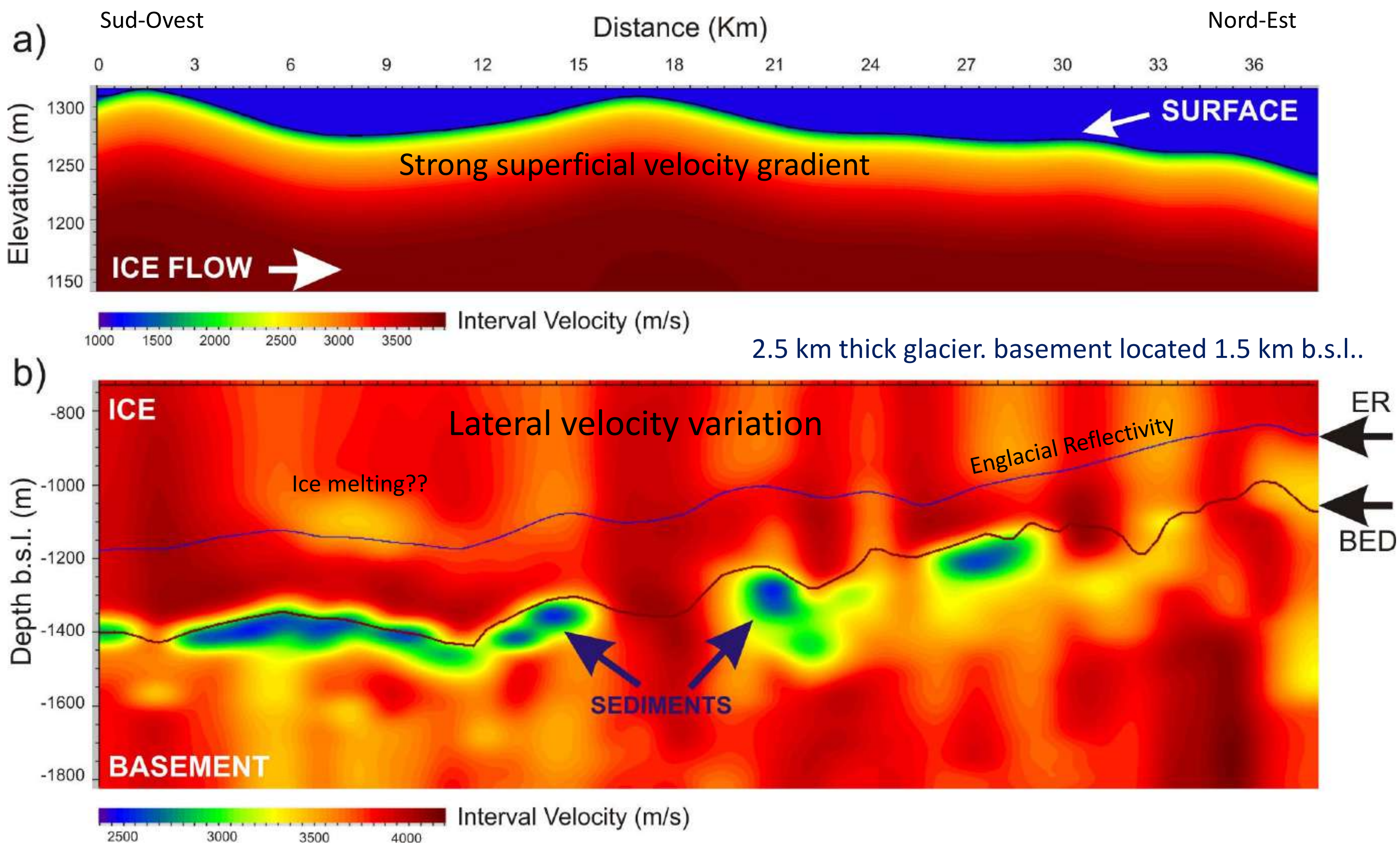
Flow speed (color) over the artificially shaded surface (grayscale) of a DEM produced from a combination of laser and radar altimetry for Pine Island (PIG) and Thwaites (TG) Glaciers. From Joughin et al. (2009).

Thwaites Glacier (TG) and Pine Island Glacier (PIG) are two of the largest ice streams of the WAIS.

Joughin et al. (2009) indicates, with remote sensing techniques, that the Thwaites is more stable than the Pine Island, probably due to a more corrugated basement and the presence of a crystalline bedrock and consolidated sediments in the inner part.

Seismic survey was run crossing an area where Joughin et al. (2009) observed a change in baseline stress.

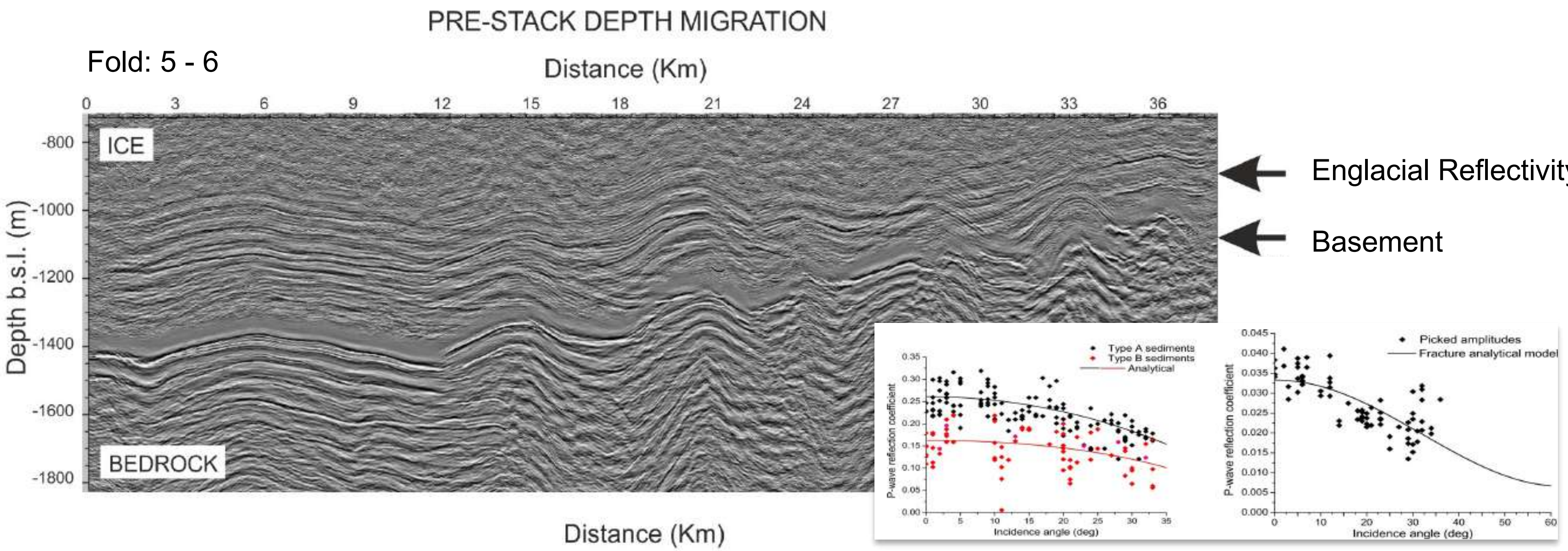
Thwaites Glacier: Interval velocity model

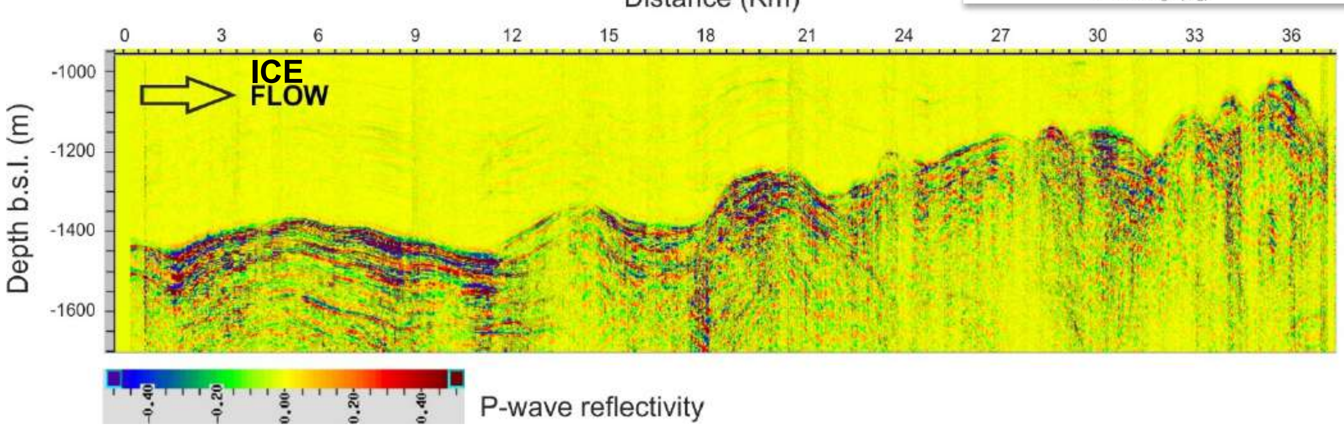


The strong superficial velocity gradient is due to the firn densification, while the lateral variation in depth are due to the stress distribution that generate ice deformation and local ice melting.

Seismic Imaging of Thwaites Glacier (Amundsen-Scott coast - WAIS)

This image shows a 2.5 km thick glacier flowing over a very rough basement located 1.5 km b.s.l...



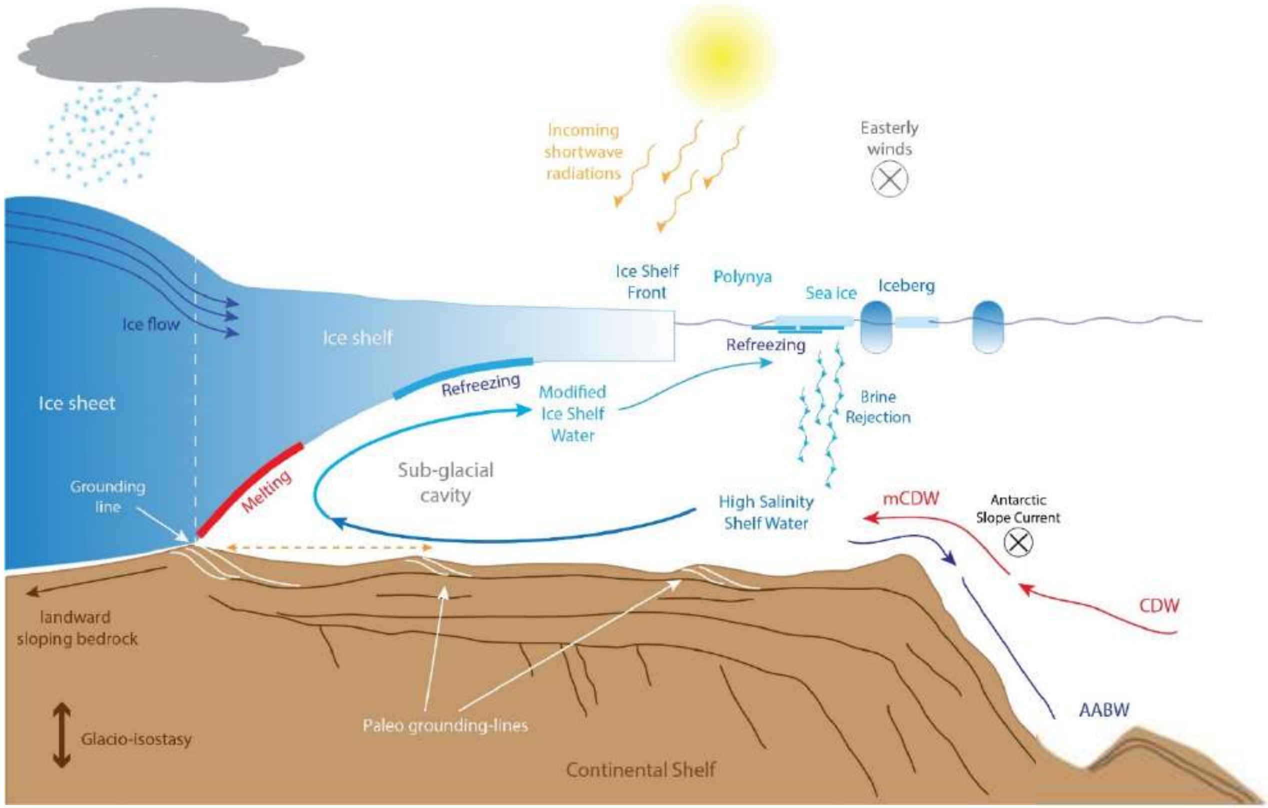


the basement consists of crystalline bedrock or consolidated sediments,

Englacial Reflectivity is due to fractures.

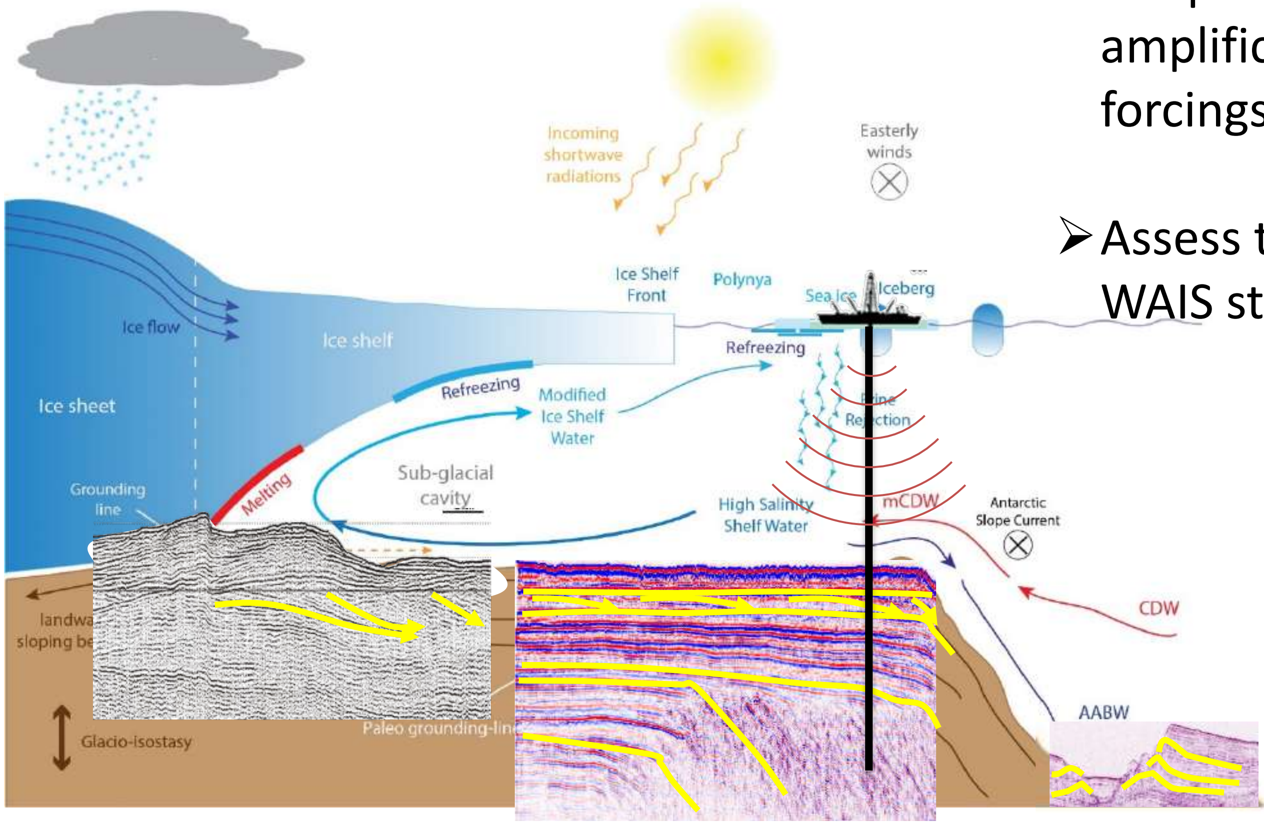
Fractures are propably produced by the huge stresses arising in the lower part of the glacier, indicating **that the principal component of the ice stream motion is deformation in the ice, rather than basal sliding.**

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

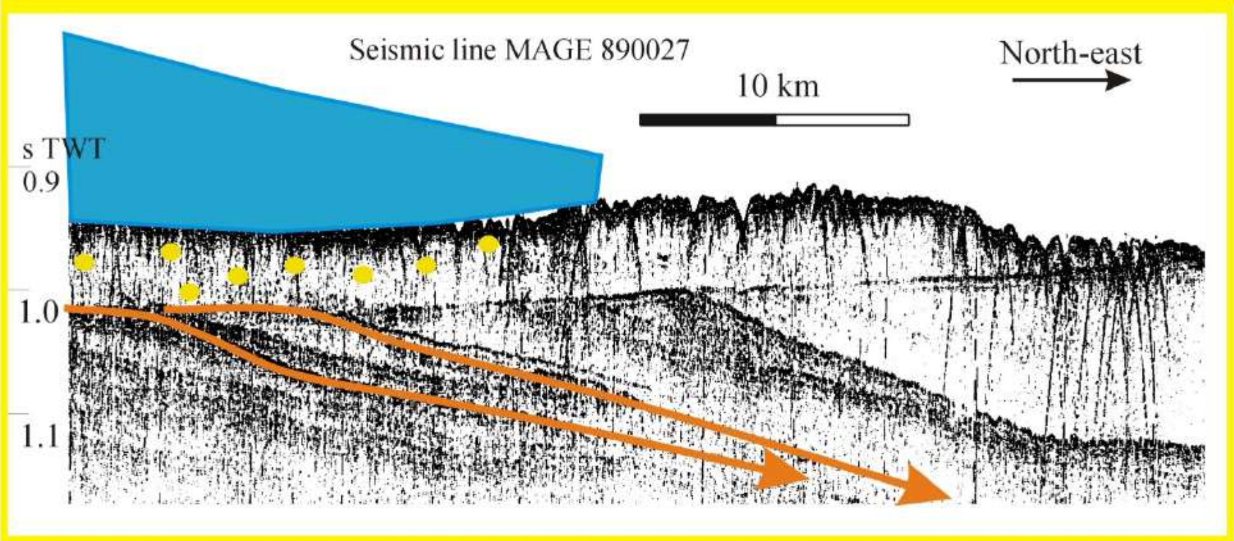
Paleo GZW indicate episodic palaeo ice-stream retreat punctuated by still-stands in the grounding-zone position (Dowdeswell et al., 2008; Ó Cofaigh et al., 2008).



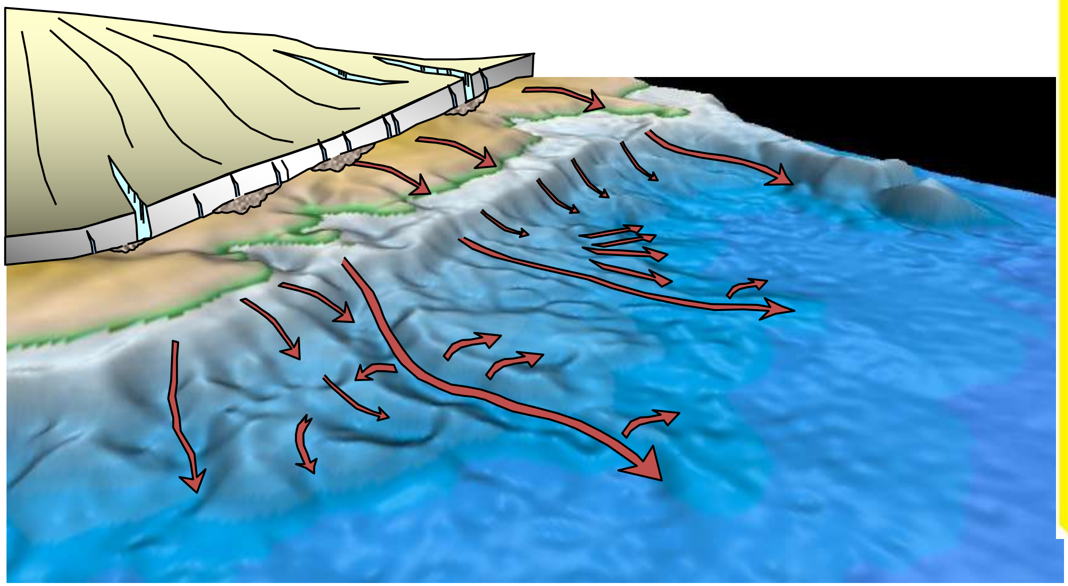
Colleoni et al., 2018

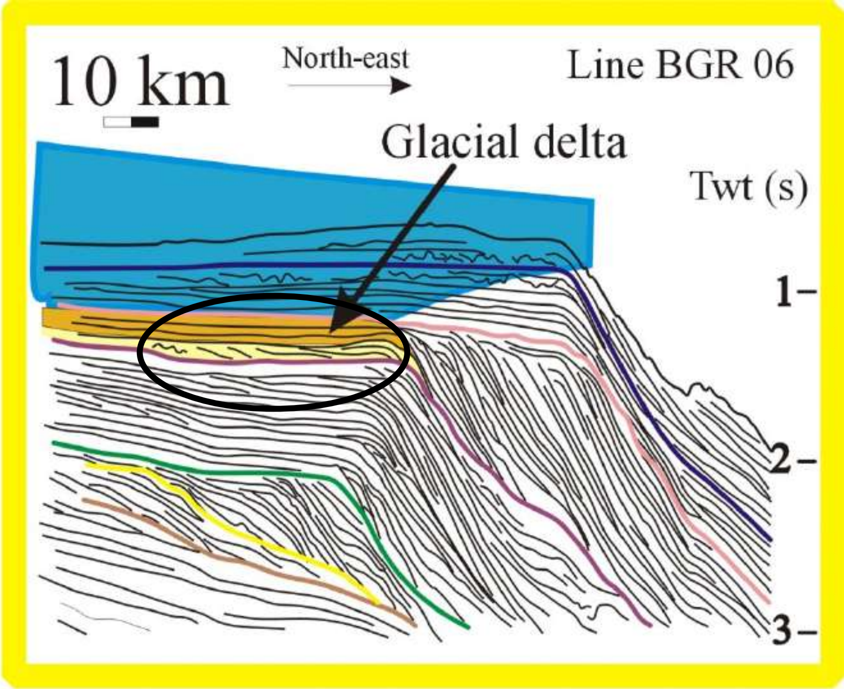
- Reconstruct ice volume change, atmospheric and oceanic temperatures to identify past polar amplification and assess its forcings/feedbacks

- Assess the role of oceanic forcing on WAIS stability/instability



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).

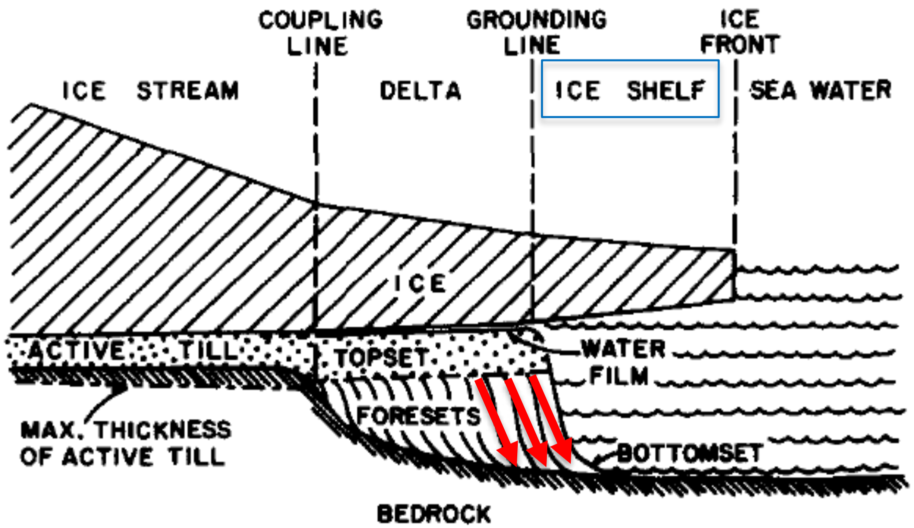
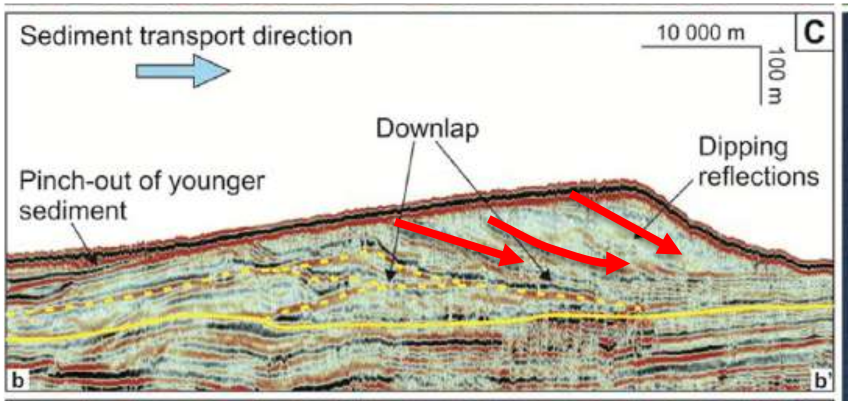
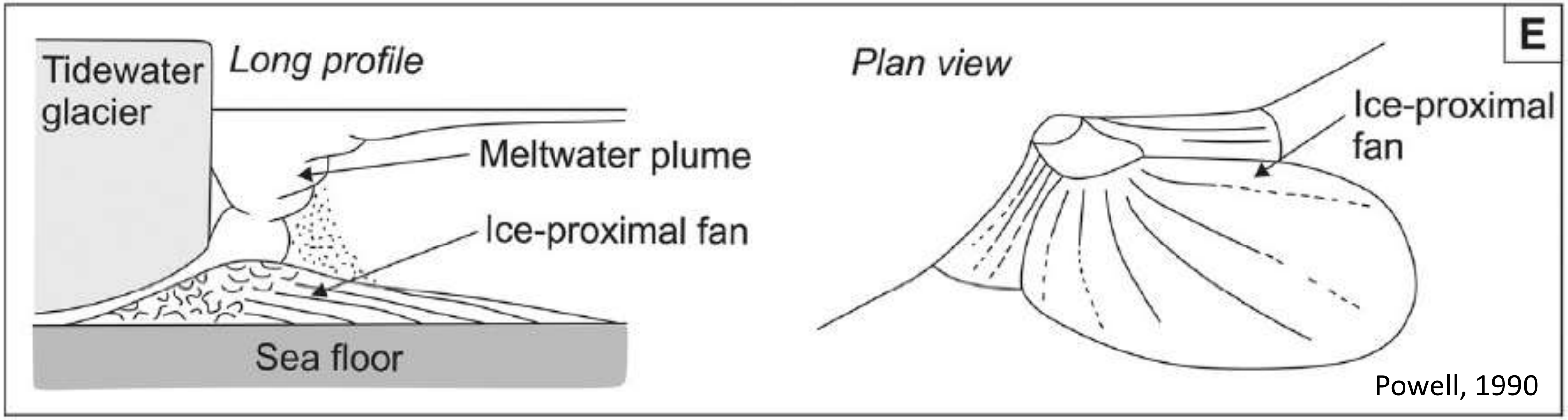


Fig.3. Cartoon of the likely configuration of the ice stream, till delta, and ice shelf.



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.

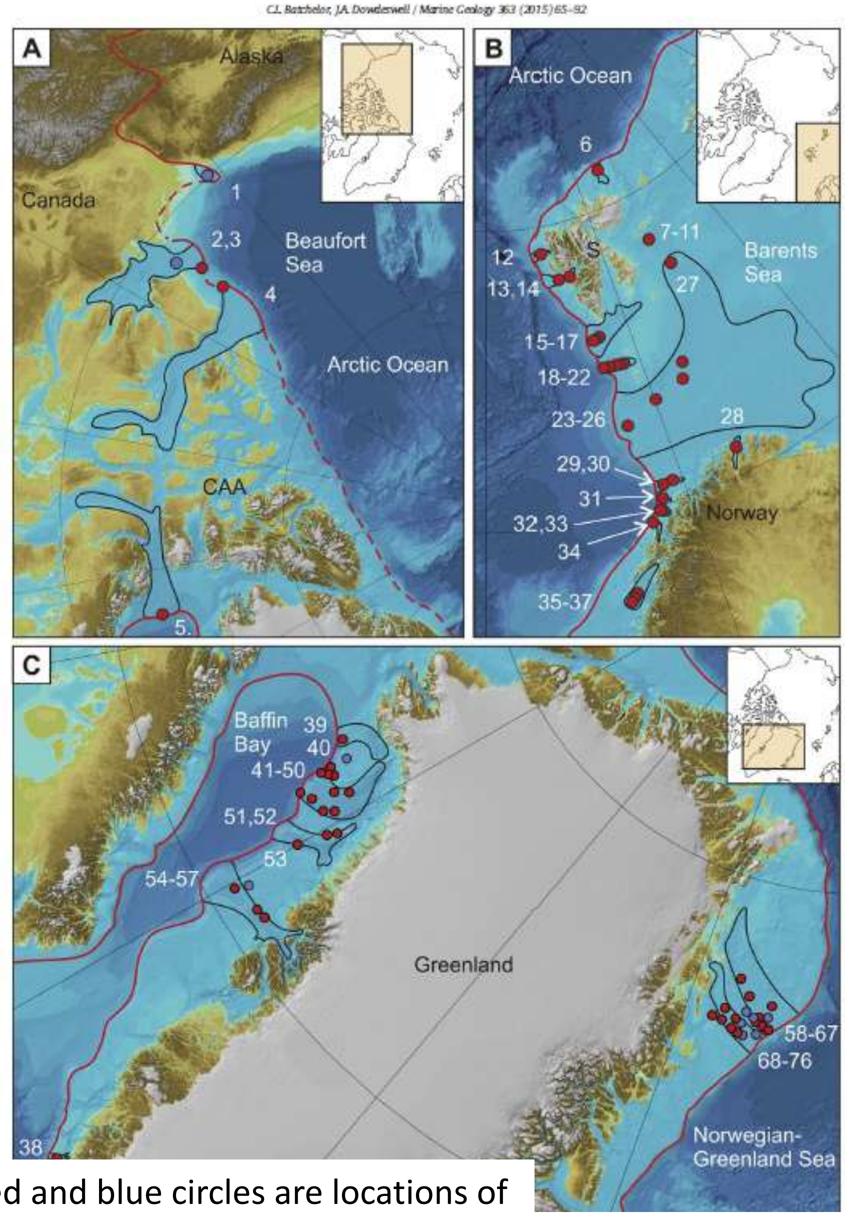
Moraine ridges and ice-proximal fans may also build up at the grounding zone during still-stands of the ice margin, but these require either considerable vertical accommodation space or sediment derived from point-sourced subglacial meltwater streams

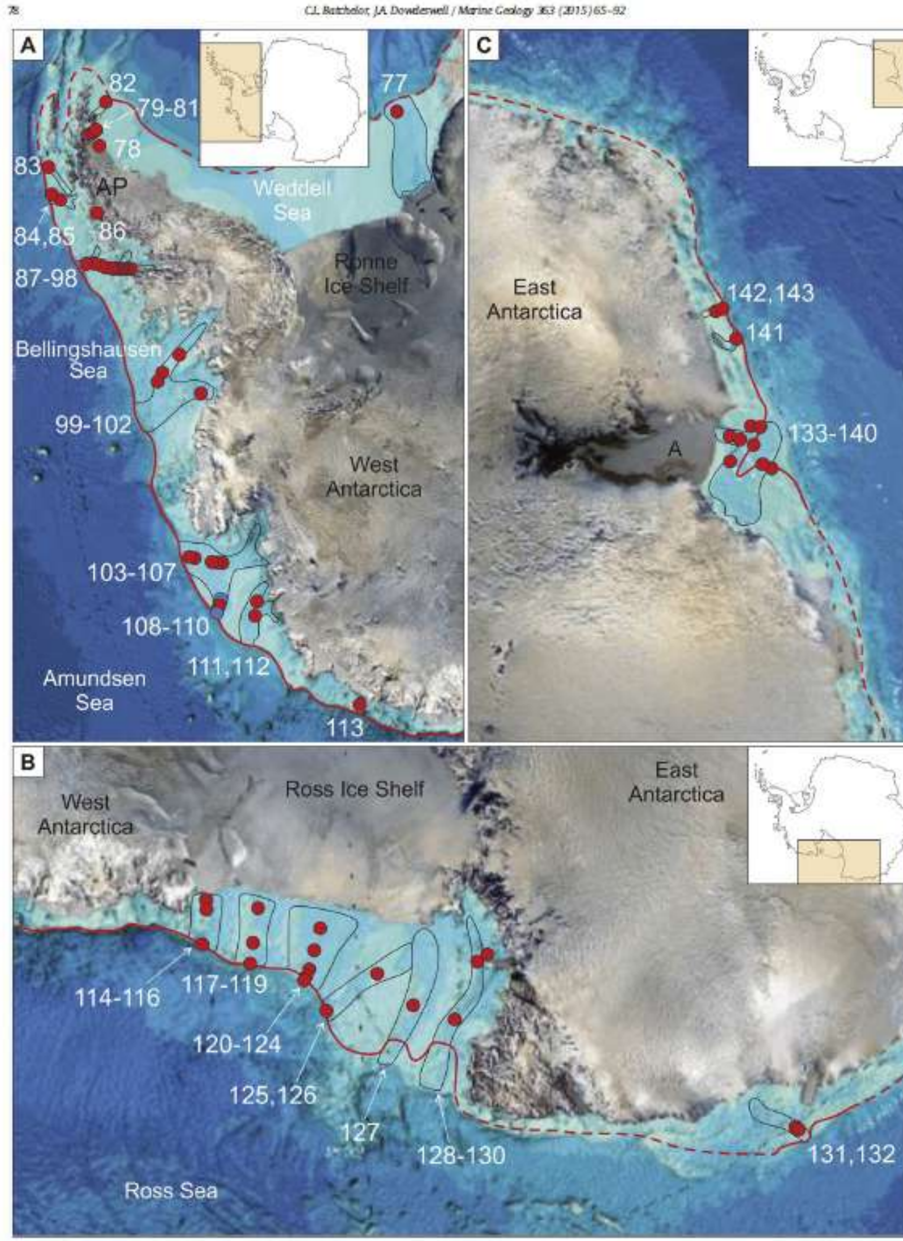


Powell, 1990

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.

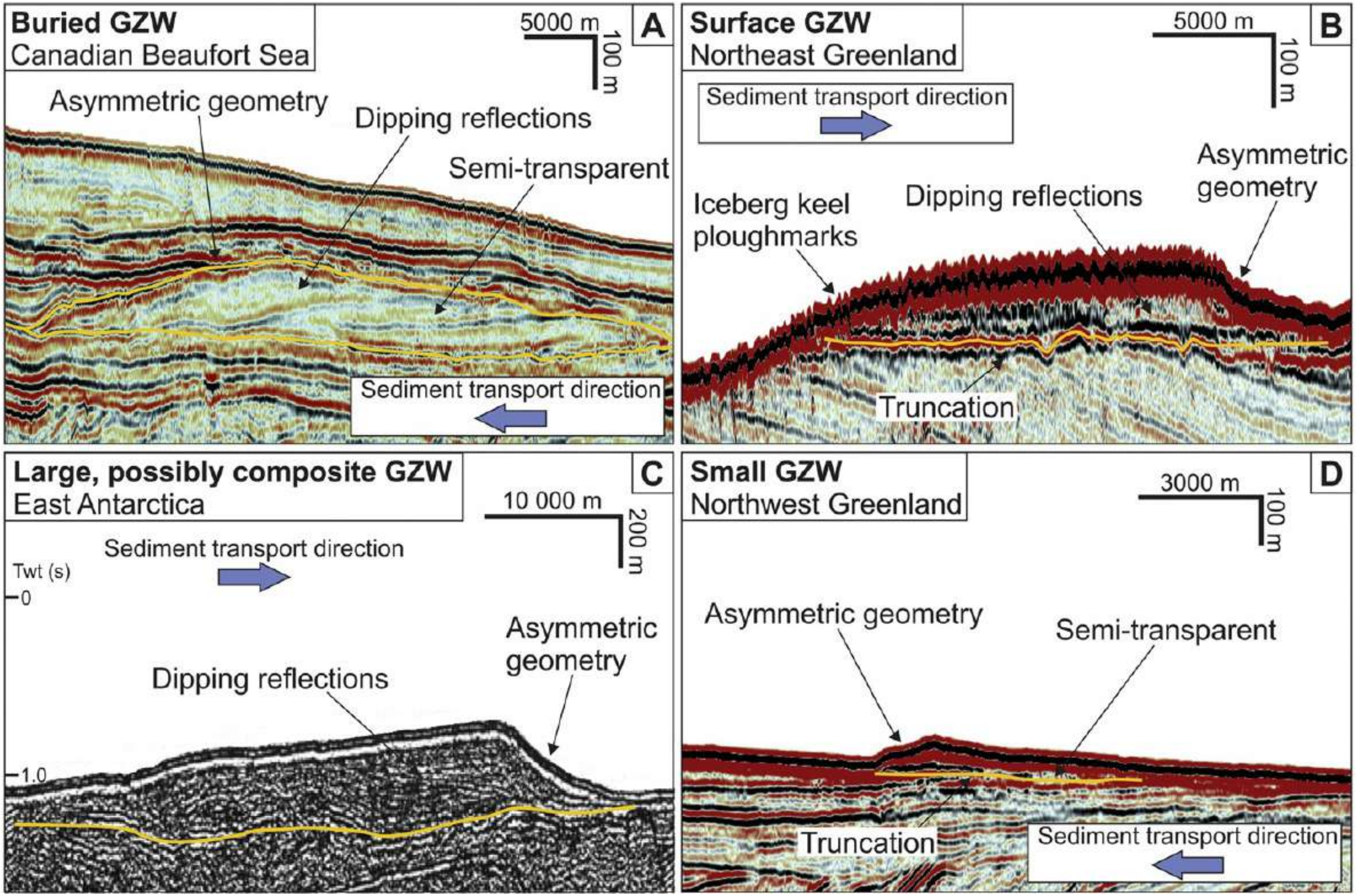




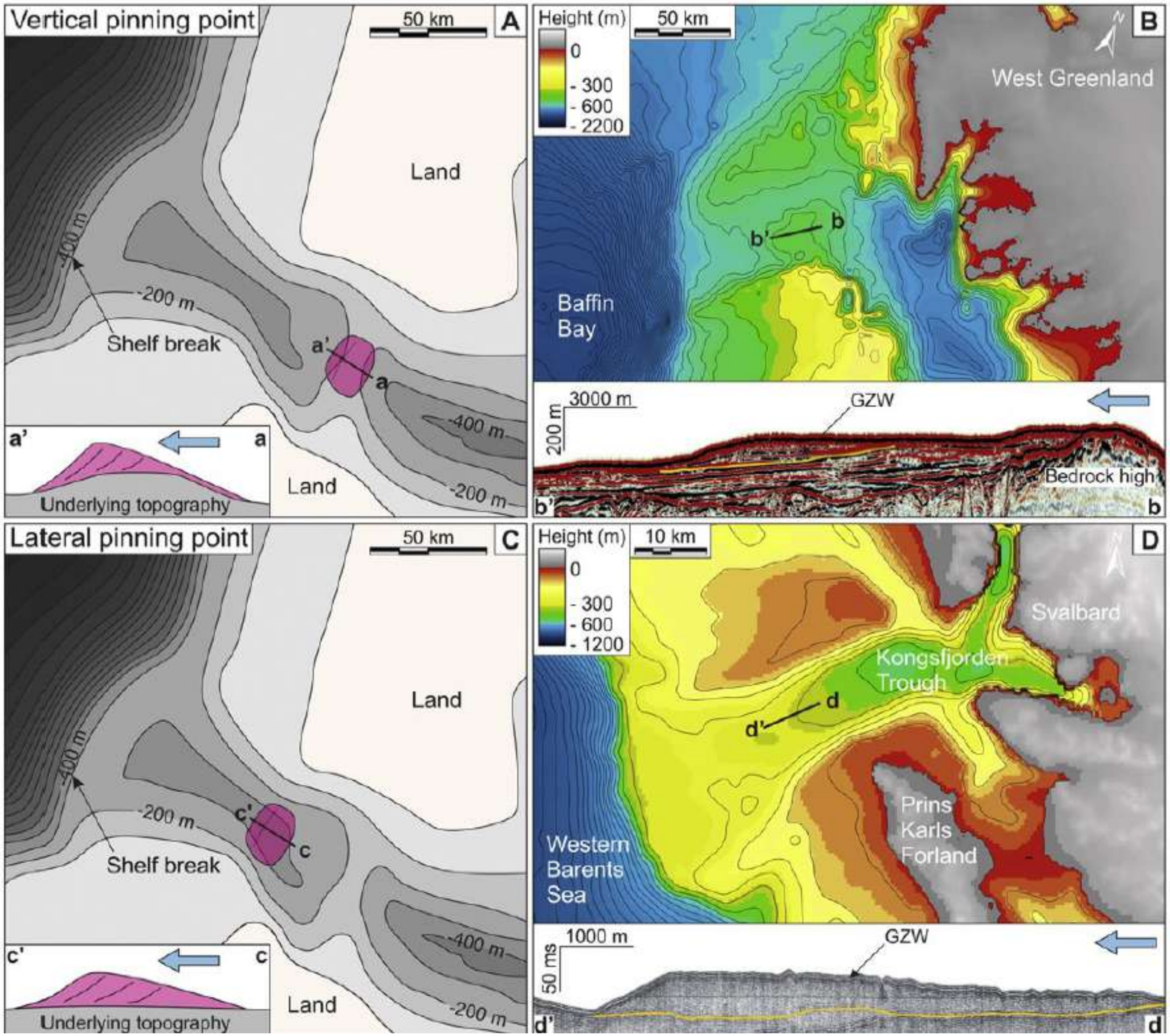
Red and blue circles are locations of surface and buried GZWs

Batchelor et al., 2015

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



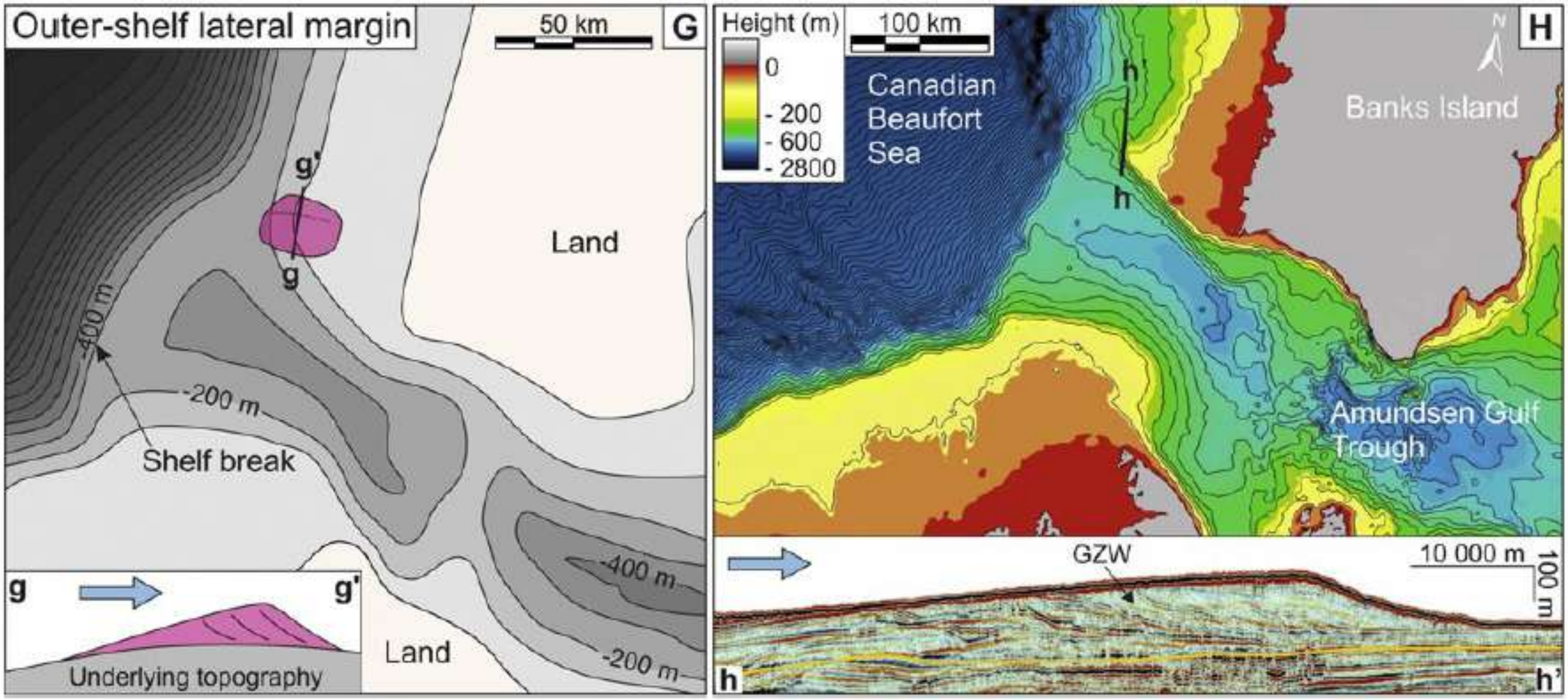
C.L. Batchelor, J.A. Dowdeswell / Marine Geology 363 (2015) 65–92



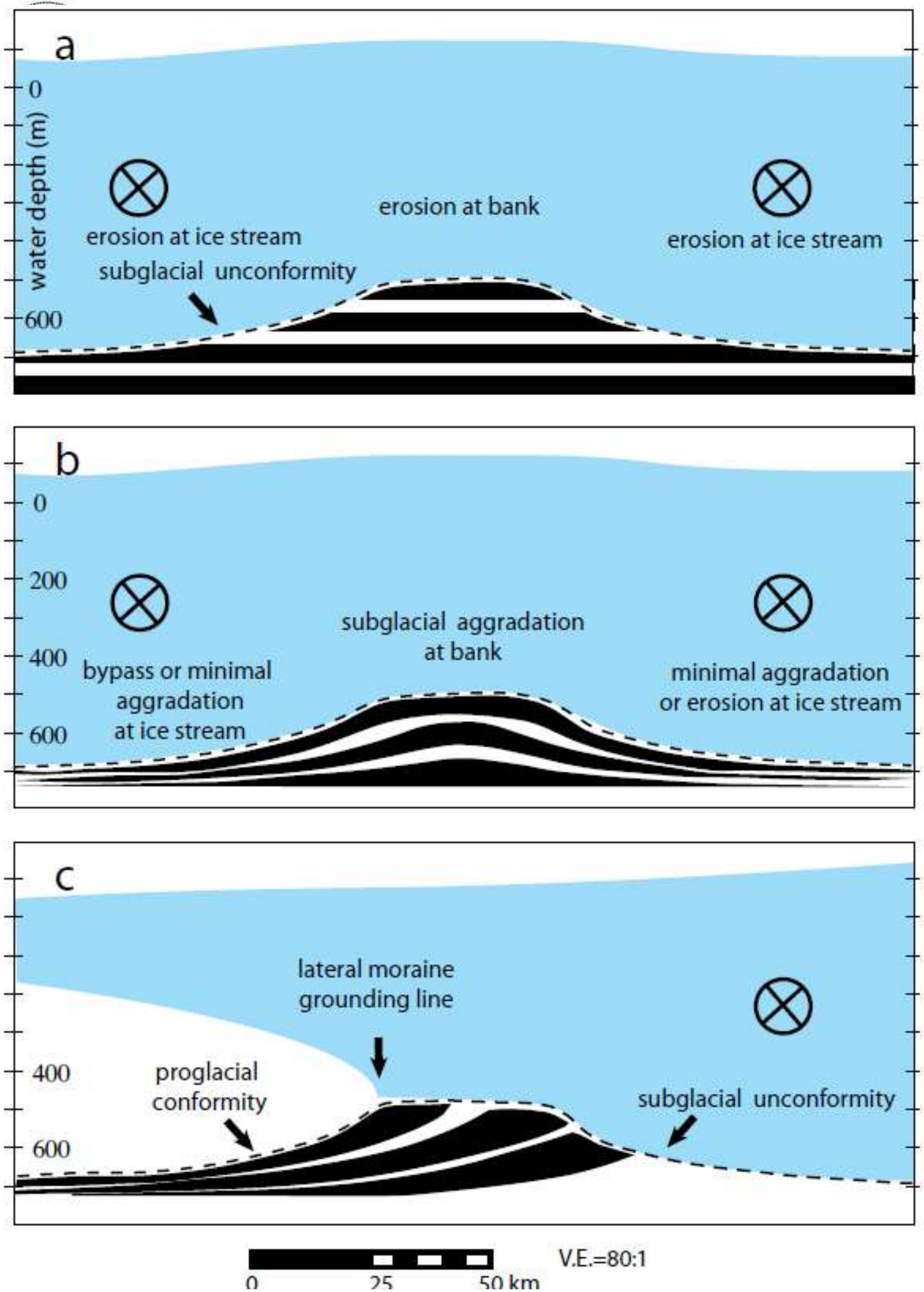
Bedrock outcrops on the seafloor can act as vertical pinning points

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.

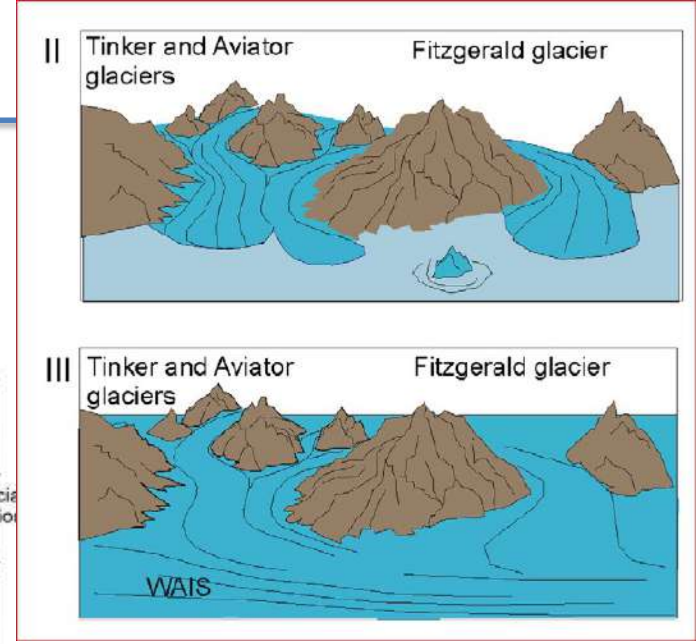
(a) Ice streams erode deep basins into the underlying strata whereas erosion between ice streams is minimal.

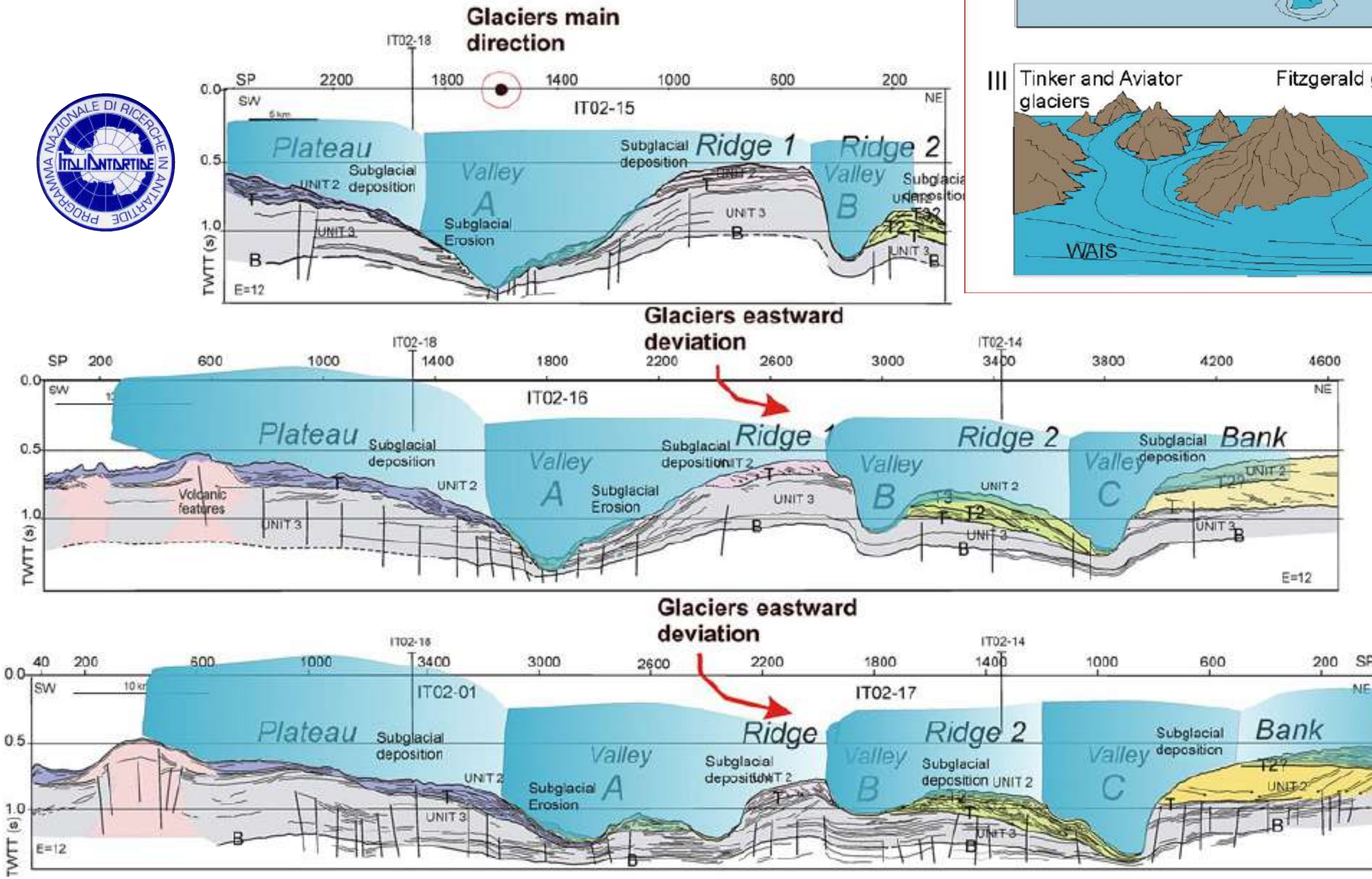
(b) Subglacial aggradation of sediment where ice flow is slowest between ice streams constructs a bank.

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

Bart and De Santis 2012

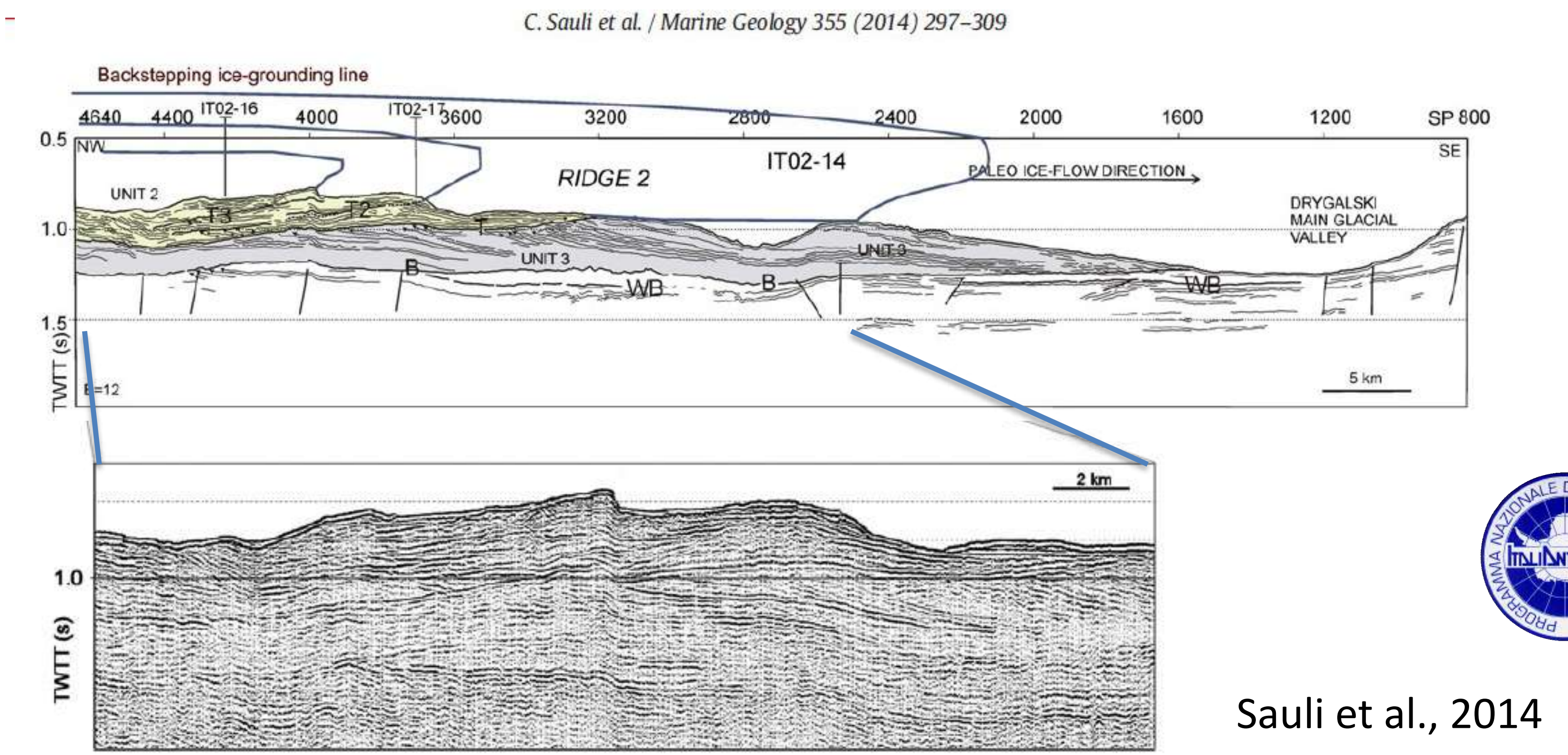
Sauli et al., 2014



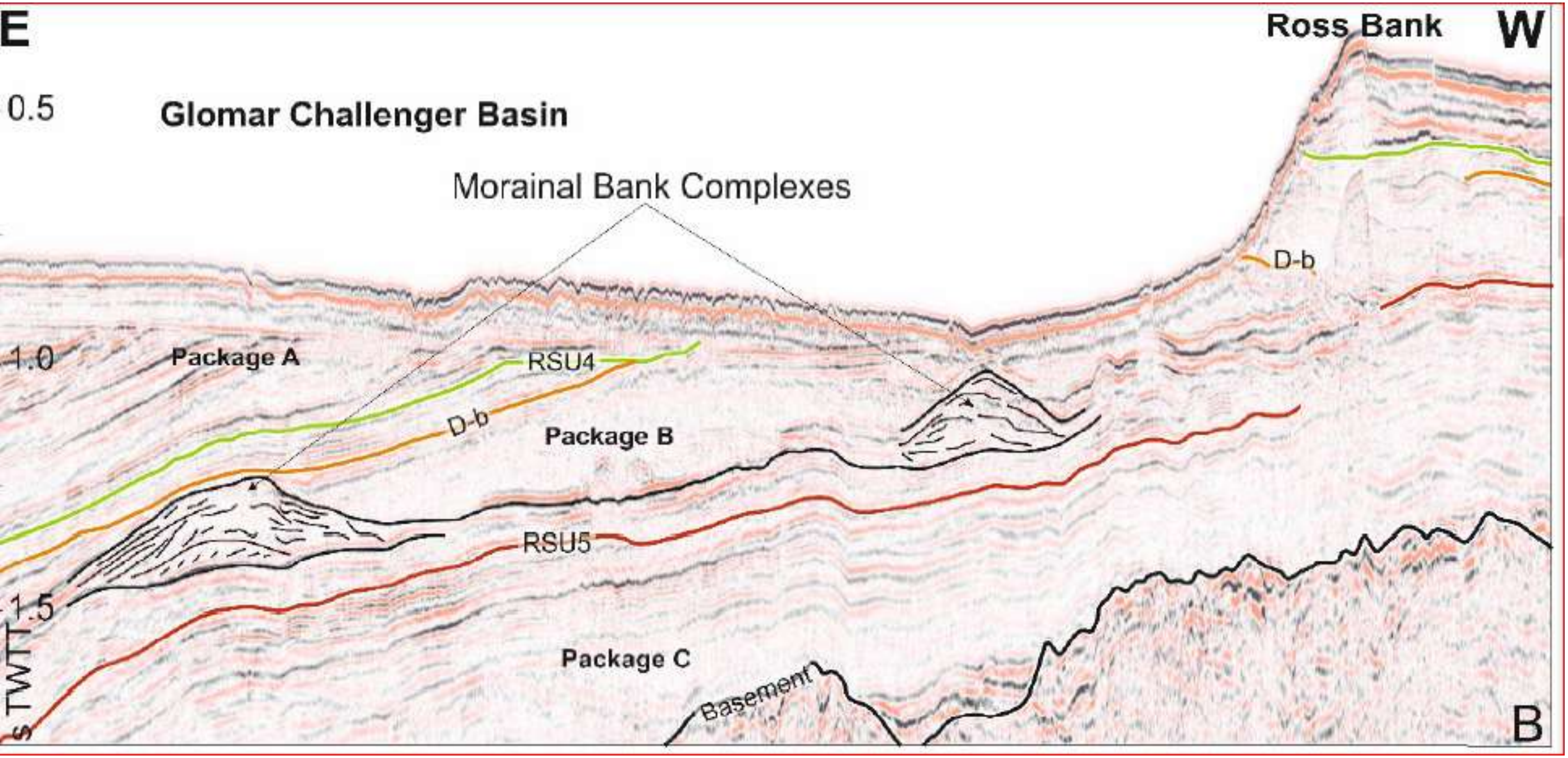


Moraines are typically composed of various unsorted ice-contact sediments and therefore possess a semitransparent to chaotic character on acoustic profiles.

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



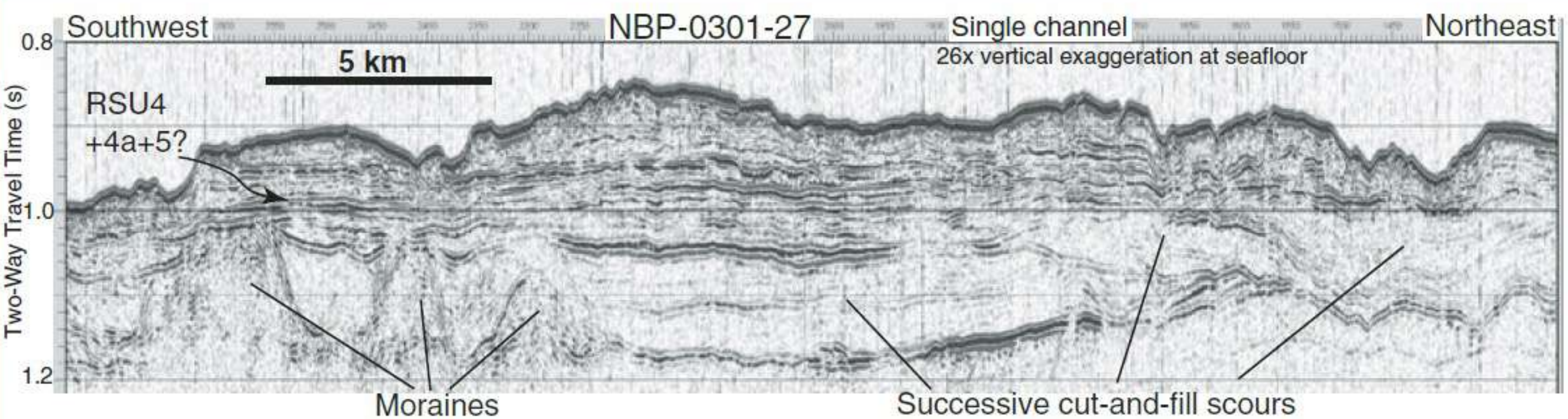
Sauli et al., 2014


E
W
Ross Bank
0.5
Glomar Challenger Basin
Morainal Bank Complexes
D-b
1.0
Package A
RSU4
D-b
Package B
RSU5
1.5
s TWT
Package C
Basement
B

Istituto Nazionale di Oceanografia e di Geofisica Sperimentale

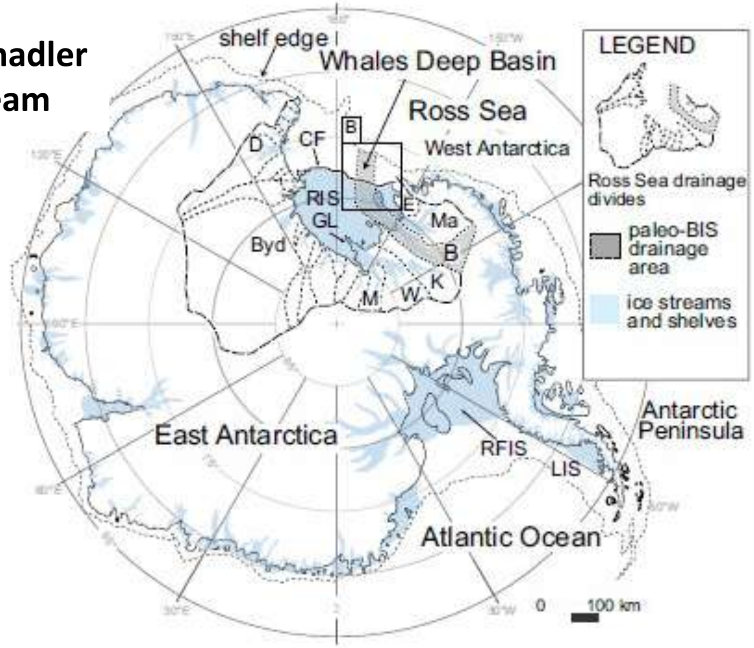
Oligocene development of the West Antarctic Ice Sheet recorded in eastern Ross Sea strata

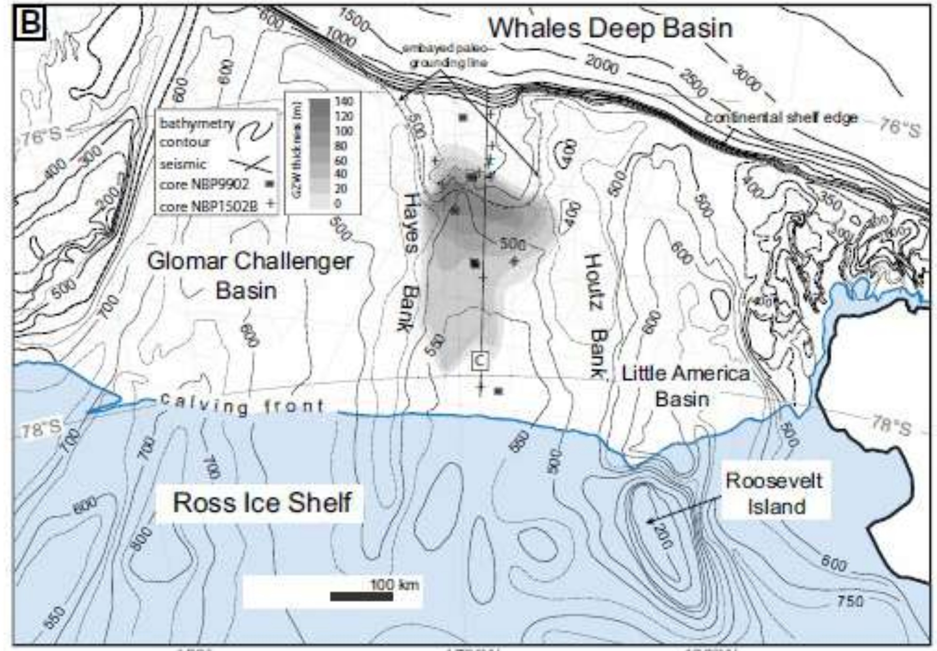
Christopher C. Sorlien Institute for Crustal Studies, University of California–Santa Barbara, Santa Barbara, California 93106, USA
Bruce P. Luyendyk
Douglas S. Wilson
Robert C. Decesari* — Department of Earth Science, University of California–Santa Barbara, Santa Barbara, California 93106, USA
Louis R. Bartek Department of Geological Sciences, CB 3315, University of North Carolina, Chapel Hill, North Carolina 27599-3315, USA
John B. Diebold Lamont-Doherty Earth Observatory, Columbia University, 61 Route 9W, Palisades, New York 10964-8000, USA



Geology 2007

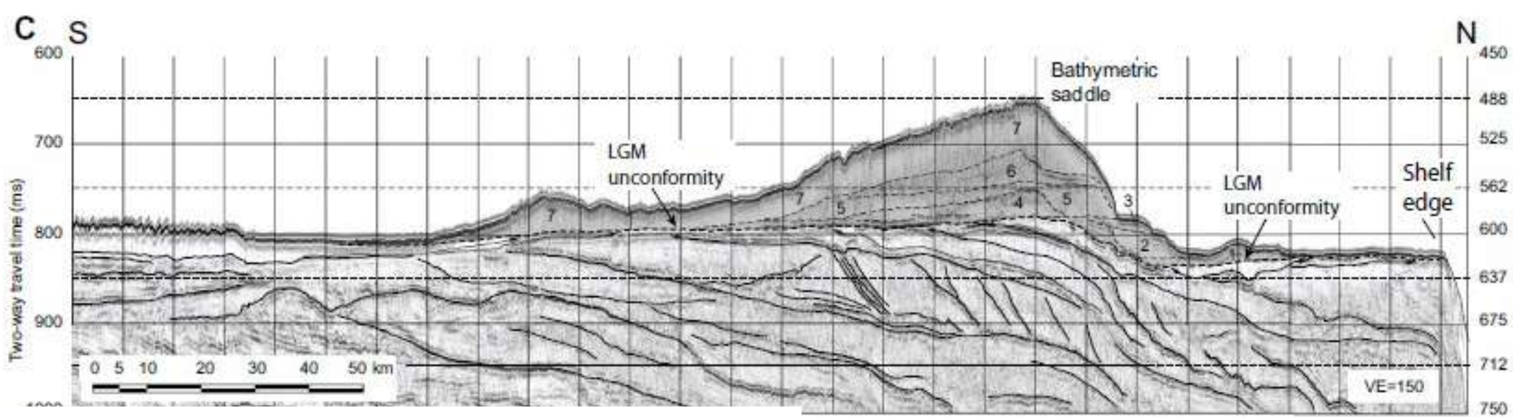
paleo–Bindschadler Ice Stream



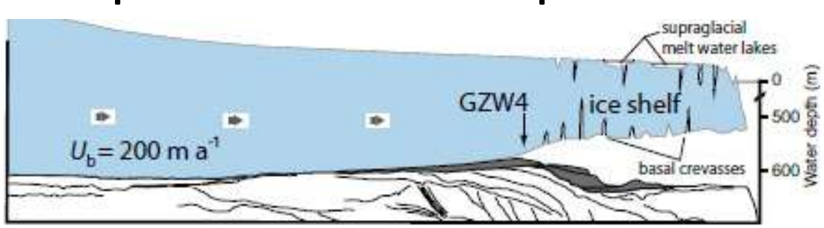


Most of GZW deposited in only 800 ± 300 years after the breakup of the fringing ice shelf

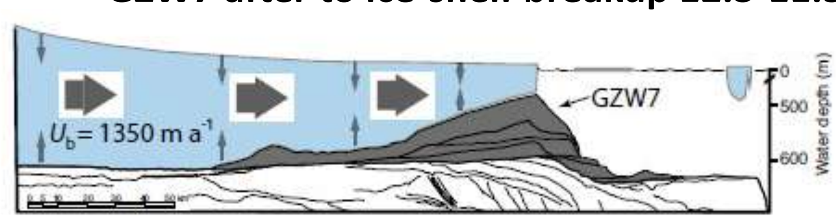
Bart, Tulaczyk, 2020

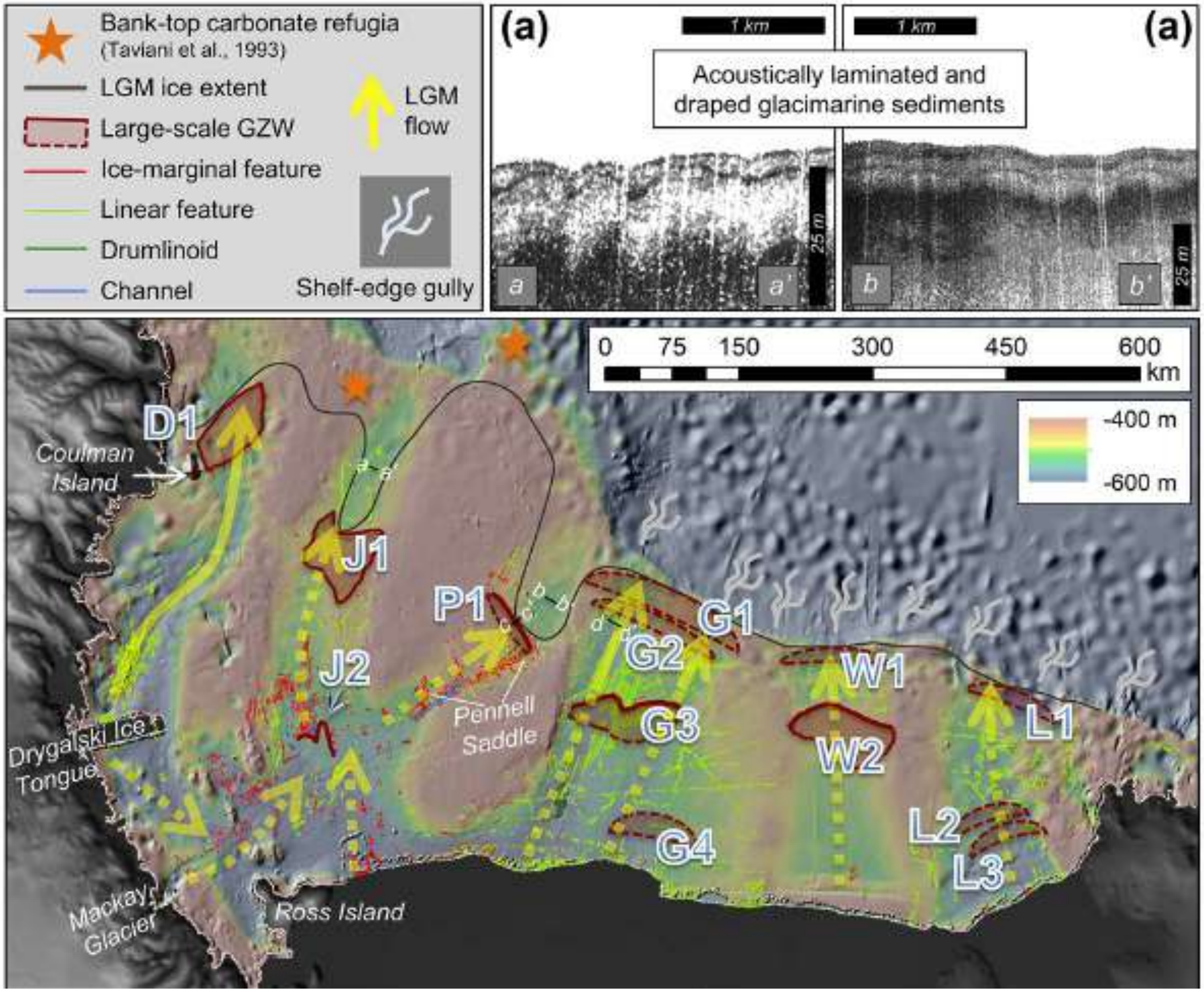


GZW4 prior to ice-shelf breakup 14.7-12.3 Ka

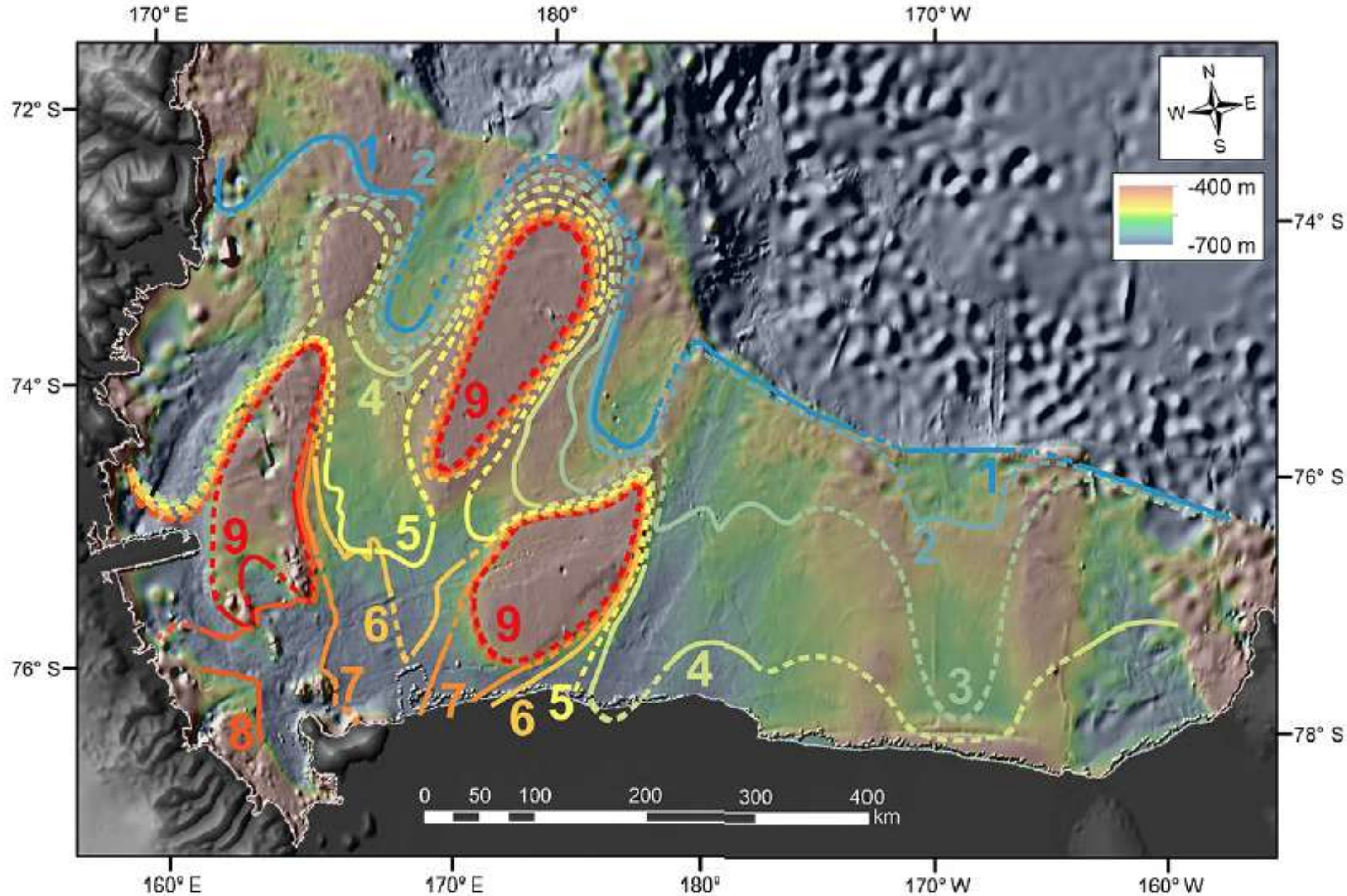


GZW7 after to ice-shelf breakup 12.3-11.5 Ka





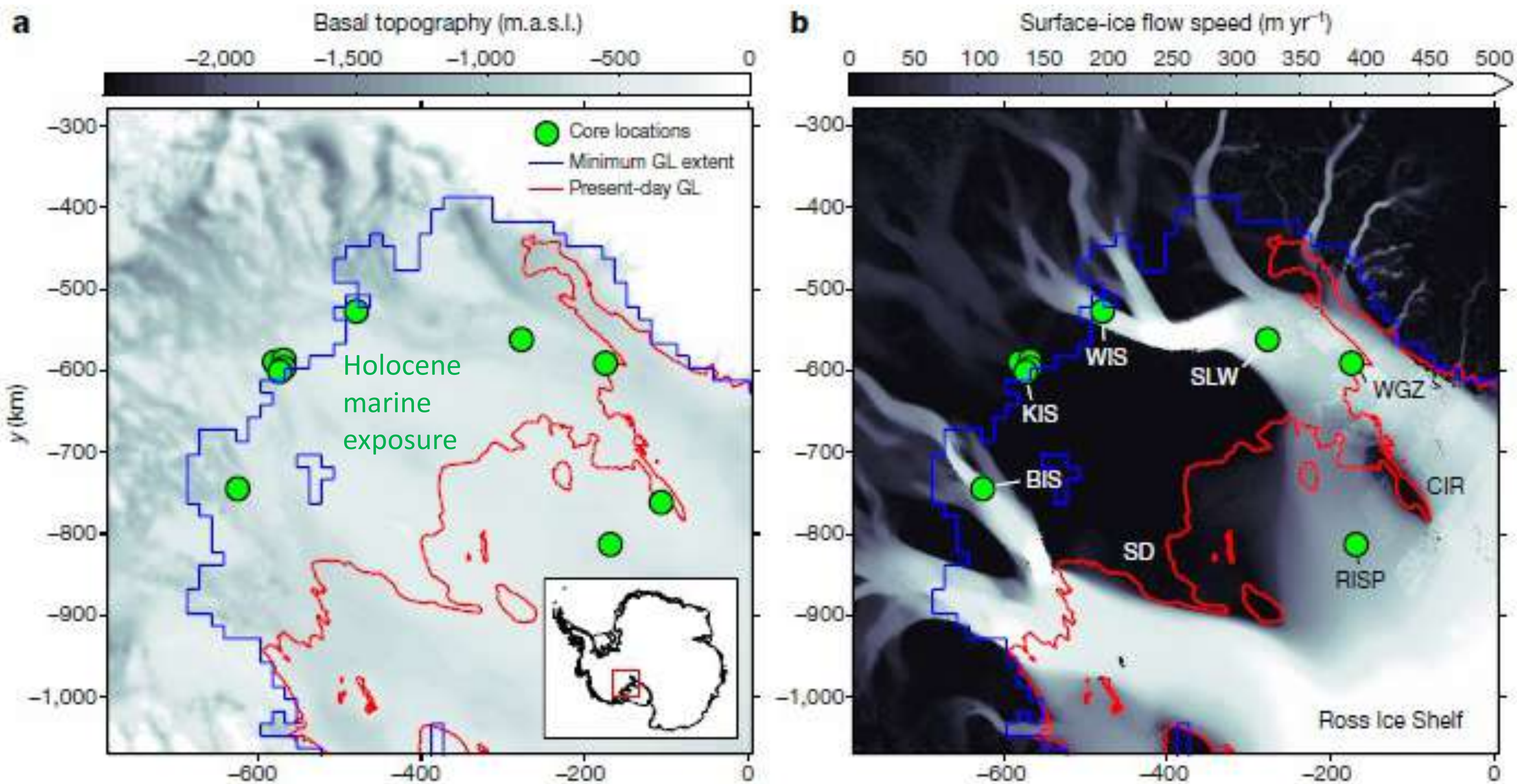
Halberstadt et al., 2016



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.

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

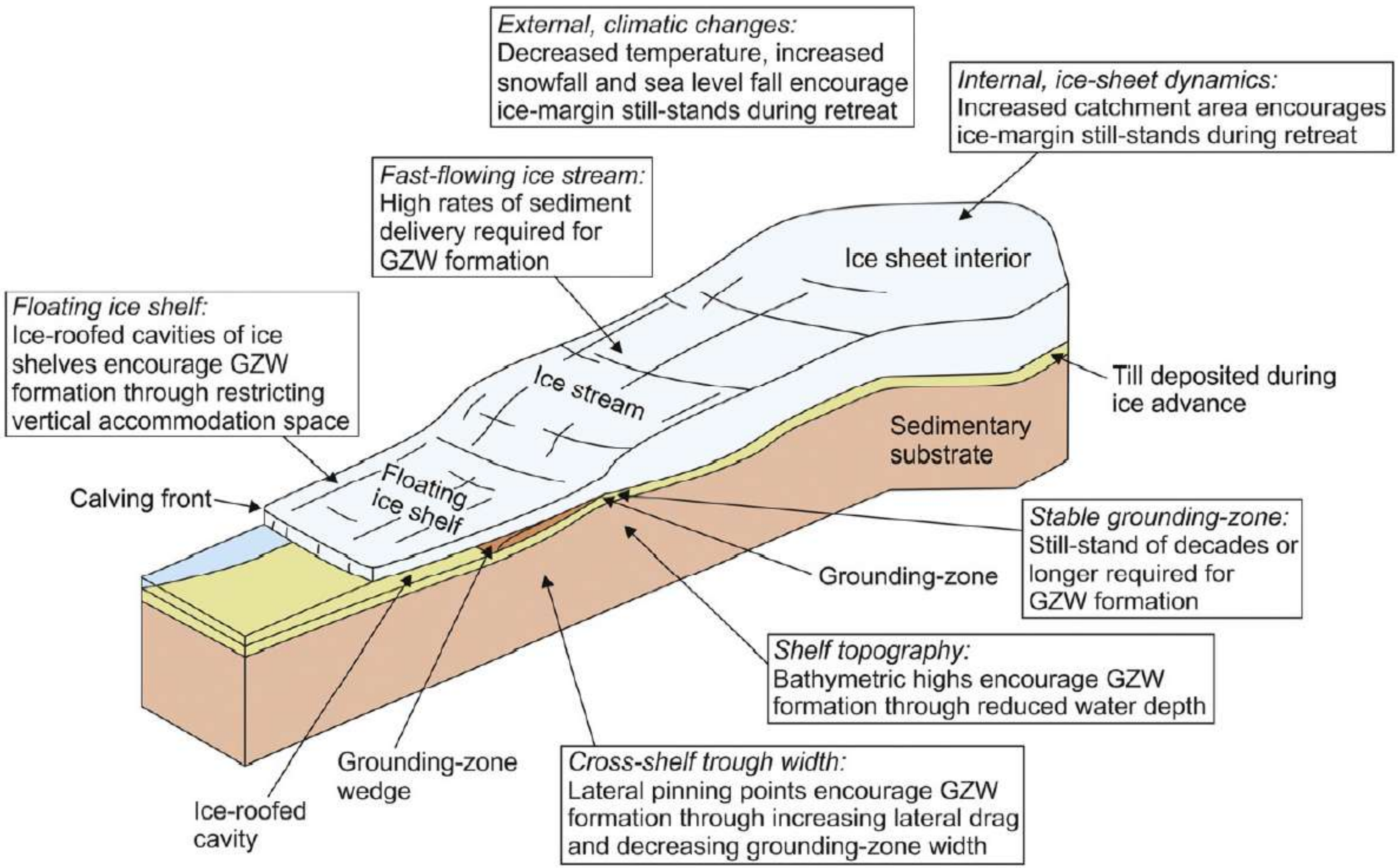
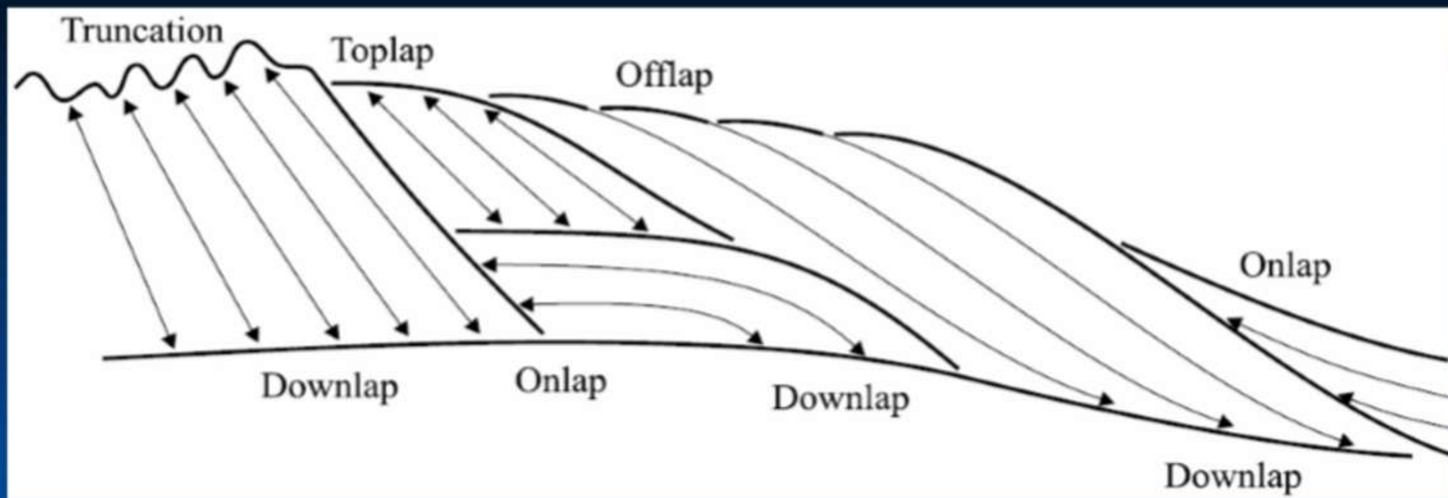


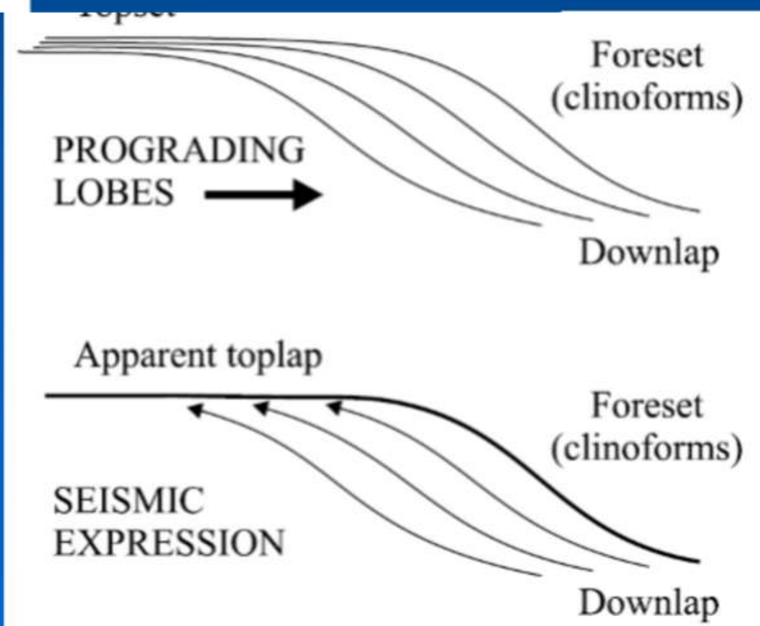
Fig. 11. Diagram illustrating the factors controlling the formation of GZWs on high-latitude continental margins.

Batchelor et al., 2015

EXERCIZE

Stratal terminations (model-independent)





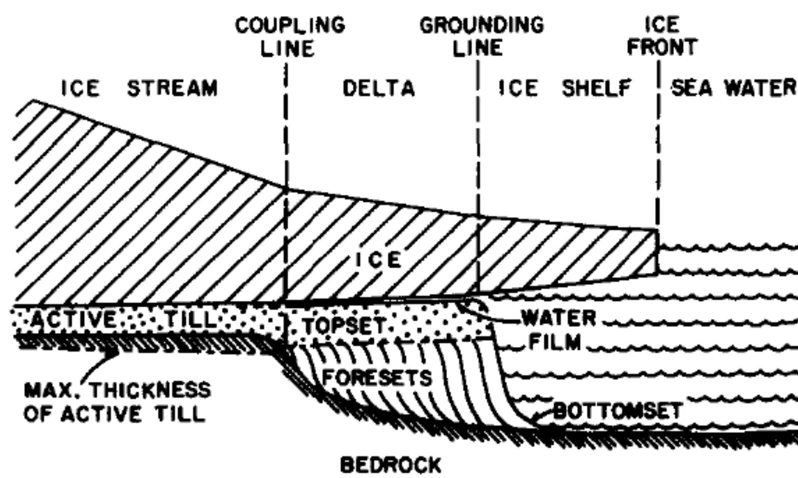
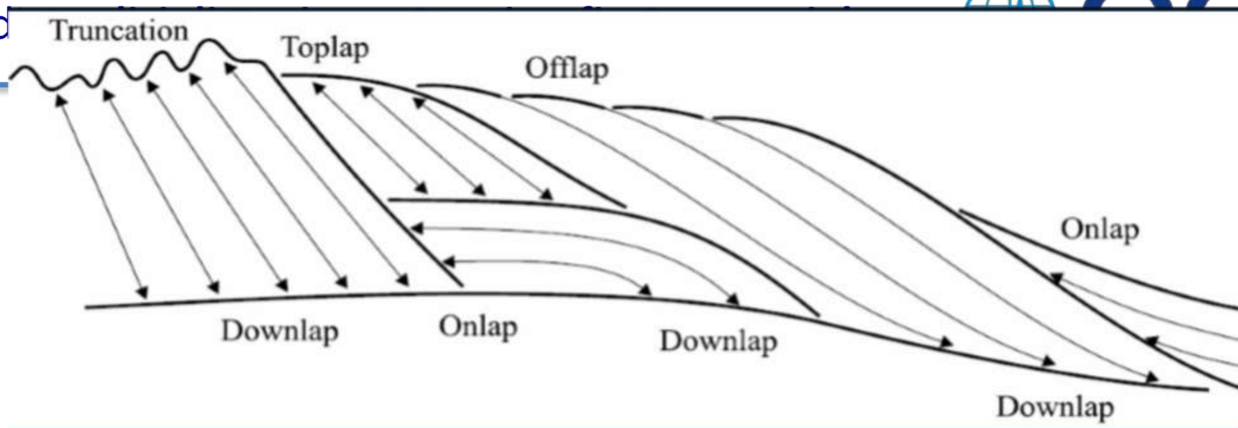


Fig.3. Cartoon of the likely configuration of the ice stream, till delta, and ice shelf.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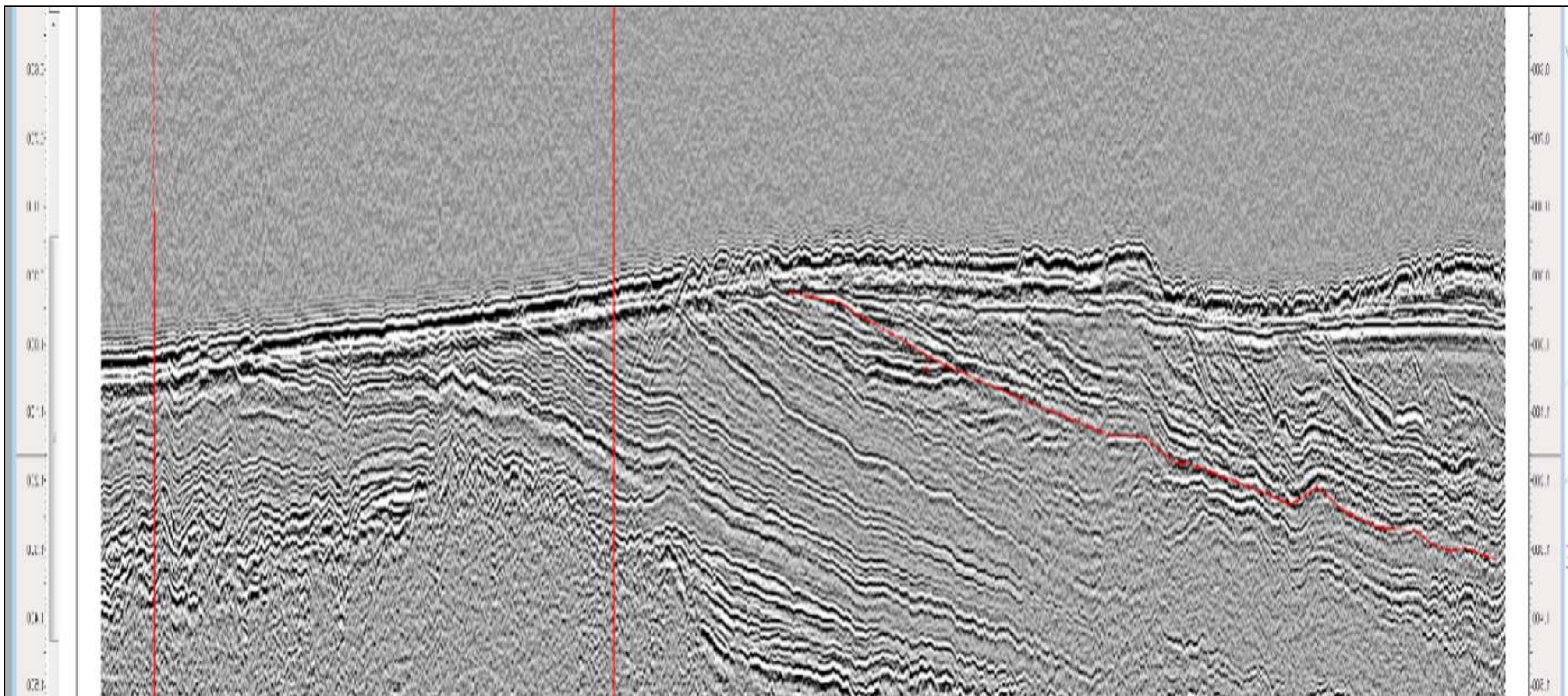
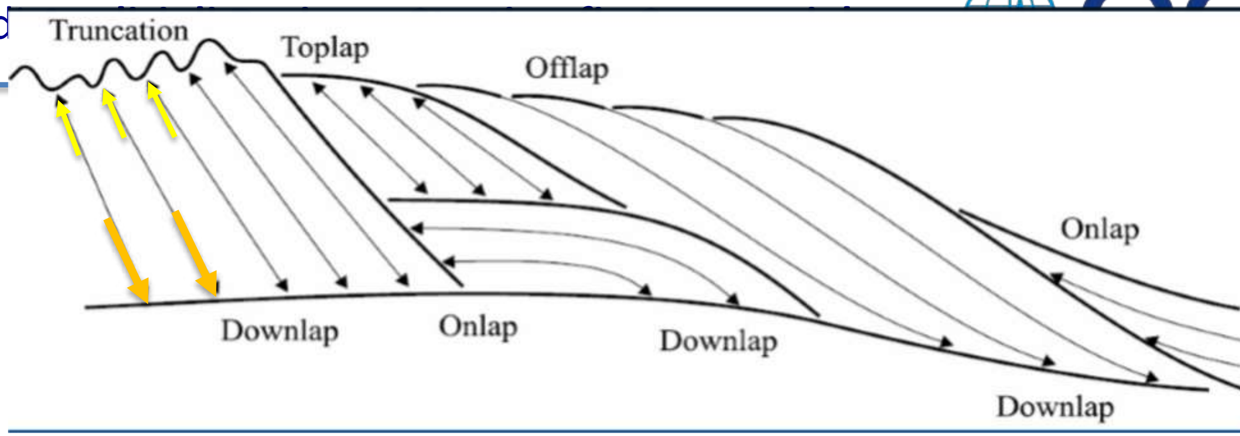
Toplap
Offlap
Onlap
Downlap
Onlap
Downlap
Downlap

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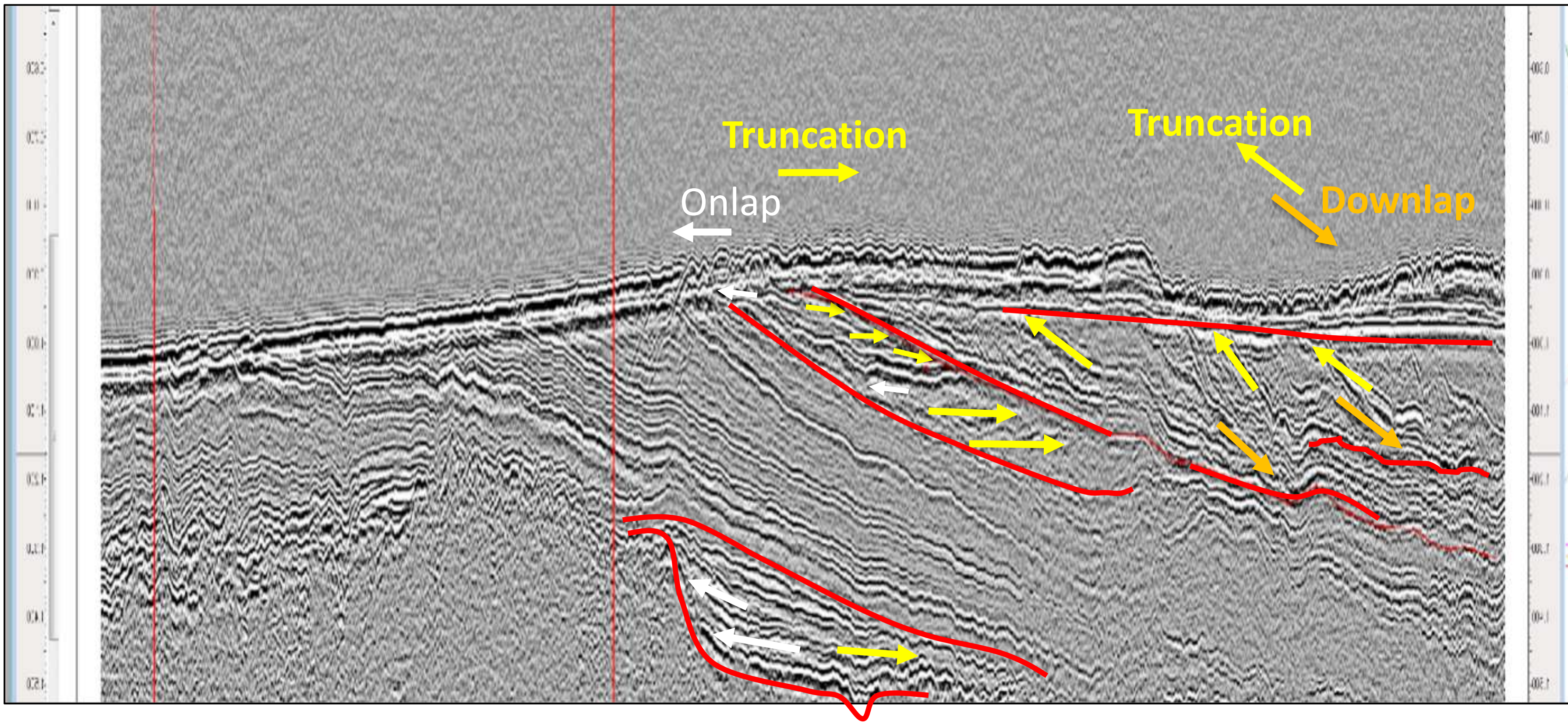
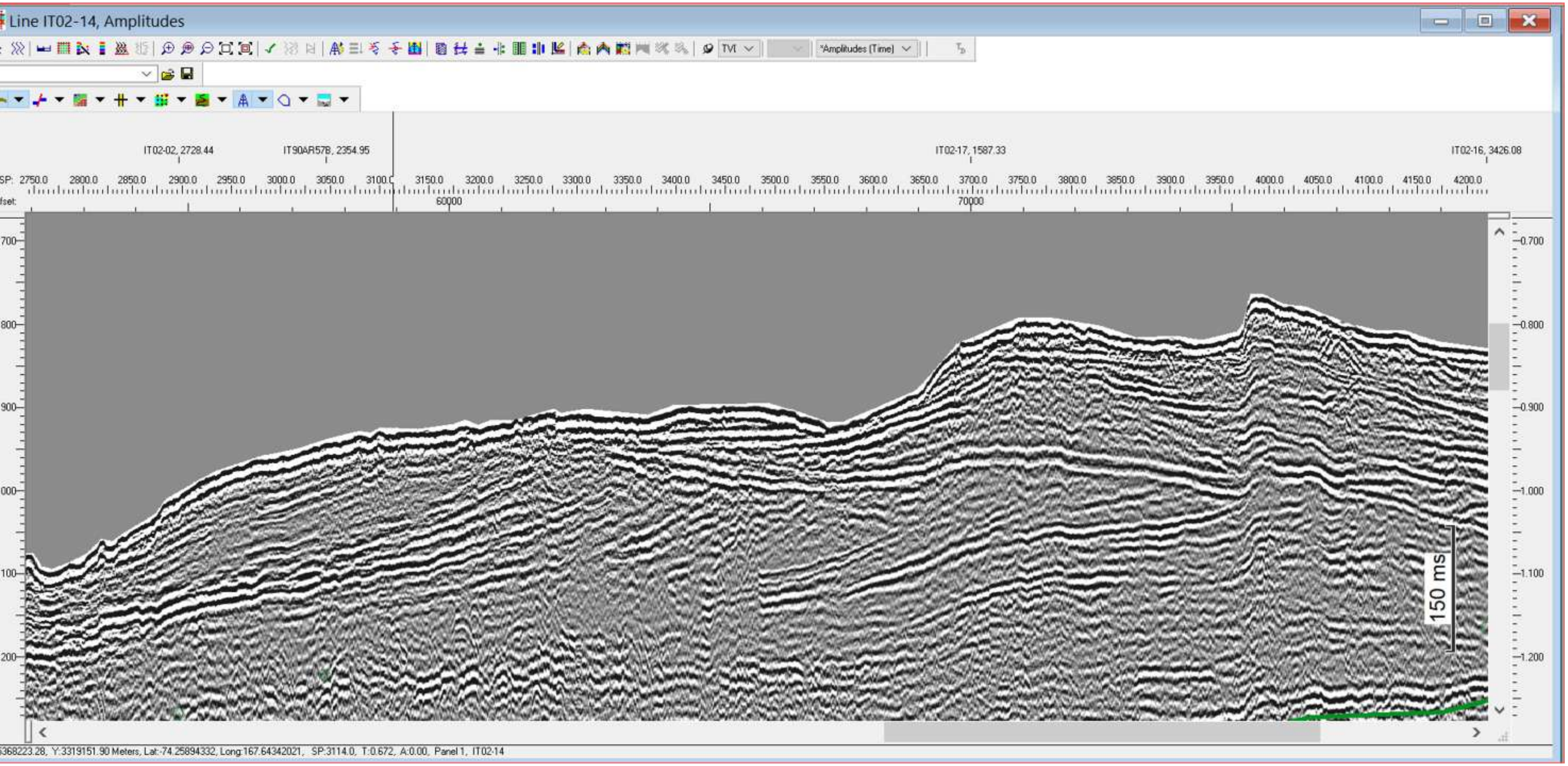
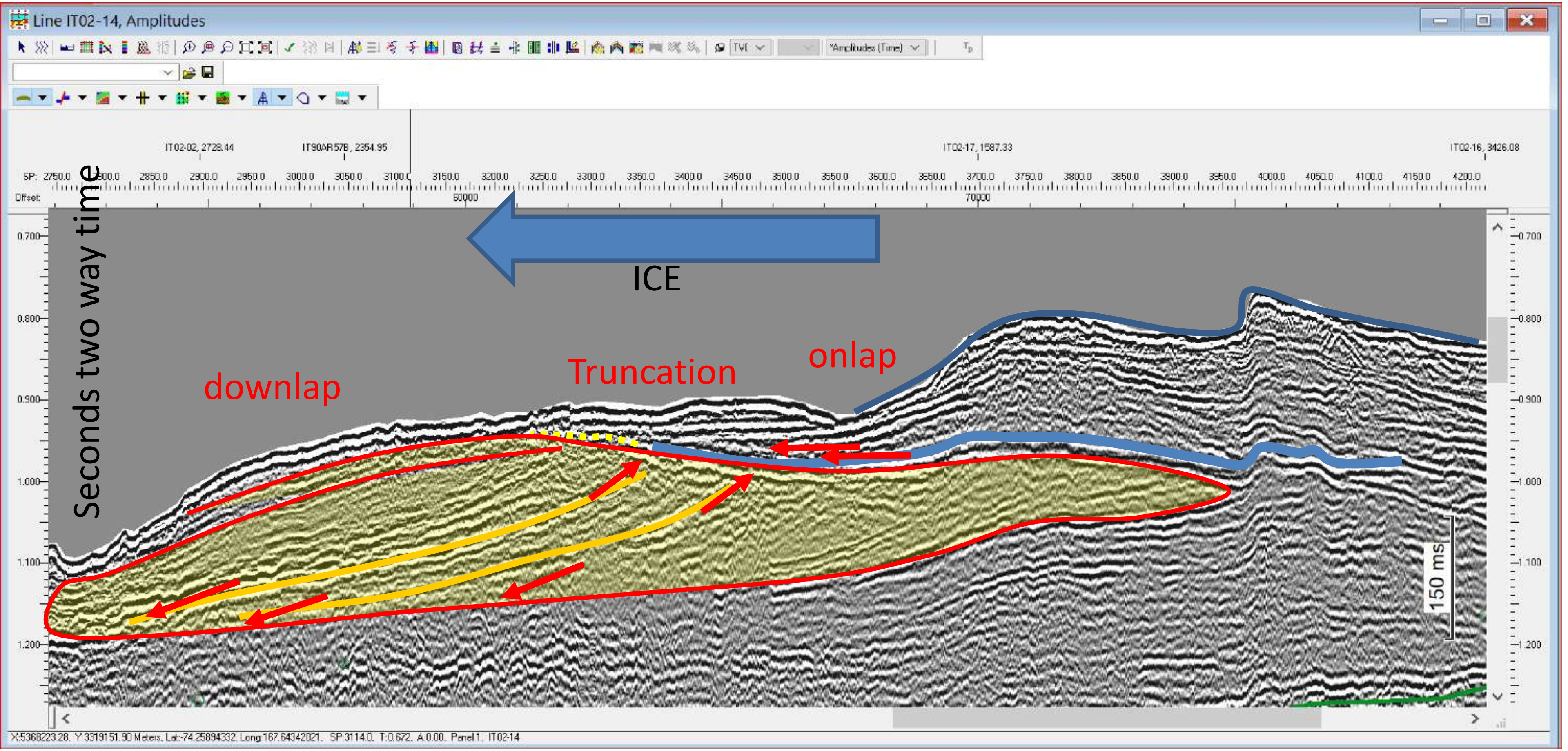
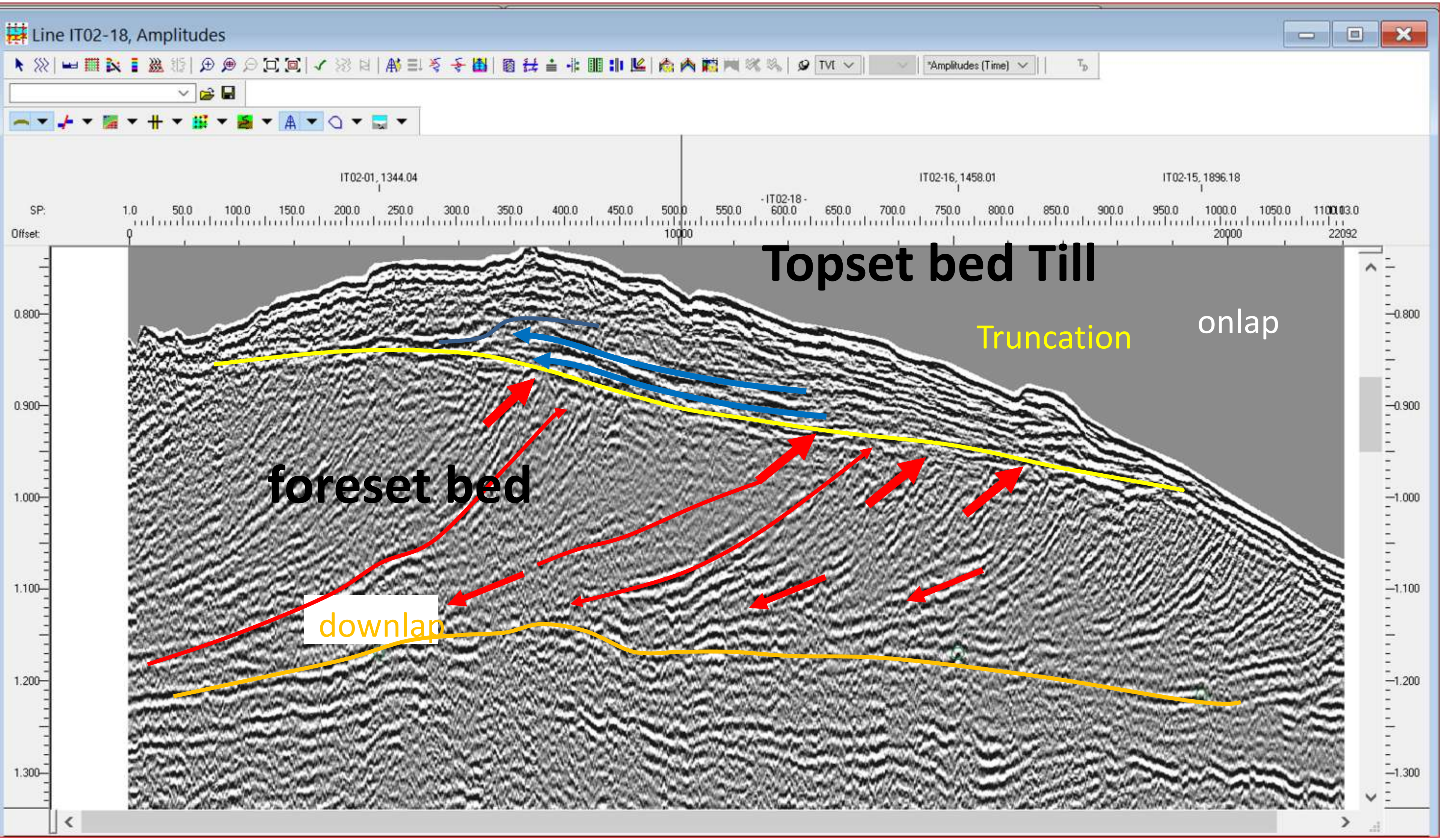
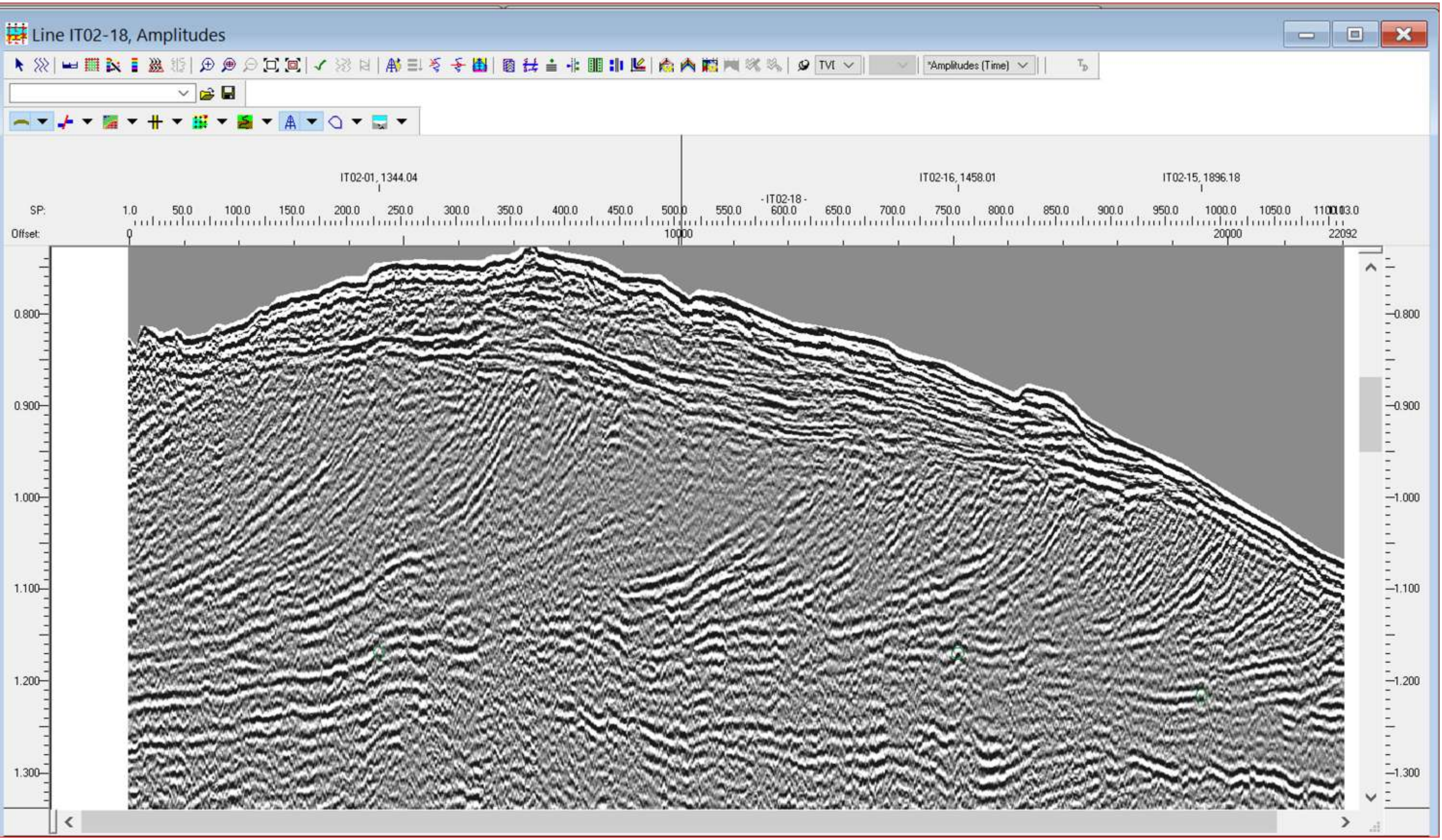
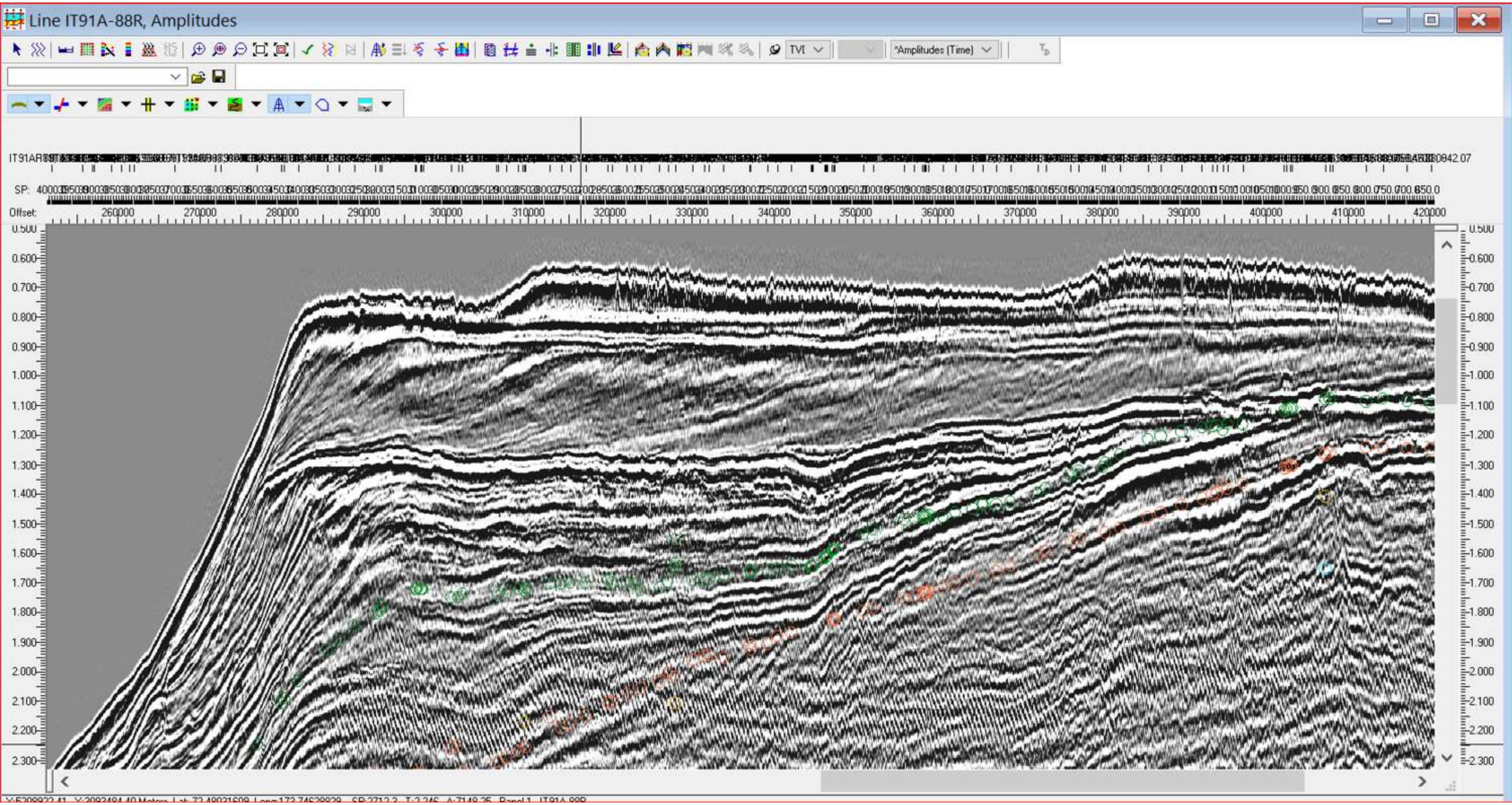

Truncation
Onlap
Truncation
Downlap


Line IT02-14, Amplitudes
IT02-02, 2728.44
IT90AR57B, 2354.95
IT02-17, 1587.33
IT02-16, 3426.08
150 ms


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


Line IT02-18, Amplitudes
IT02-01, 1344.04
IT02-16, 1458.01
IT02-15, 1896.18
IT02-18
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
TVI
*Amplitudes (Time)
SP:
Offset:
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270000
280000
290000
300000
310000
320000
330000
340000
350000
360000
370000
380000
390000
400000
410000
420000
0.500
0.600
0.700
0.800
0.900
1.000
1.100
1.200
1.300
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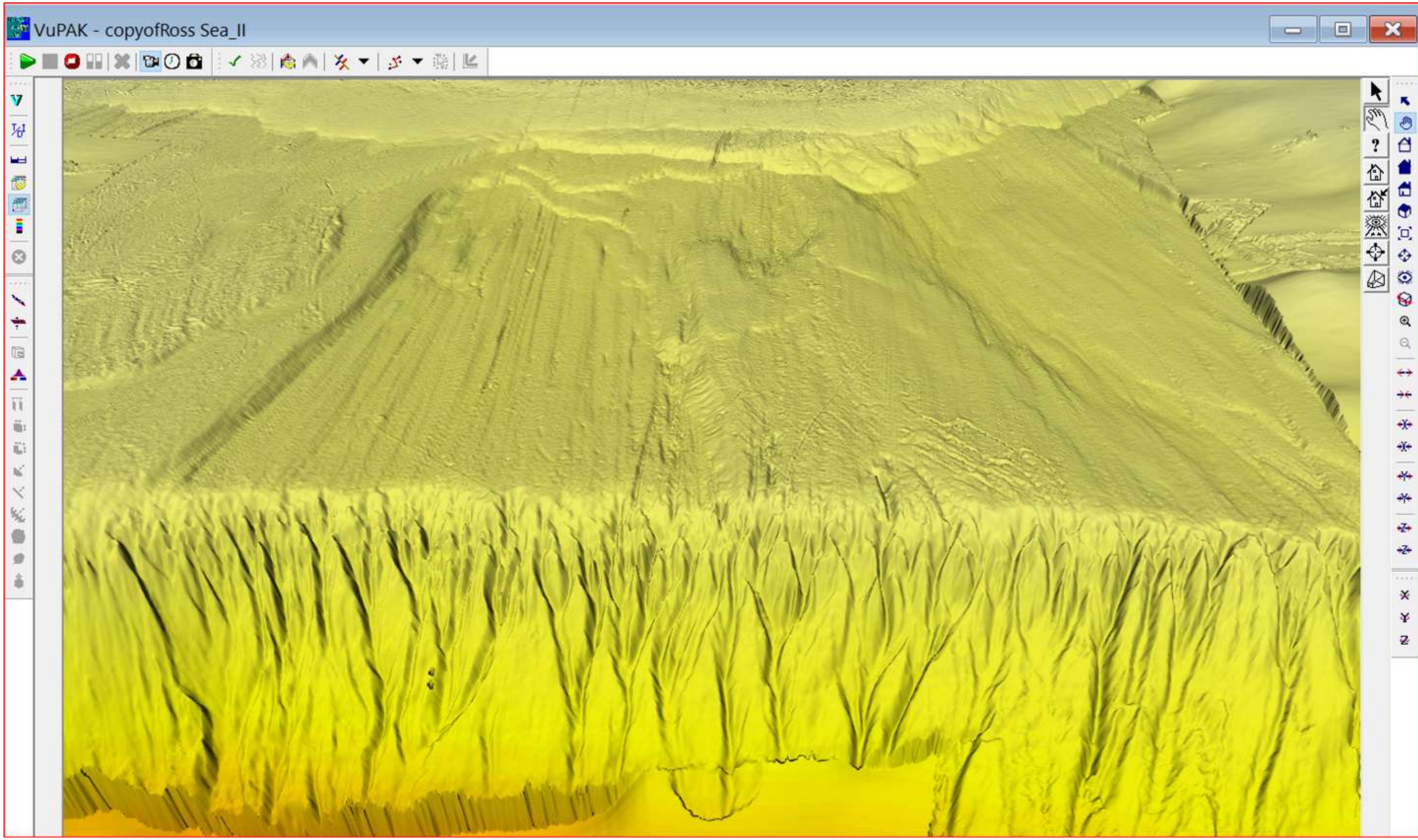
2.000
2.100
2.200
2.300

EXERCIZE


VuPAK - copyofRoss Sea_II

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10.1002/2017JF004259

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

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

Istituto Nazionale di Oceanografia e di Geofisica Sperimentale