

The Role of Refreezing Meltwater Beneath Antarctic and Greenland Ice Sheets

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Overview

- Refreezing Basics
- Gem & Black Refrozen Ice
- Major Modes
 - Large Lake
 - Refreezing From Well Defined Water Networks
 - Refreezing and Deformation
 - Surface Meltwater Refreezing in Ablation Zone
- Mechanisms
- Implications & Conclusions

Refreezing -Overview

- Why does it matter
 - Changes stratigraphy thermal structure and rheology of ice sheet
 - More more in a warming world – more water more refreezing
- What water refreezes?
 - Basal Melt, Surface Melt, Subglacial Aquifers

What Does it Look Like:

Gem & Black Refrozen Ice

Vostok Gem Ice

Bubble Free, Distinct Chemistry, Large Crystals

- SS



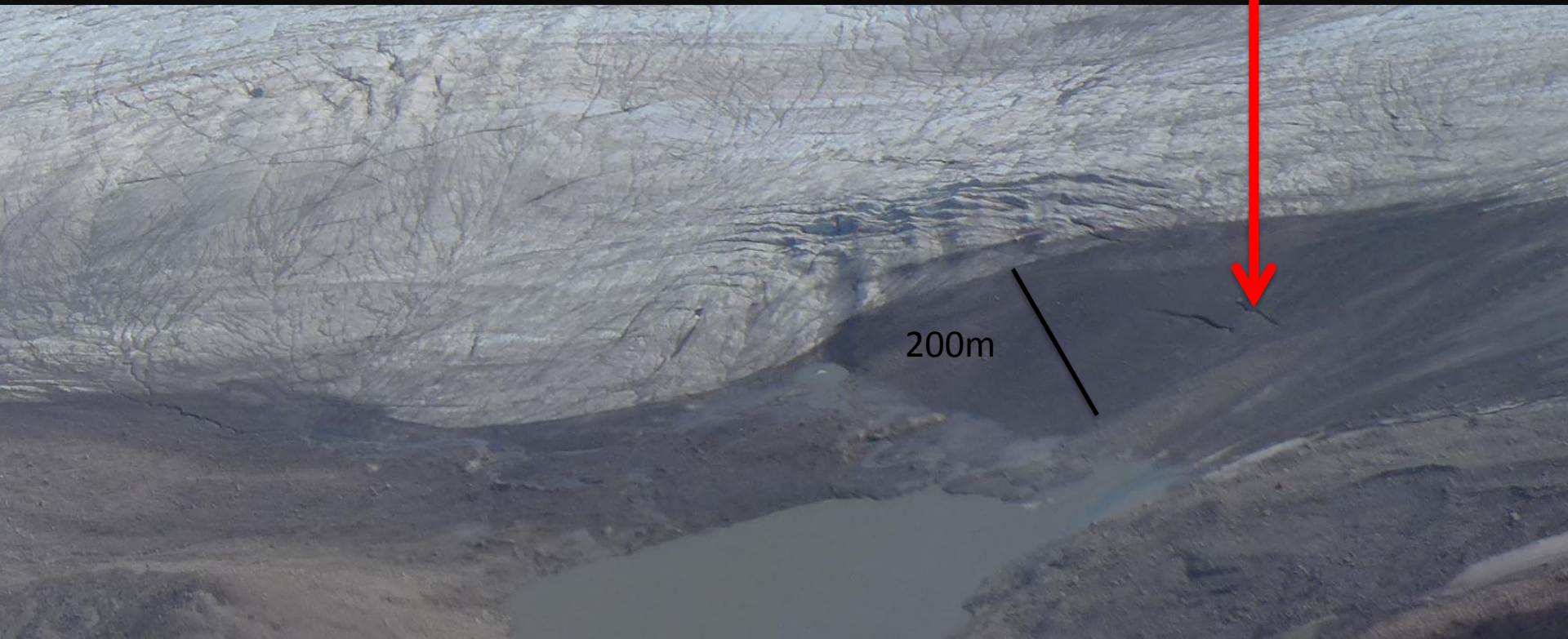
Vostok Swamp Ice

Bubble Free, Distinct Chemistry, Large Crystals Debris



Greenland Black Ice (Debris Rich) Often Rocks accumulate on top (Ask Jeff Sevrinhaus)

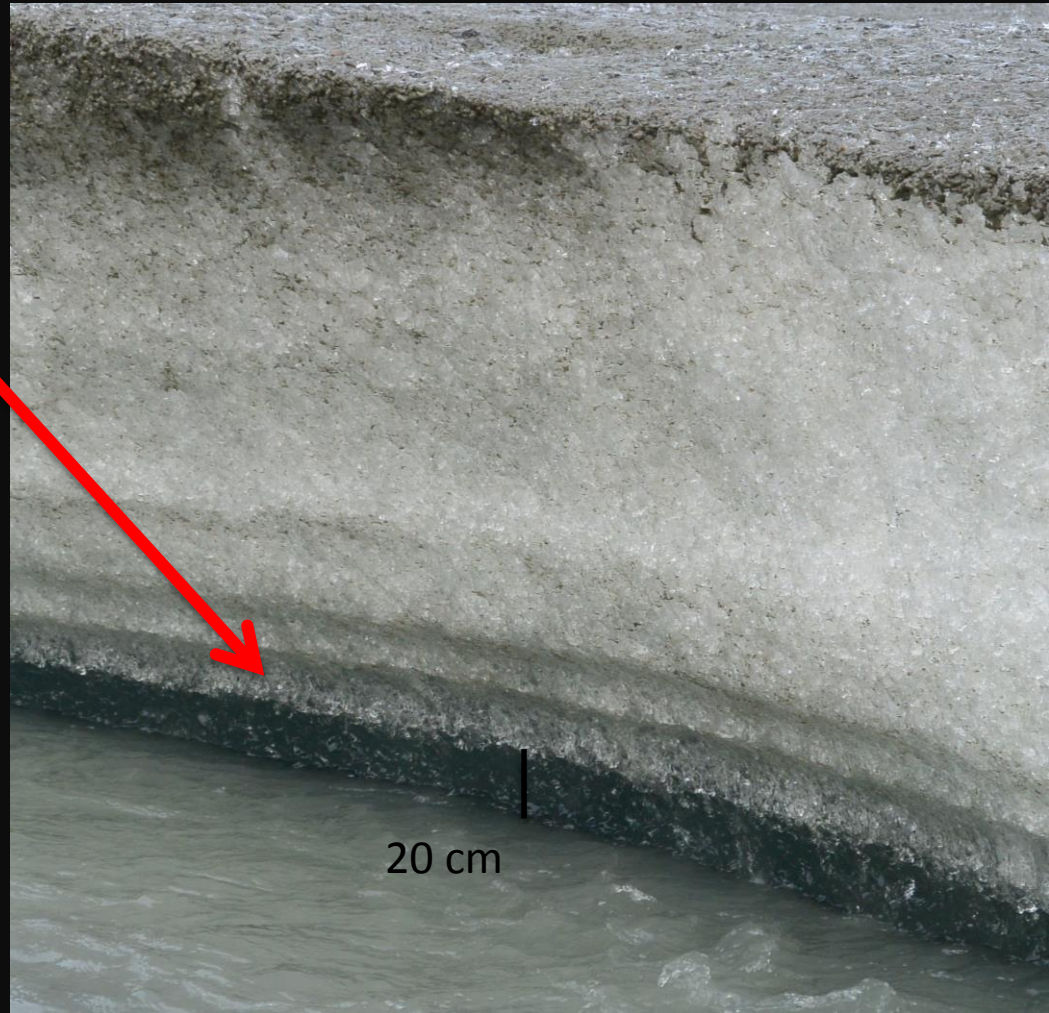
Pakitsoq see Reeh et al 1997
Image From IcePod Flight 2014



Russell Glacier @ the Road

Sugden et al Nature 1987

Black
Bubble Free
Distinct Oxygen 18



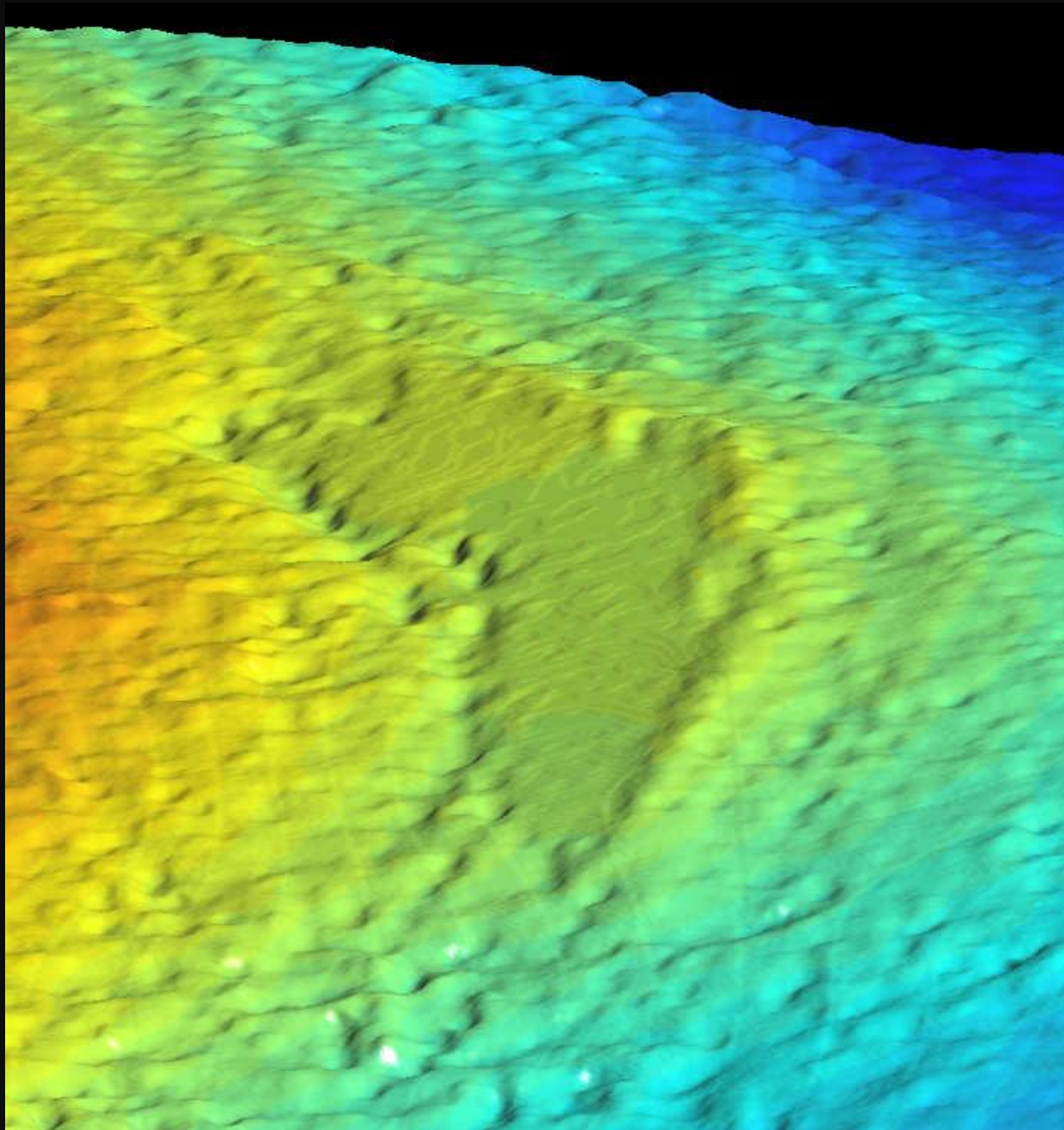
Refreezing Occurs in Multiple Places

Large Lakes

Refreezing From Well Defined Water Networks

Refreezing and Deformation

Surface Meltwater Refreezing in Ablation Zone

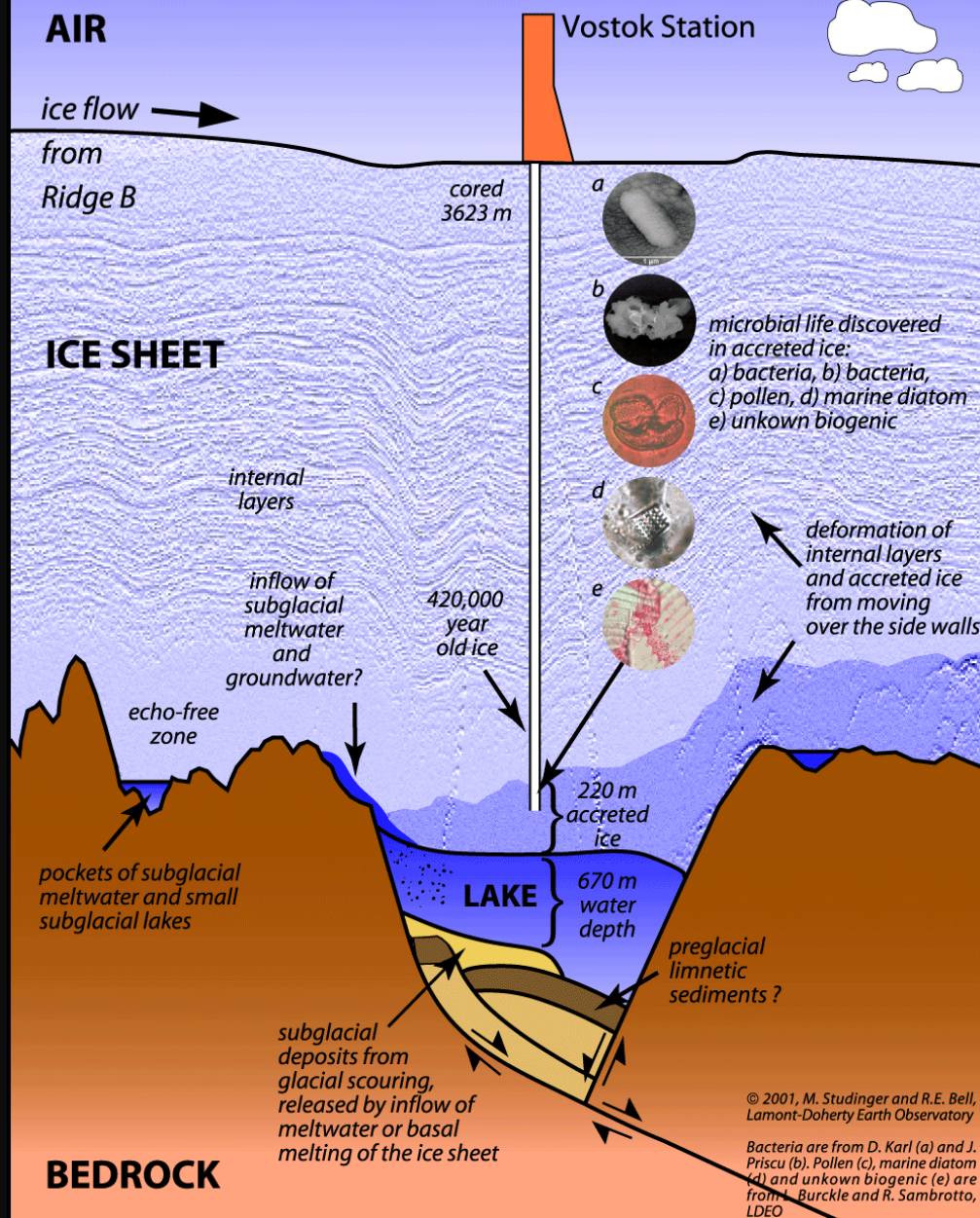


Lake
Vostok

Ice Surface
Elevation

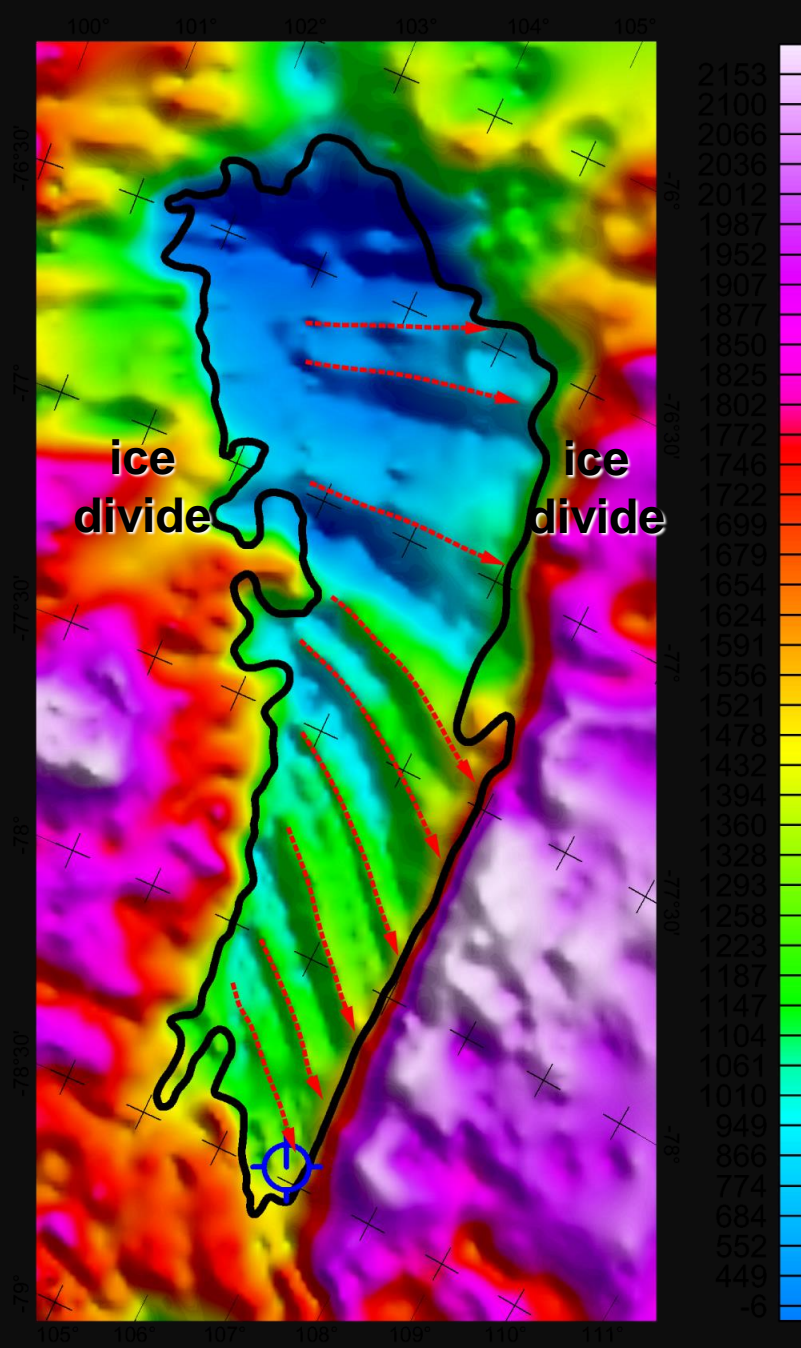


The Subglacial Lake Vostok System



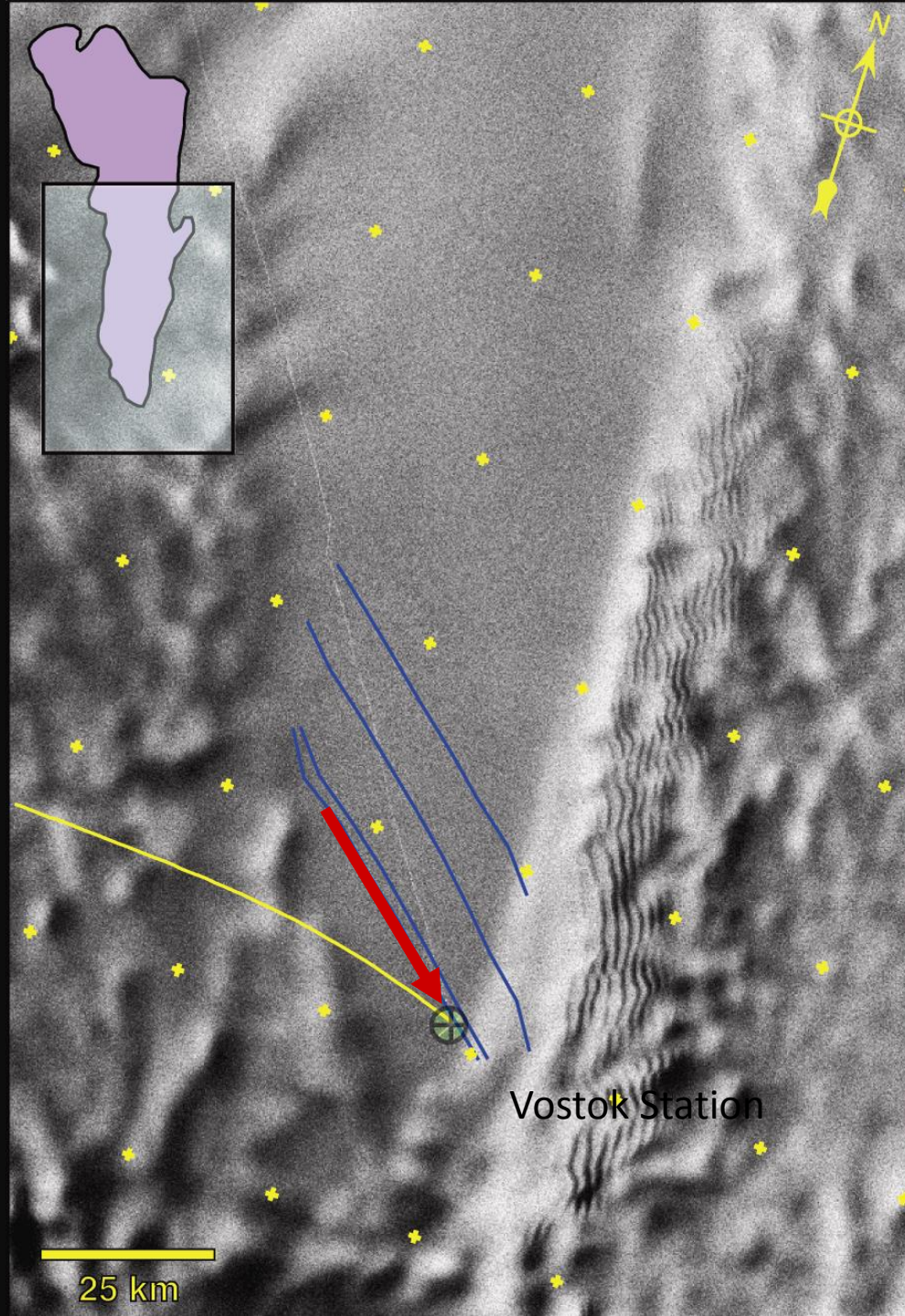
Ice Sheet Flows Across the Lake

Here Flow Direction Preserved in
Internal Layers



Elevation of Internal Layer A [m asl]

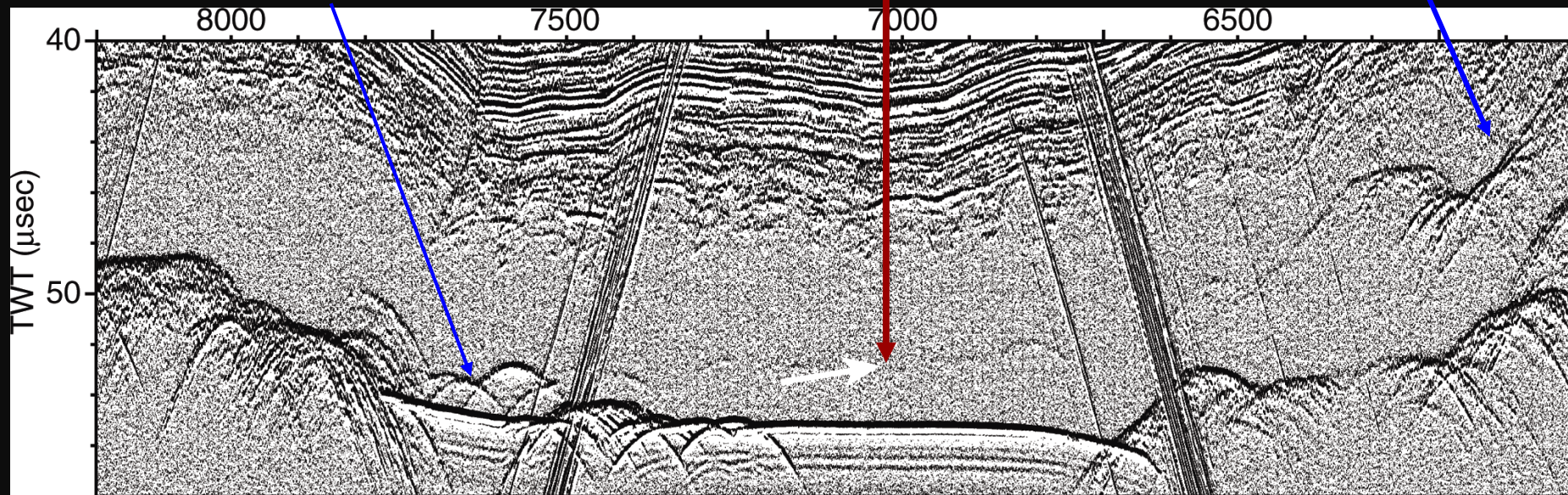
Refreezing Along Flow Produces Deformation and Gem Ice



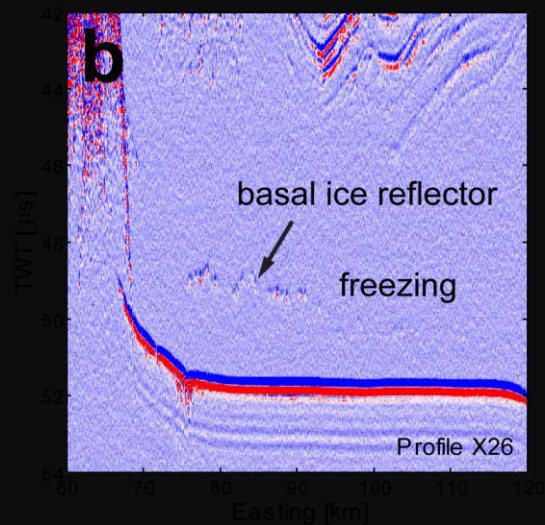
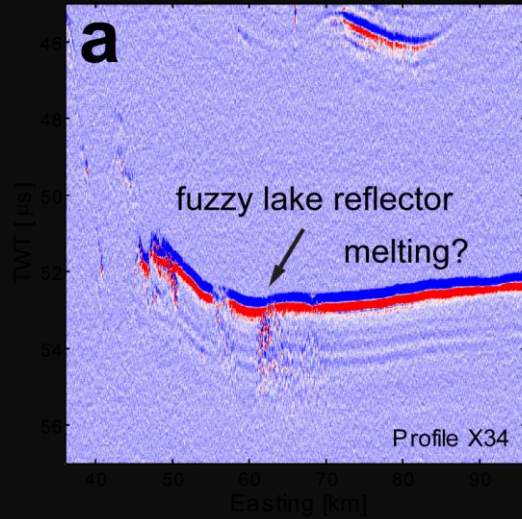
Refrozen Ice

Vostok Core

Refrozen Ice
Leaving Lake

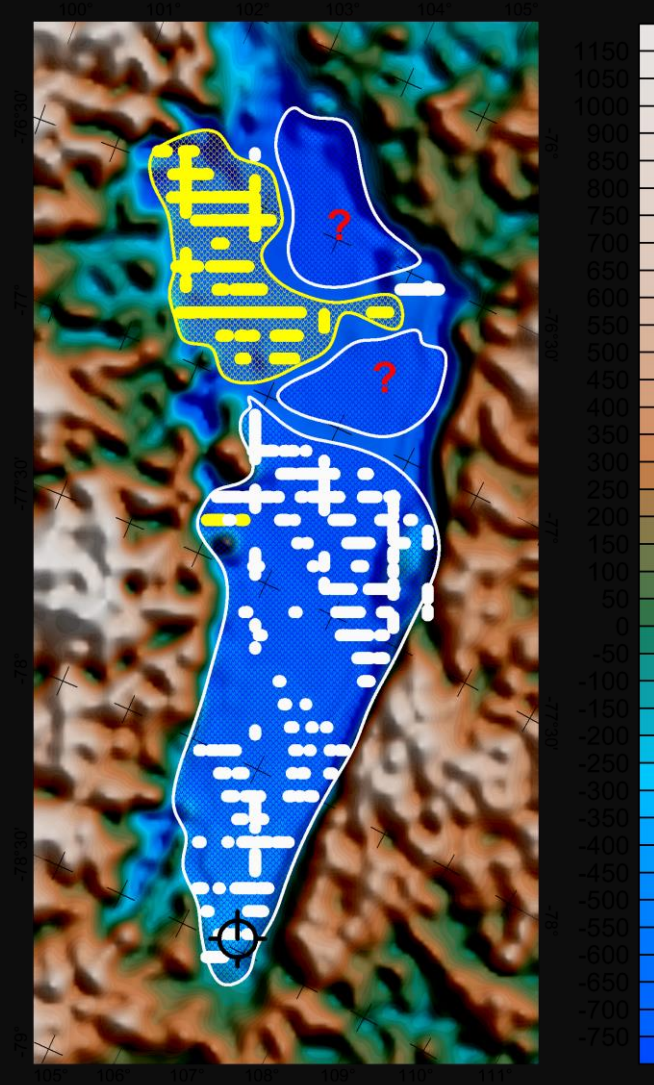


Melt in North



Freeze in South

Keeps Water in Lake Vostok "Young"
Sort of ~55-110,000 yr residence time



Not Just Lake Vostok

Similar Reflectors over Other Lakes

Lake Concordia Near Dome C

Tikku et al.

Subglacial/Lake Elevation [m]

What are Major Modes

Large Lake

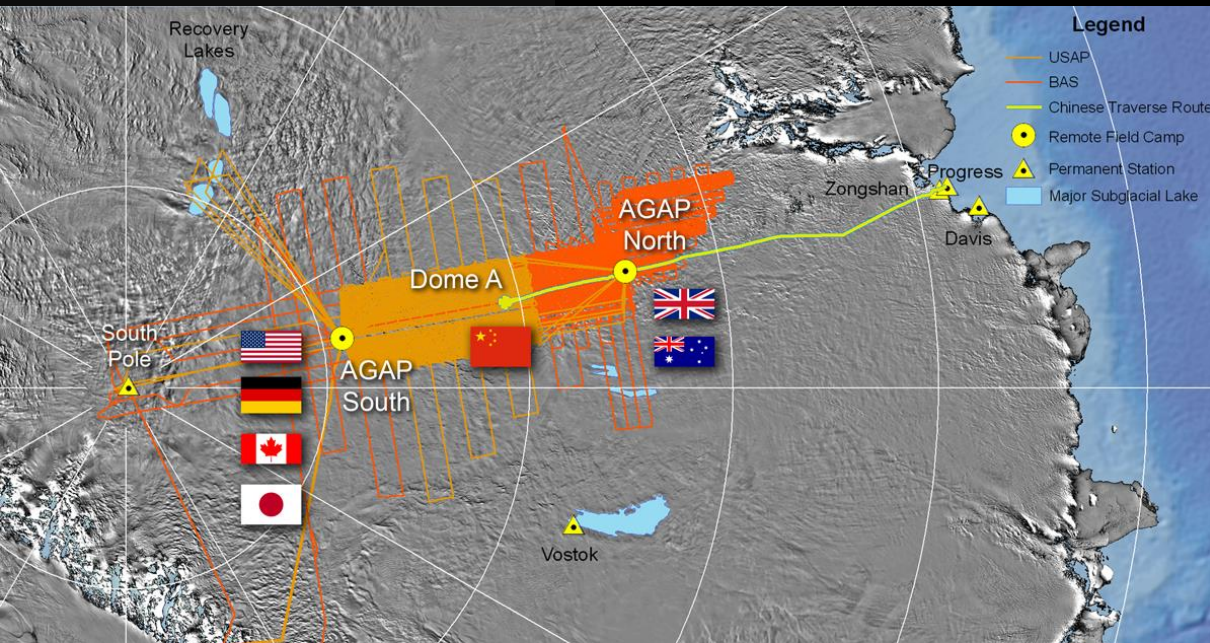
Refreezing From Well Defined Water Networks

Refreezing and Deformation

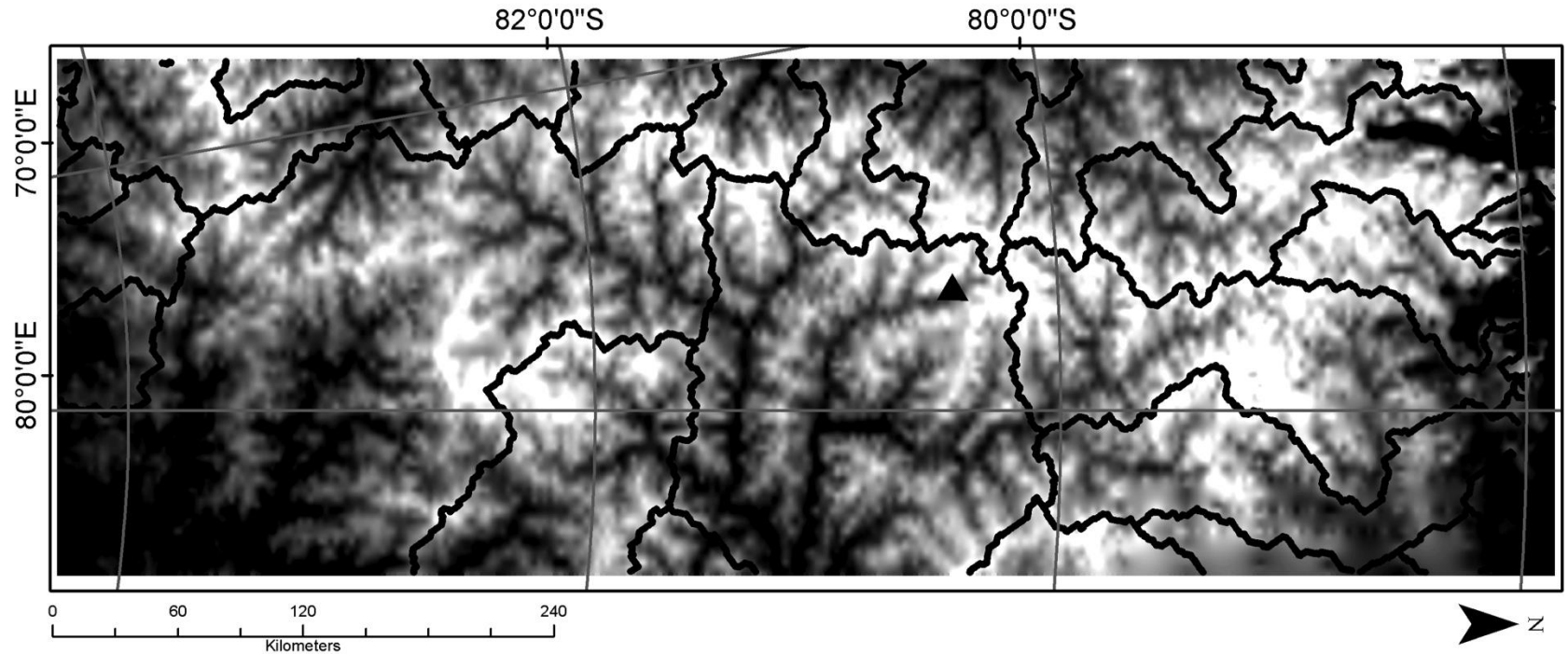
Surface Meltwater Refreezing in Ablation Zone



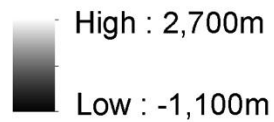
INTERNATIONAL 2007-2008
POLAR YEAR



Water in the Valleys

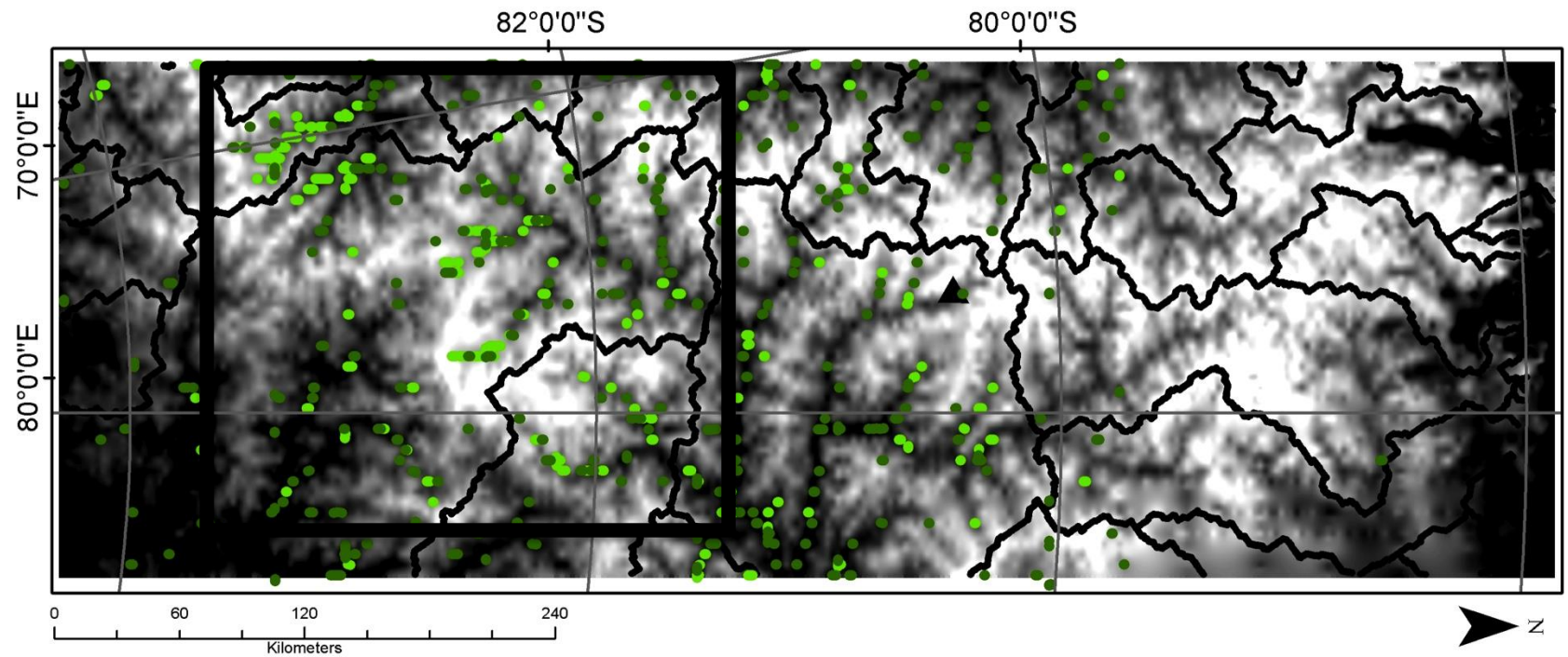


Subglacial Topography



▲ Dome A

— Subglacial Hydrologic Basins

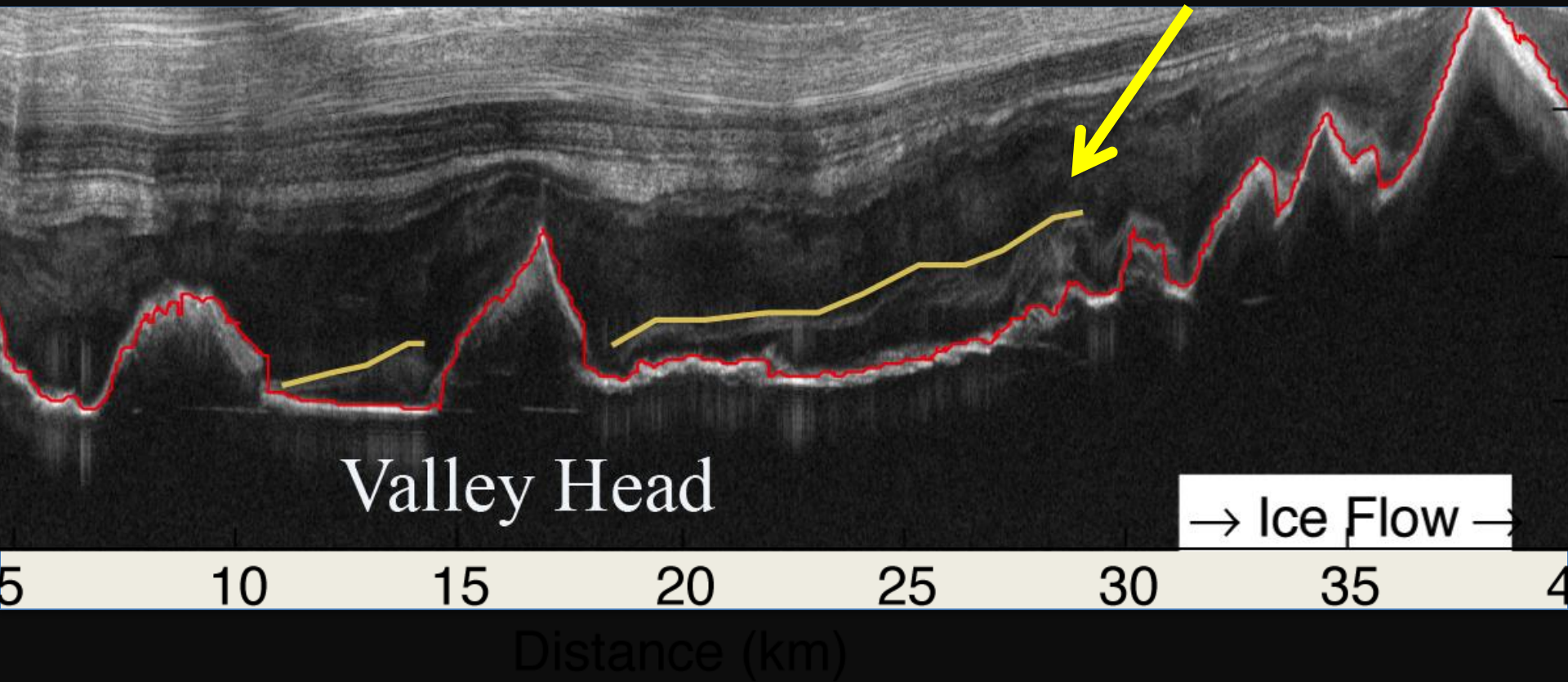


Subglacial Topography

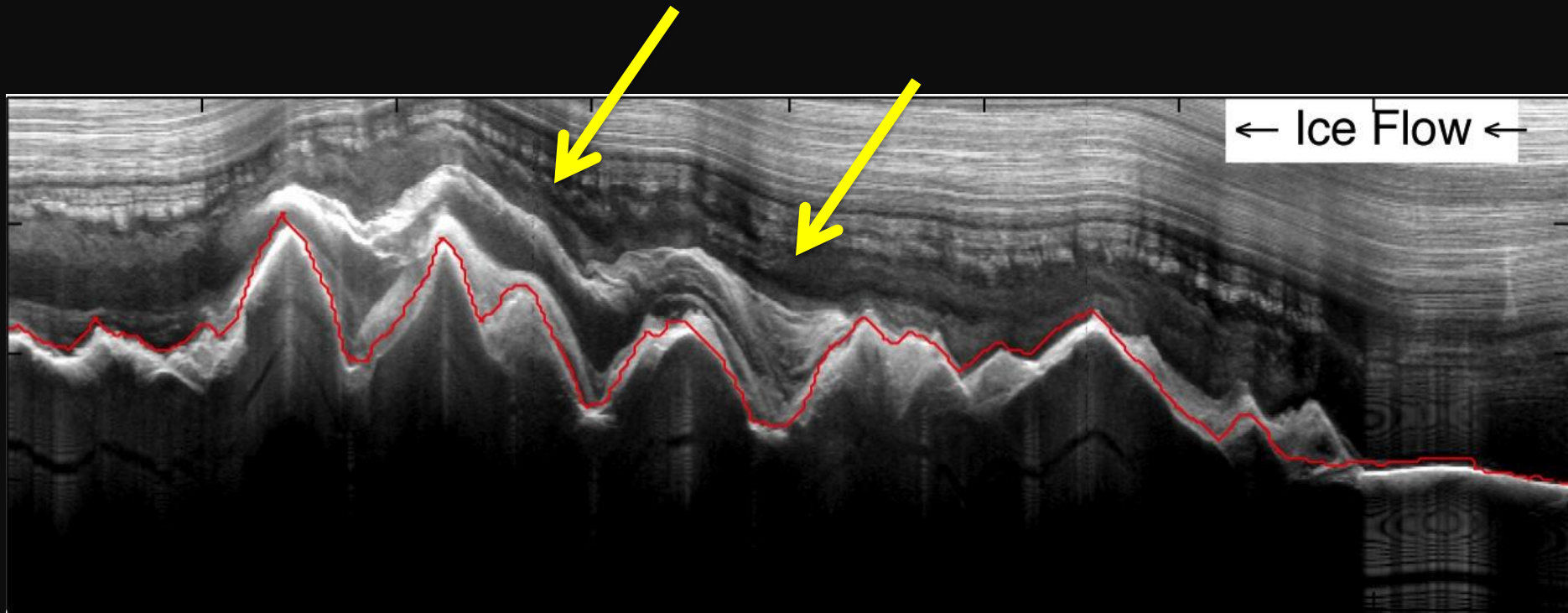


- ▲ Dome A
- Subglacial Hydrologic Basins

Reflectors Similar Vostok Emerging from Basal Water Networks



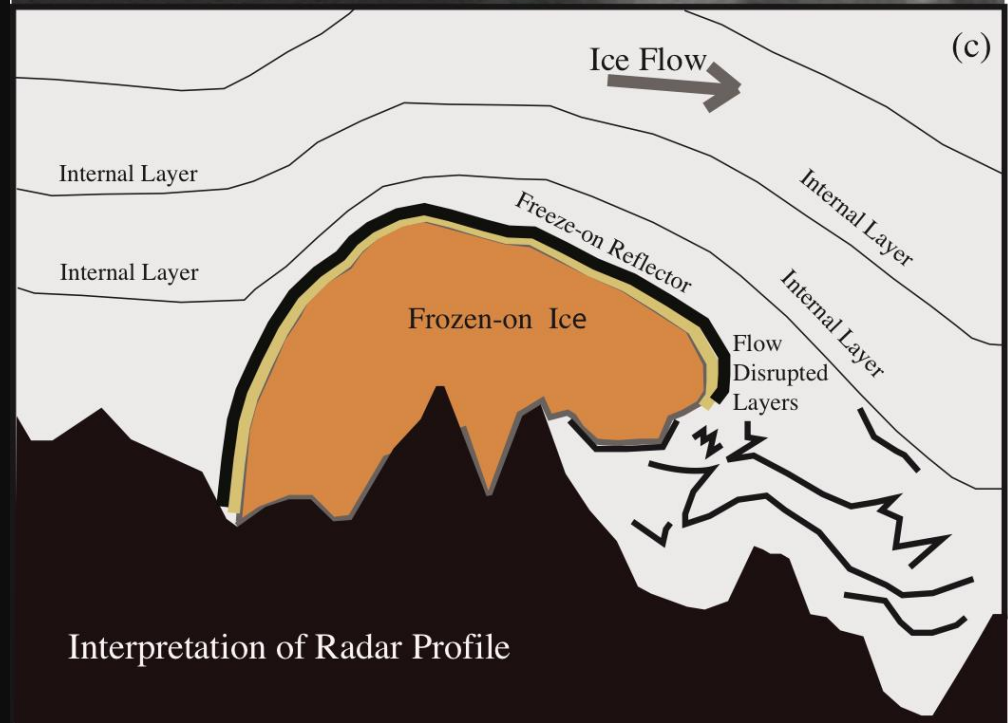
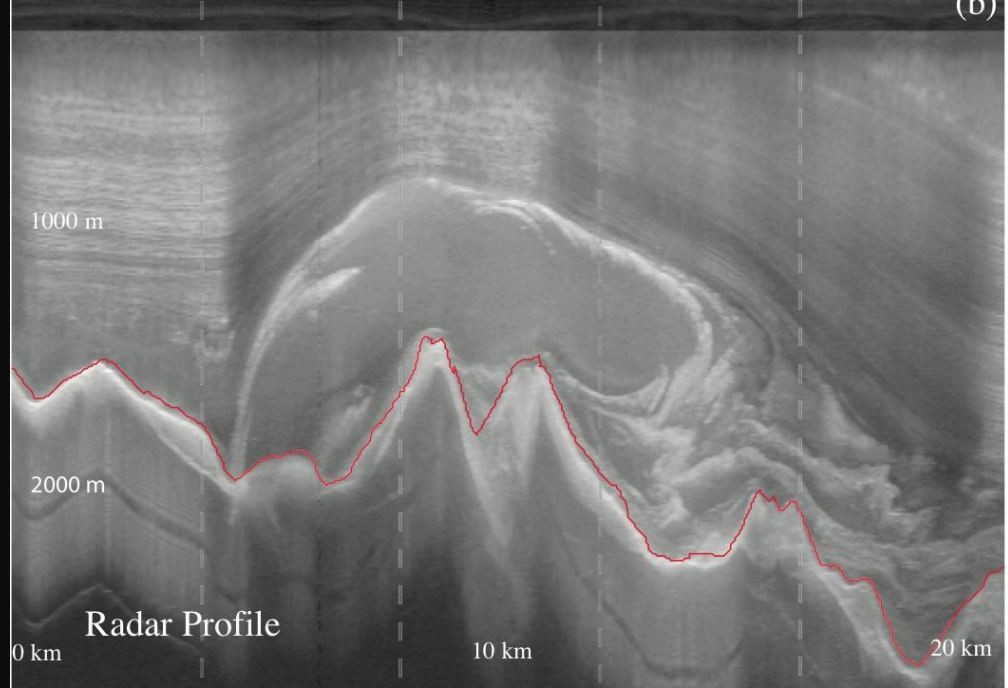
On Both Sides of Dome A



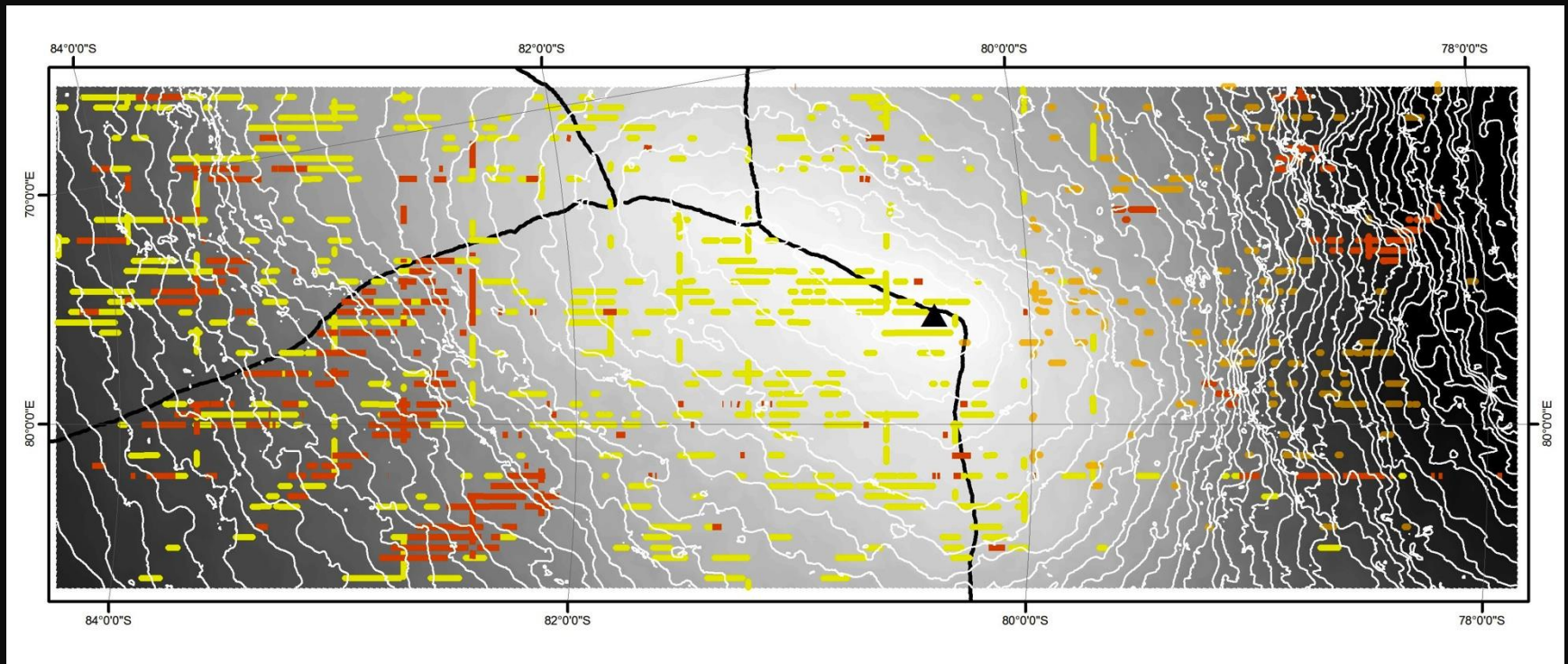
Up to 1000m
Thick---50%
of the Ice
Sheet

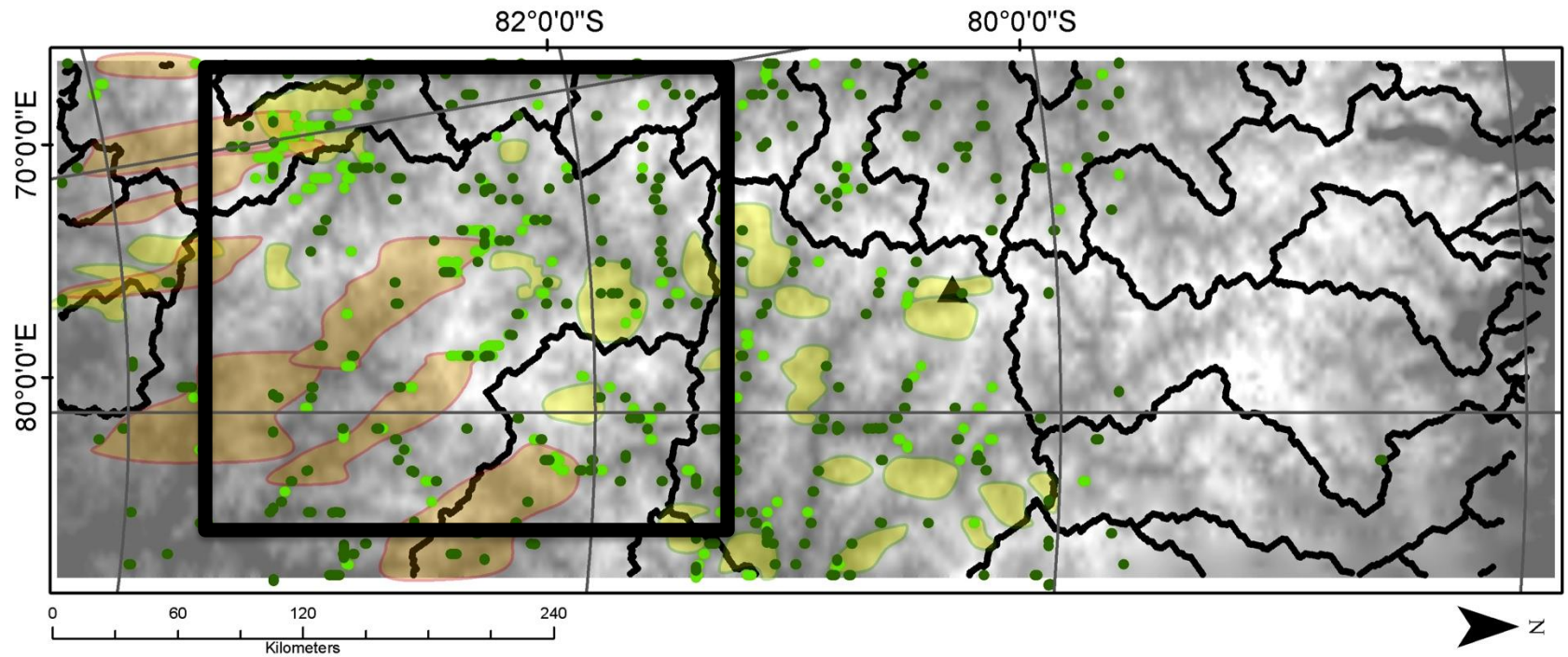
Also from
Basal Water
Network

Deformation
in Front of
over
Freeze-on

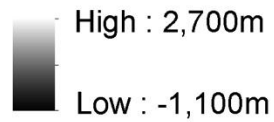


Orange - Distribution of Well Defined Bright Reflector Ice Surface Contours Coherent Features



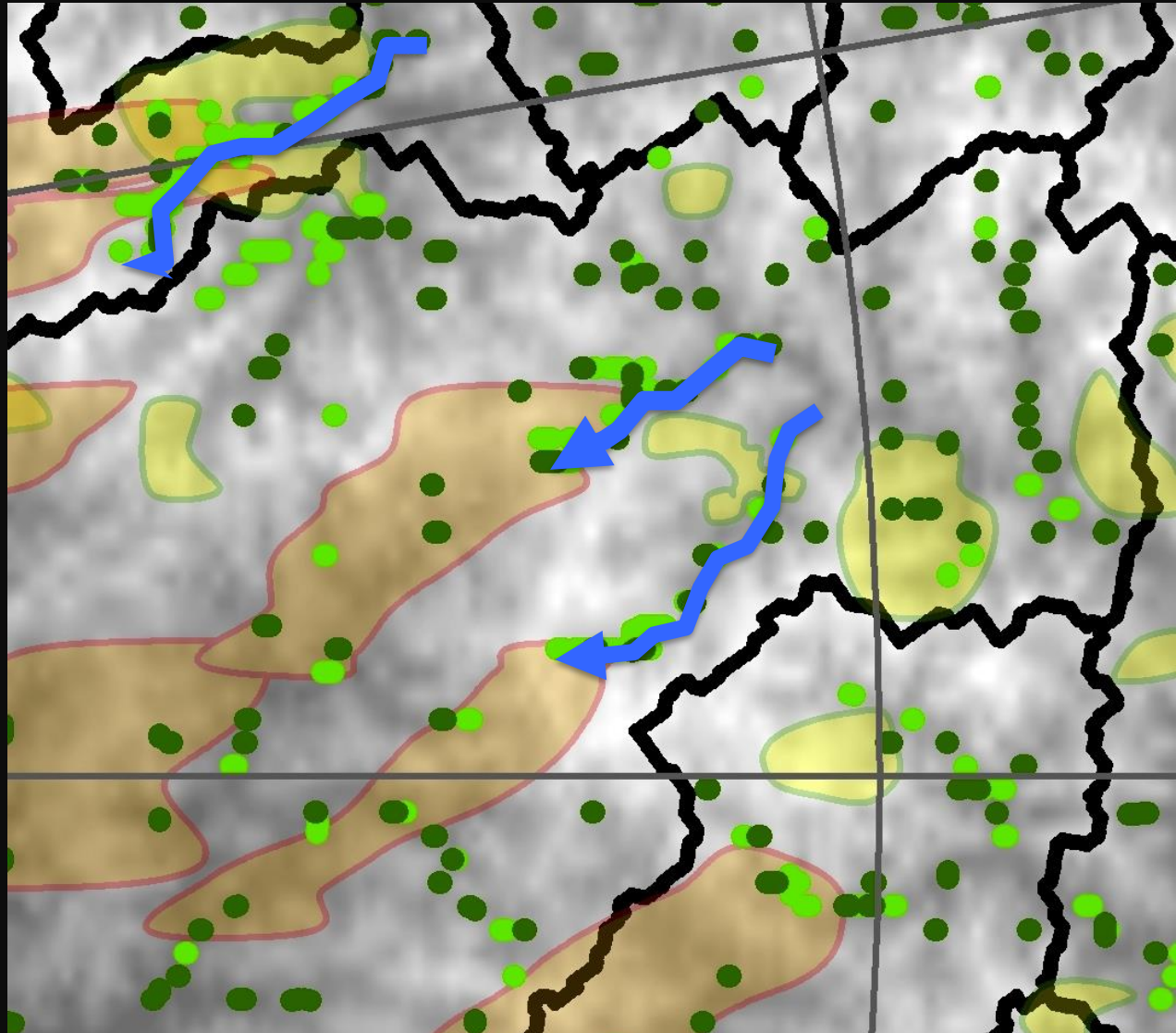


Subglacial Topography



- ▲ Dome A
- Subglacial Hydrologic Basins
- Basal Brightness Reflectors (Unclear)
- Basal Brightness Reflectors (Clear)
- Frozen-on Ice Package: Valley Wall
- Frozen-on Ice Package: Valley Head

Basal Ice At the End of the Water Networks Refreezing Occurs at Ridgelines



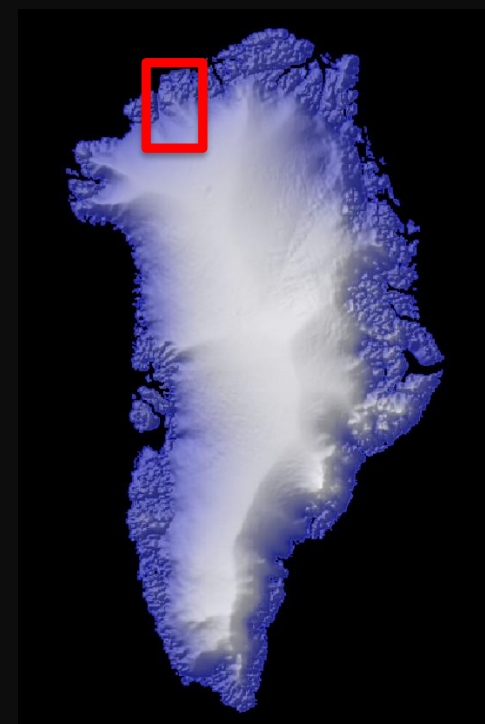
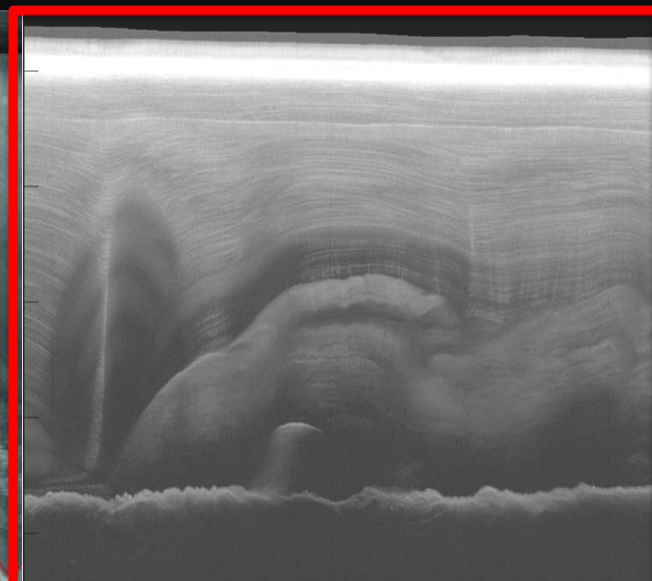
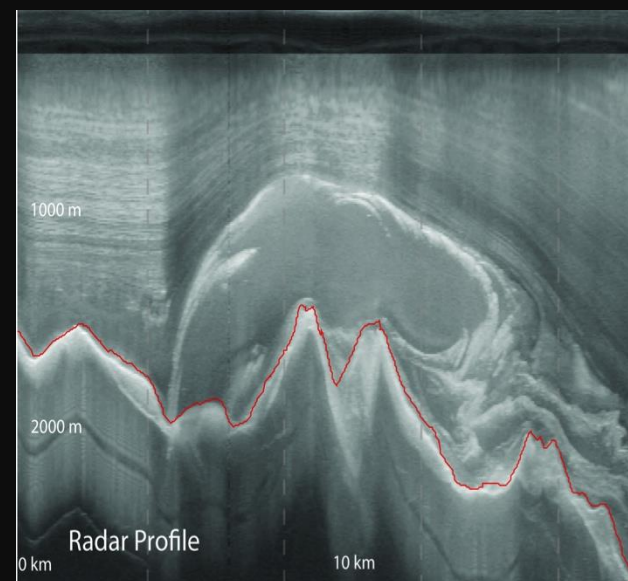
What are Major Modes

Large Lake

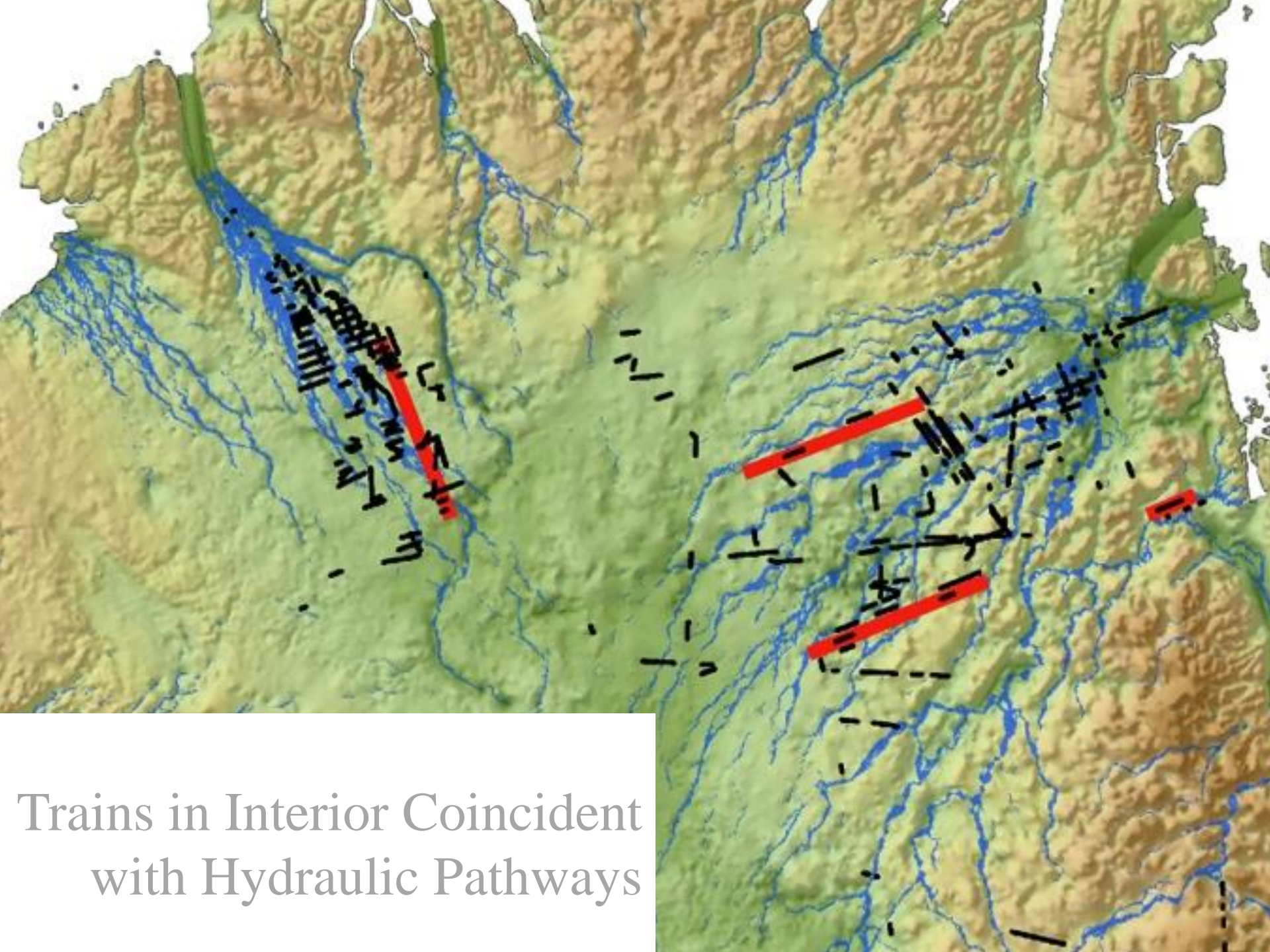
Refreezing From Well Defined Water Networks

Refreezing and Deformation

Surface Meltwater Refreezing in Ablation Zone



Antarctica Greenland
Dome A Petermann

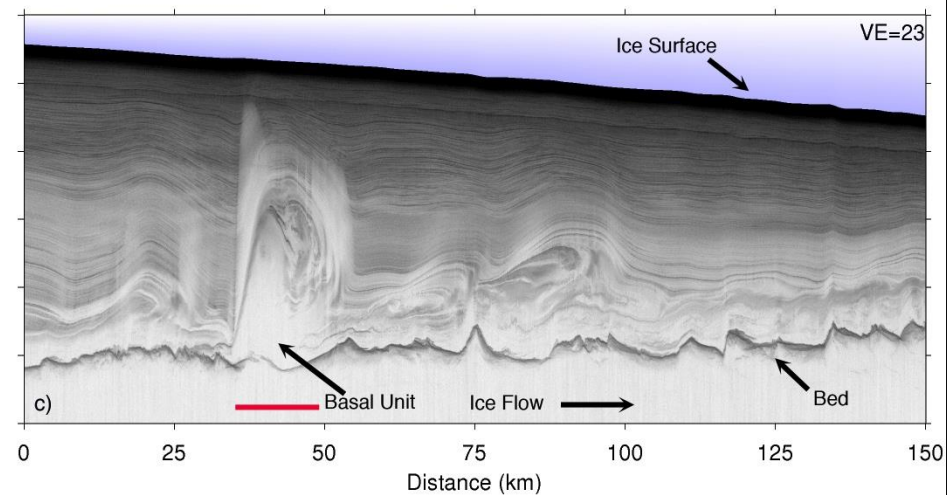
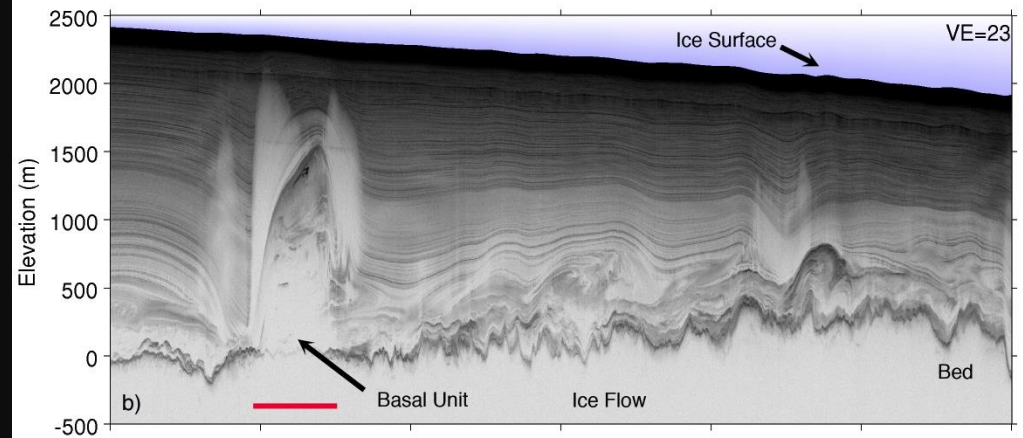
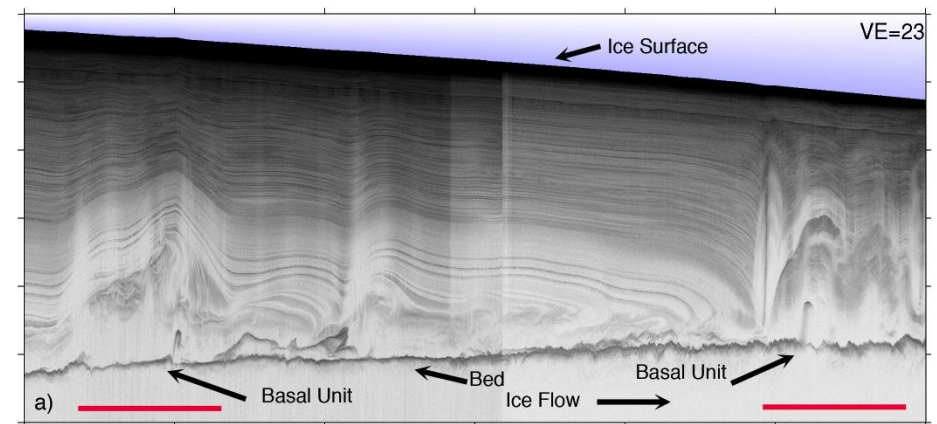
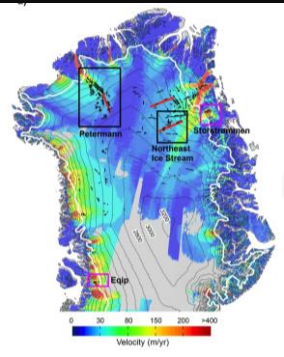


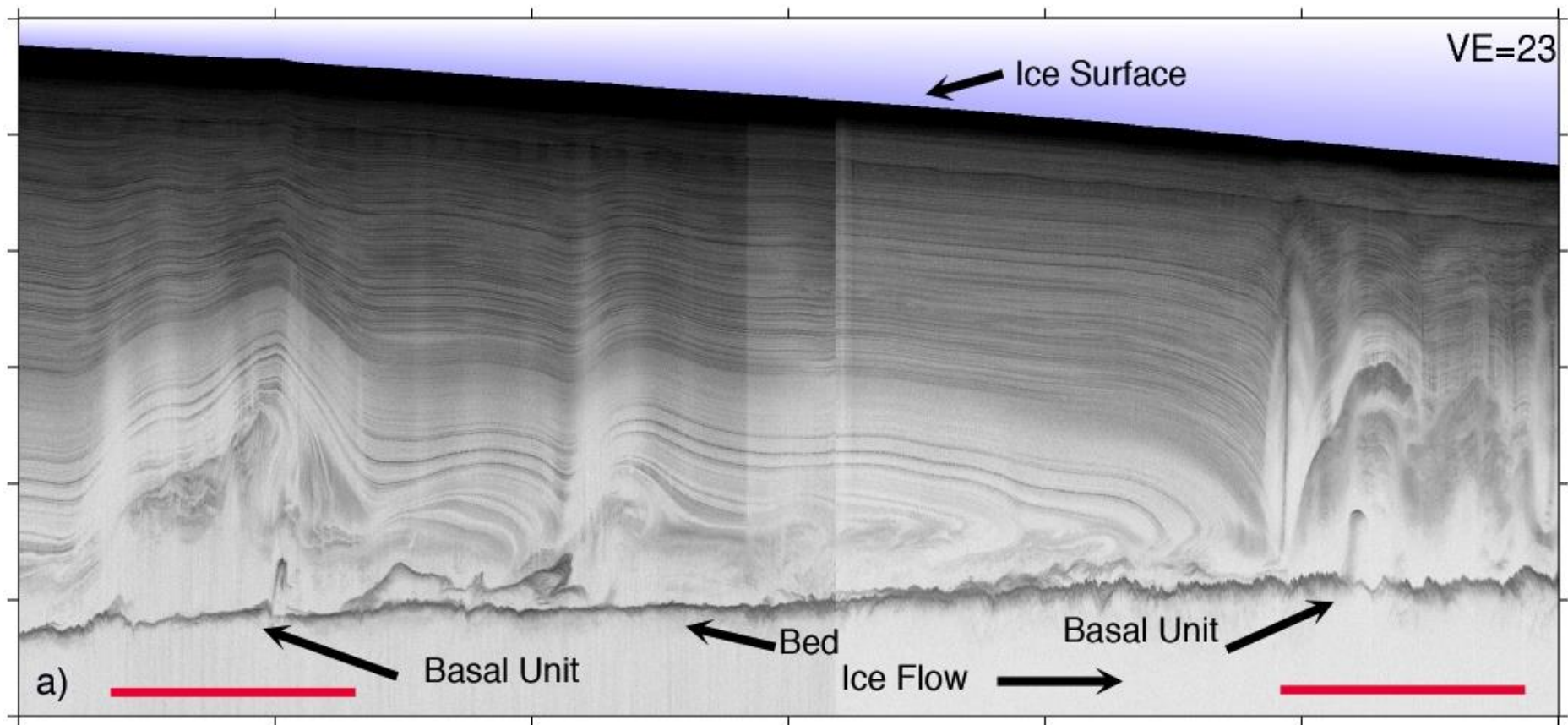
Trains in Interior Coincident
with Hydraulic Pathways

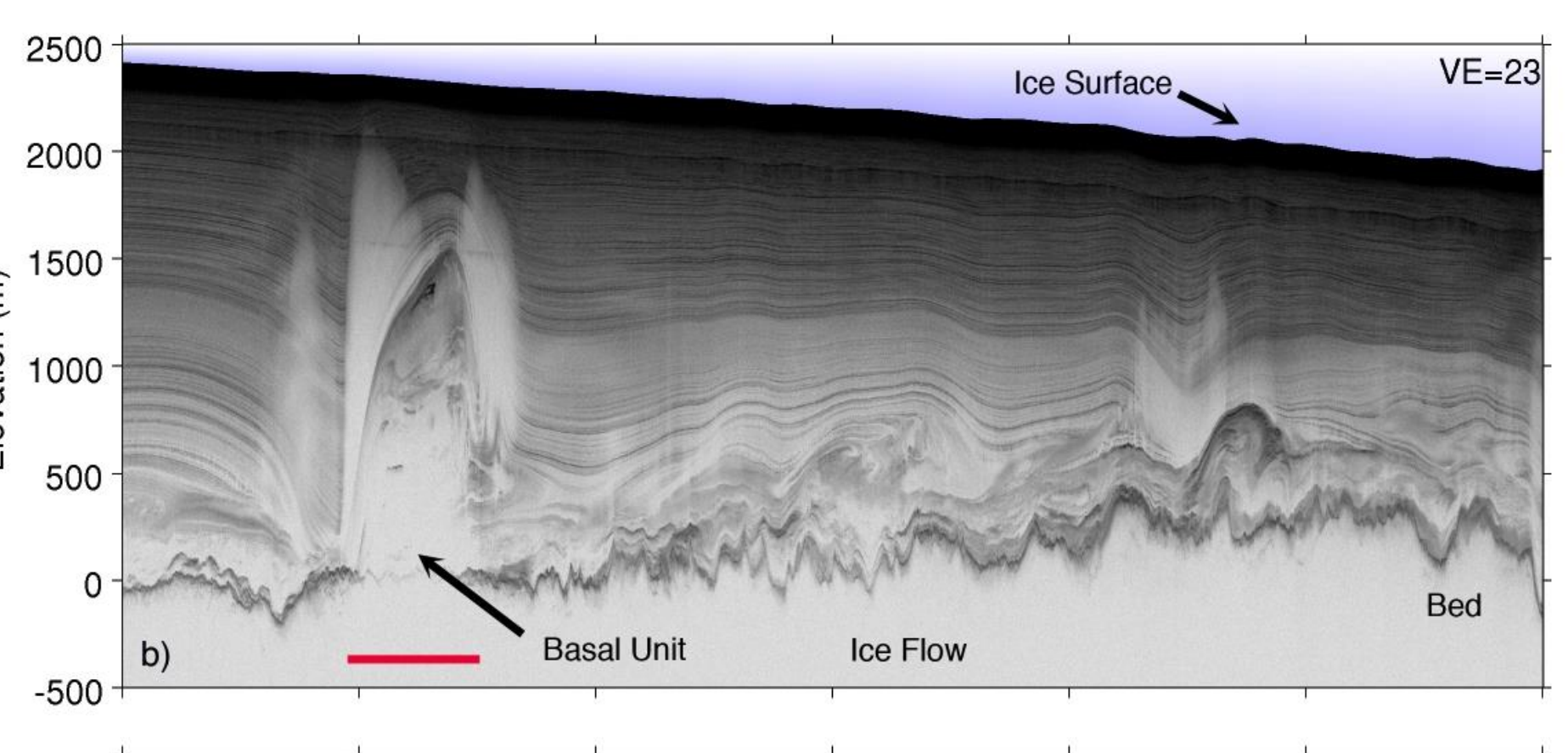
PETERMANN

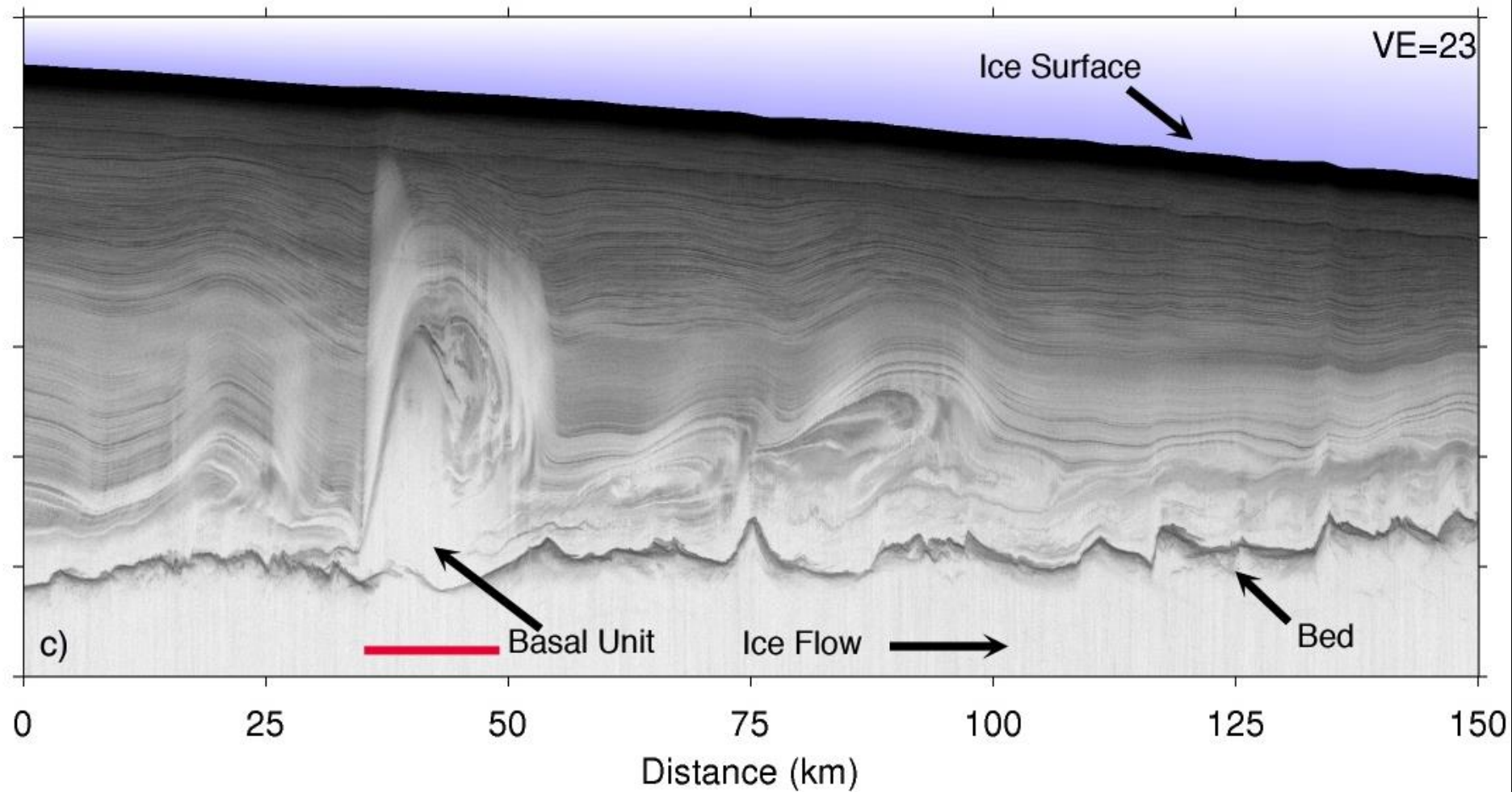
NORTHEAST ICE
STREAM (NEGIS)

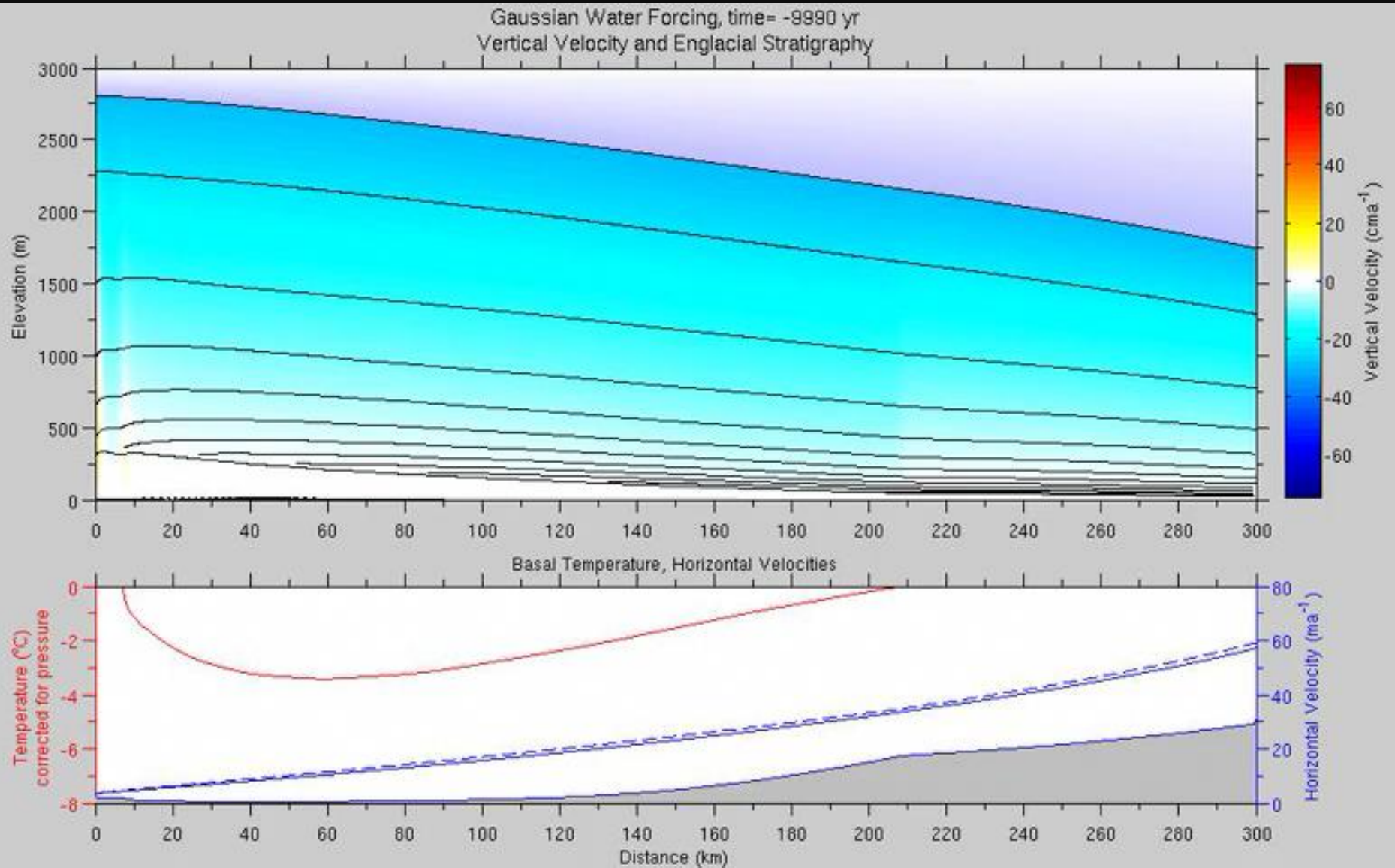
NORTHEAST ICE
STREAM (NEGIS)











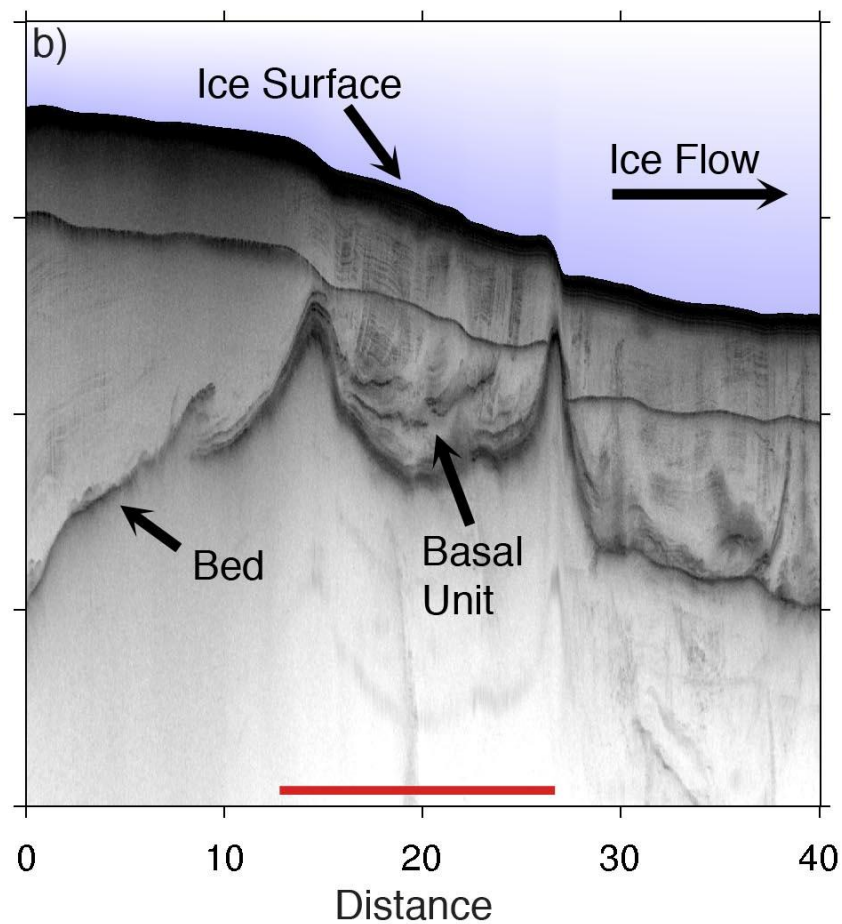
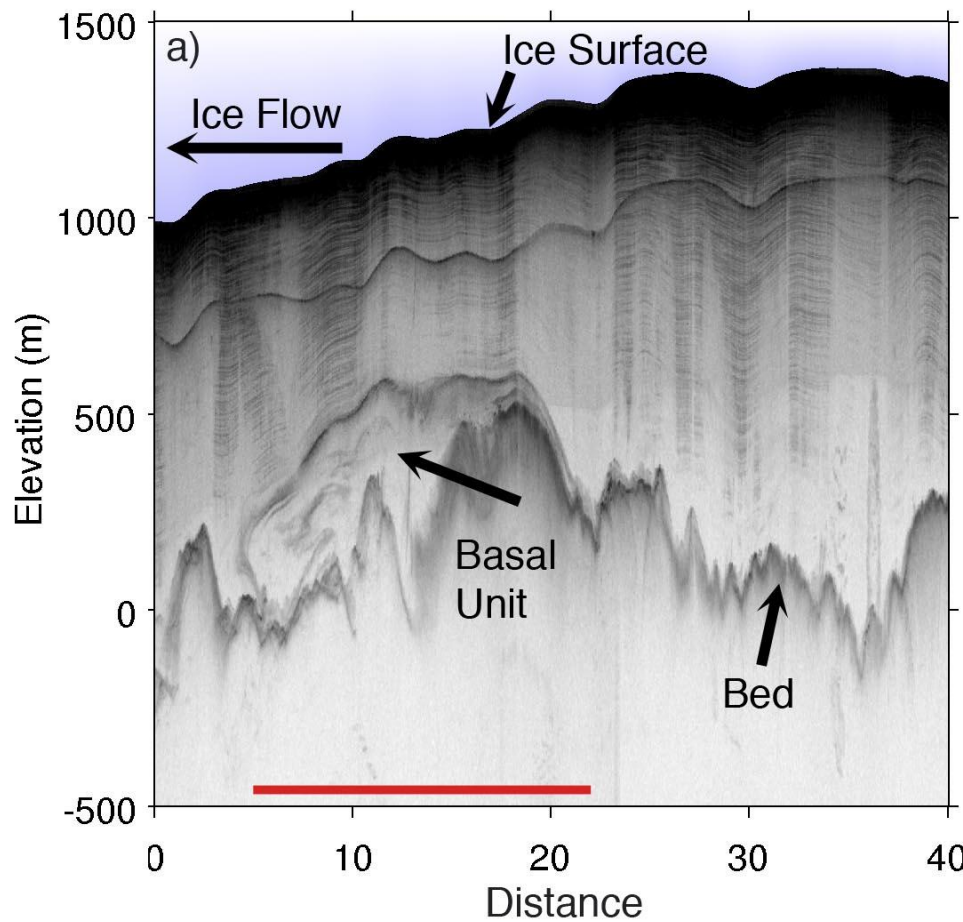
What are Major Modes

Large Lake

Refreezing From Well Defined Water Networks

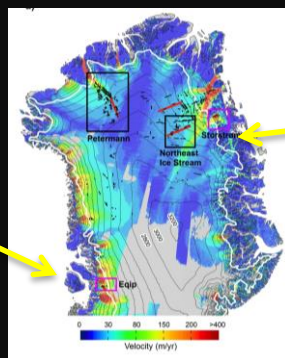
Refreezing and Deformation

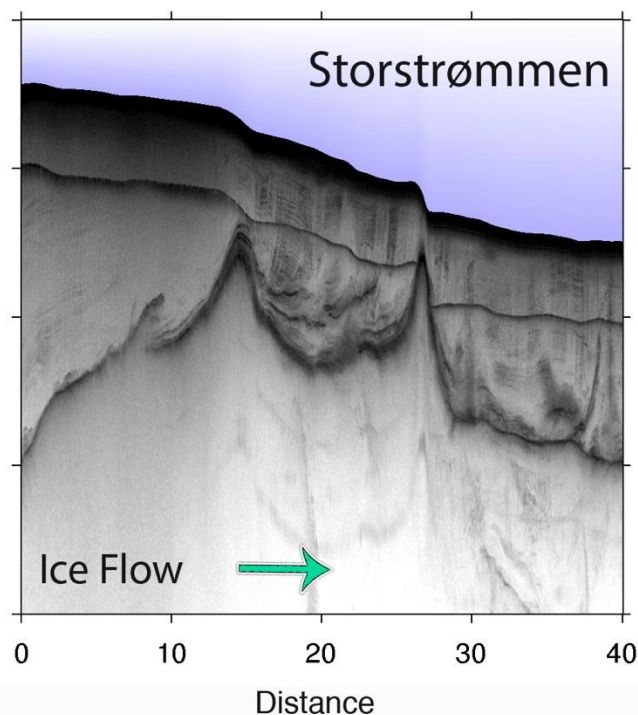
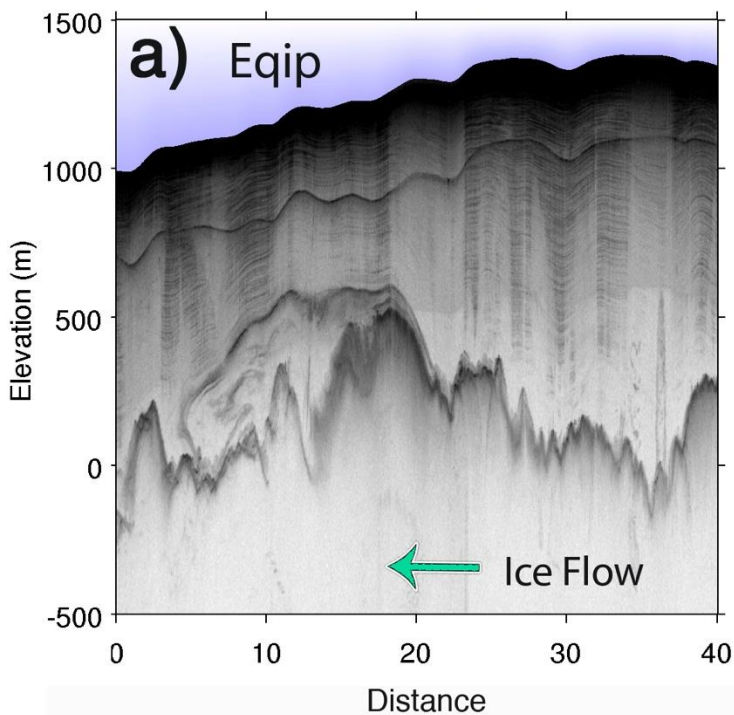
Surface Meltwater Refreezing in Ablation Zone



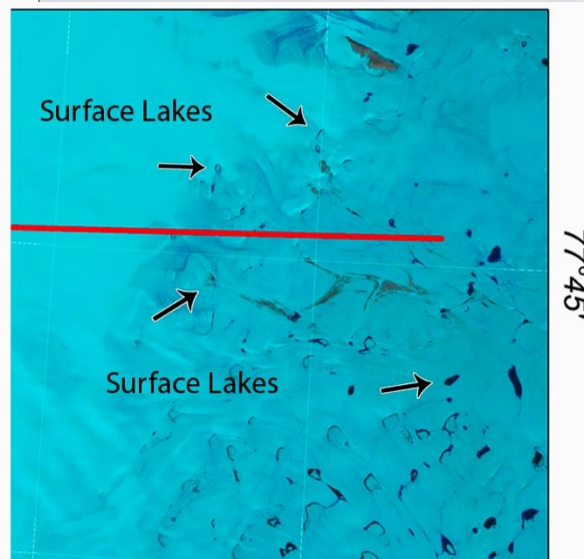
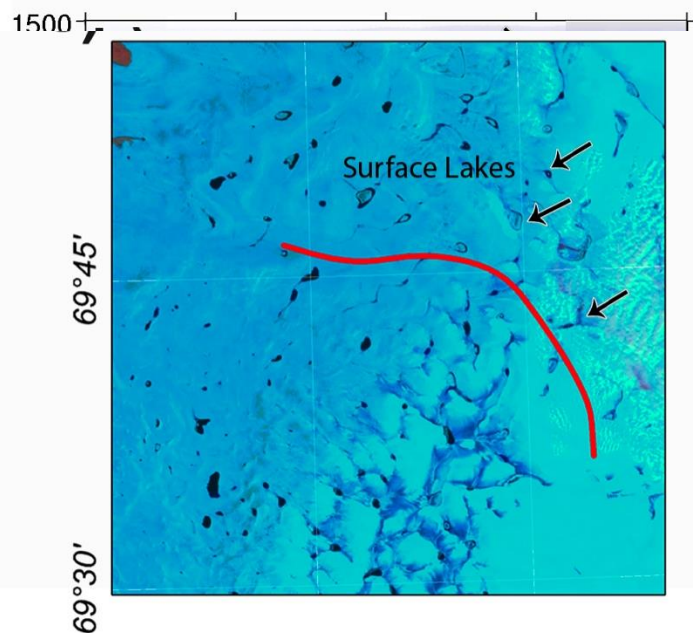
EQIP

STORSTOMMEN

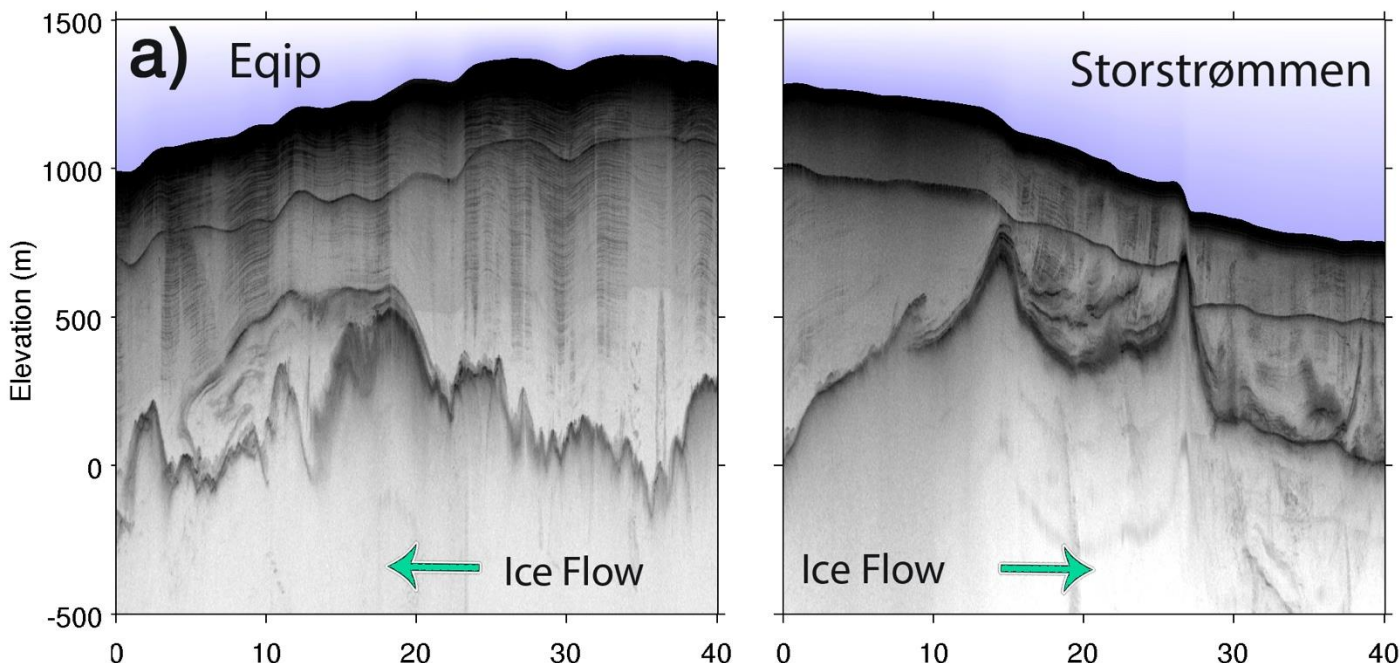




Isolated
Marginal
Units Not
Coincident
With
Hydraulic
Pathways



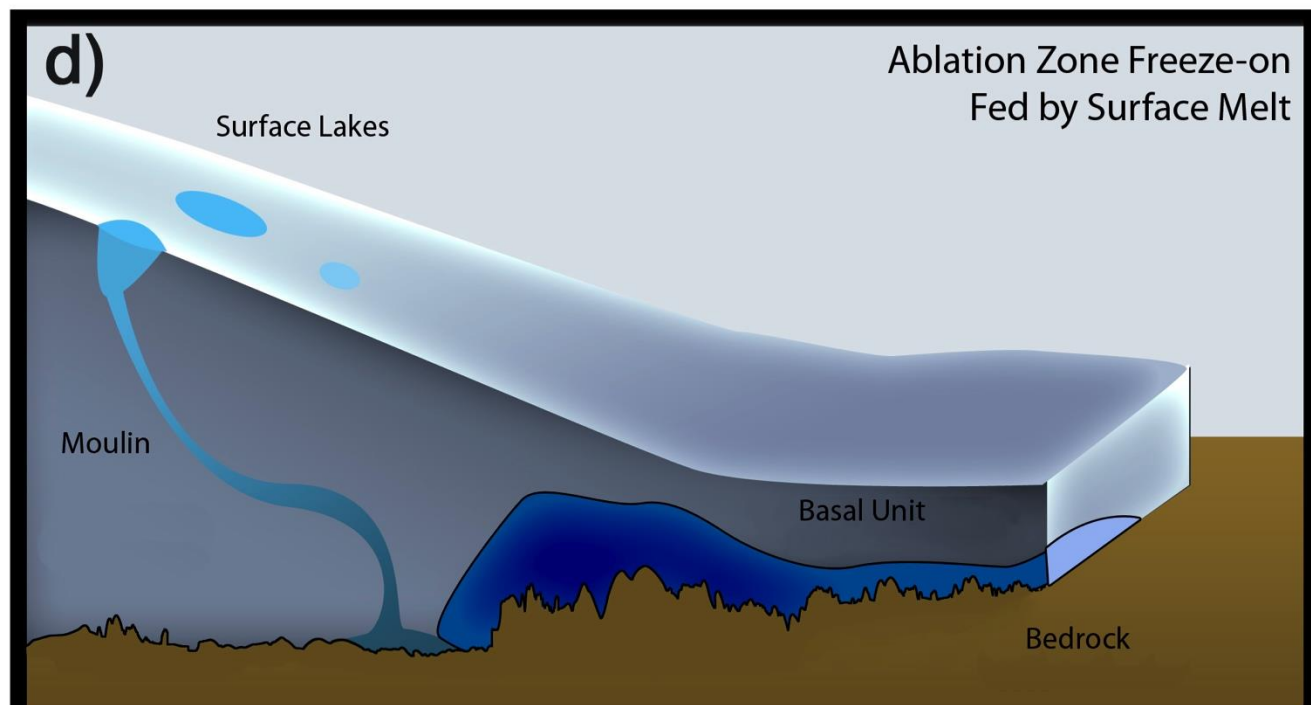
Beneath
Surface
Lakes and
Crevasses



SURFACE MELTWATER AS WATER SOURCE

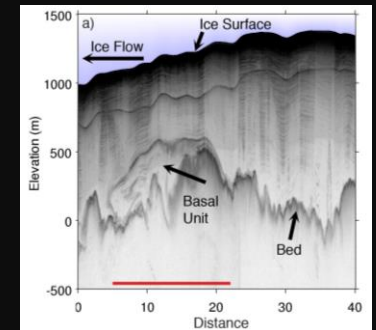
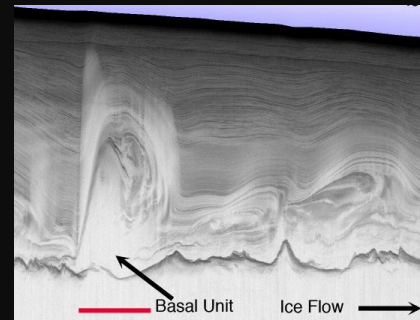
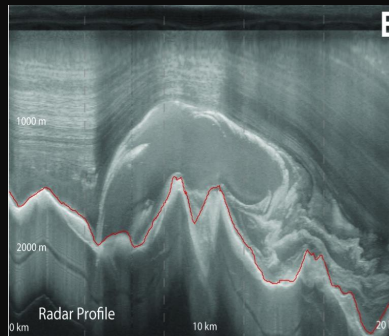
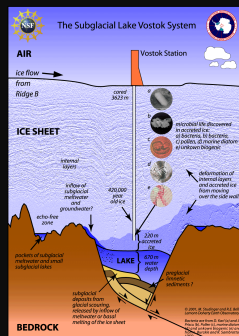
Isolated
Ablation Zone
Units Not
Coincident
With
Hydraulic
Pathways

Beneath
Surface Lakes
and Crevasses

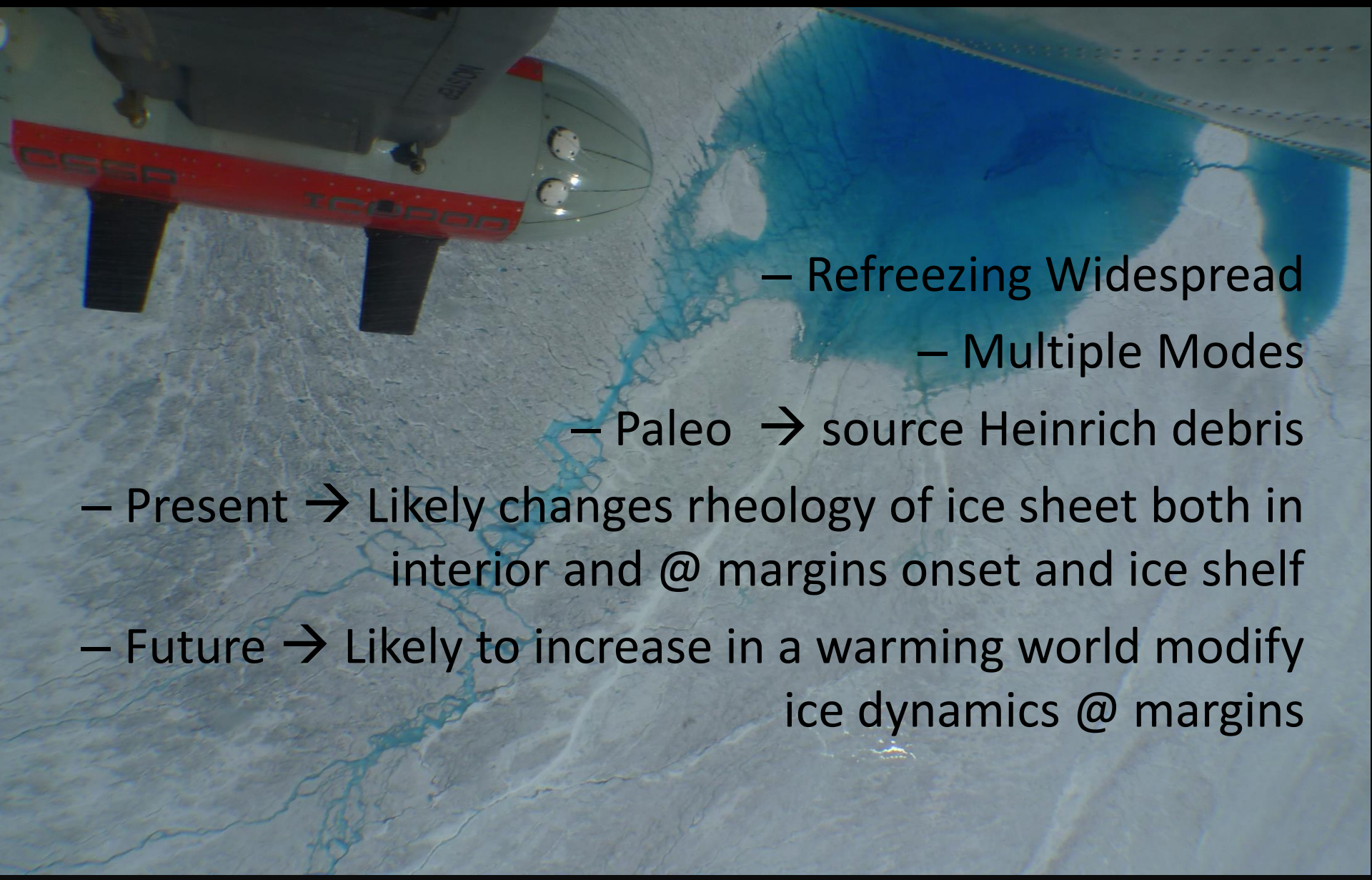


- Mechanisms

- Refreezing both supercooling and conductiive cooling
- Often associated or even dominated deformation



Implications & Conclusions



- Refreezing Widespread
- Multiple Modes
- Paleo → source Heinrich debris
- Present → Likely changes rheology of ice sheet both in interior and @ margins onset and ice shelf
- Future → Likely to increase in a warming world modify ice dynamics @ margins

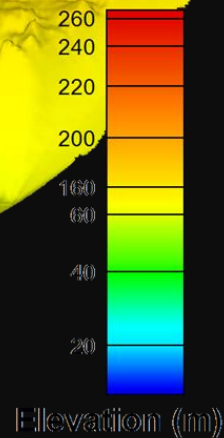
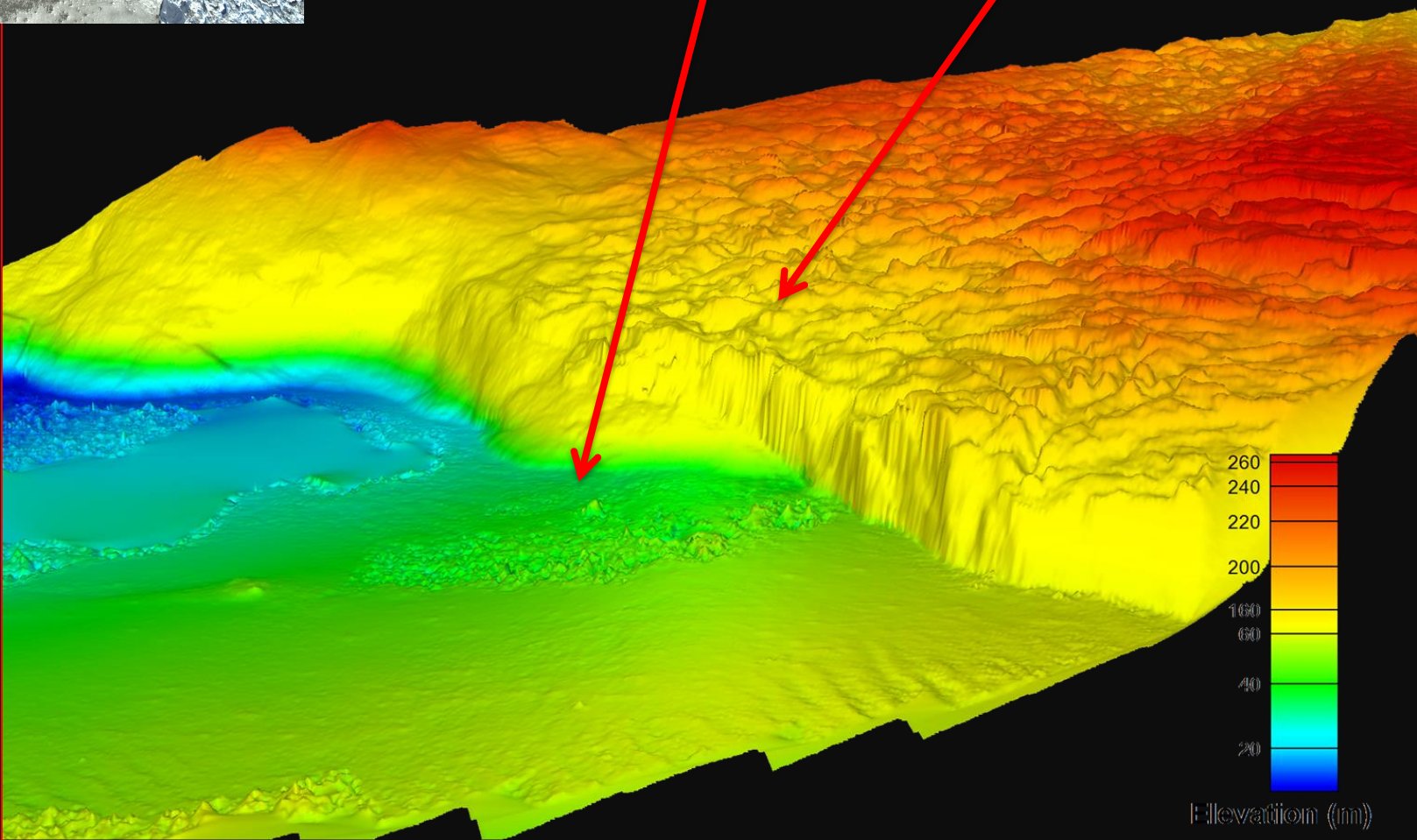




Digital Elevation Model
From Images

Equip
Calving Front

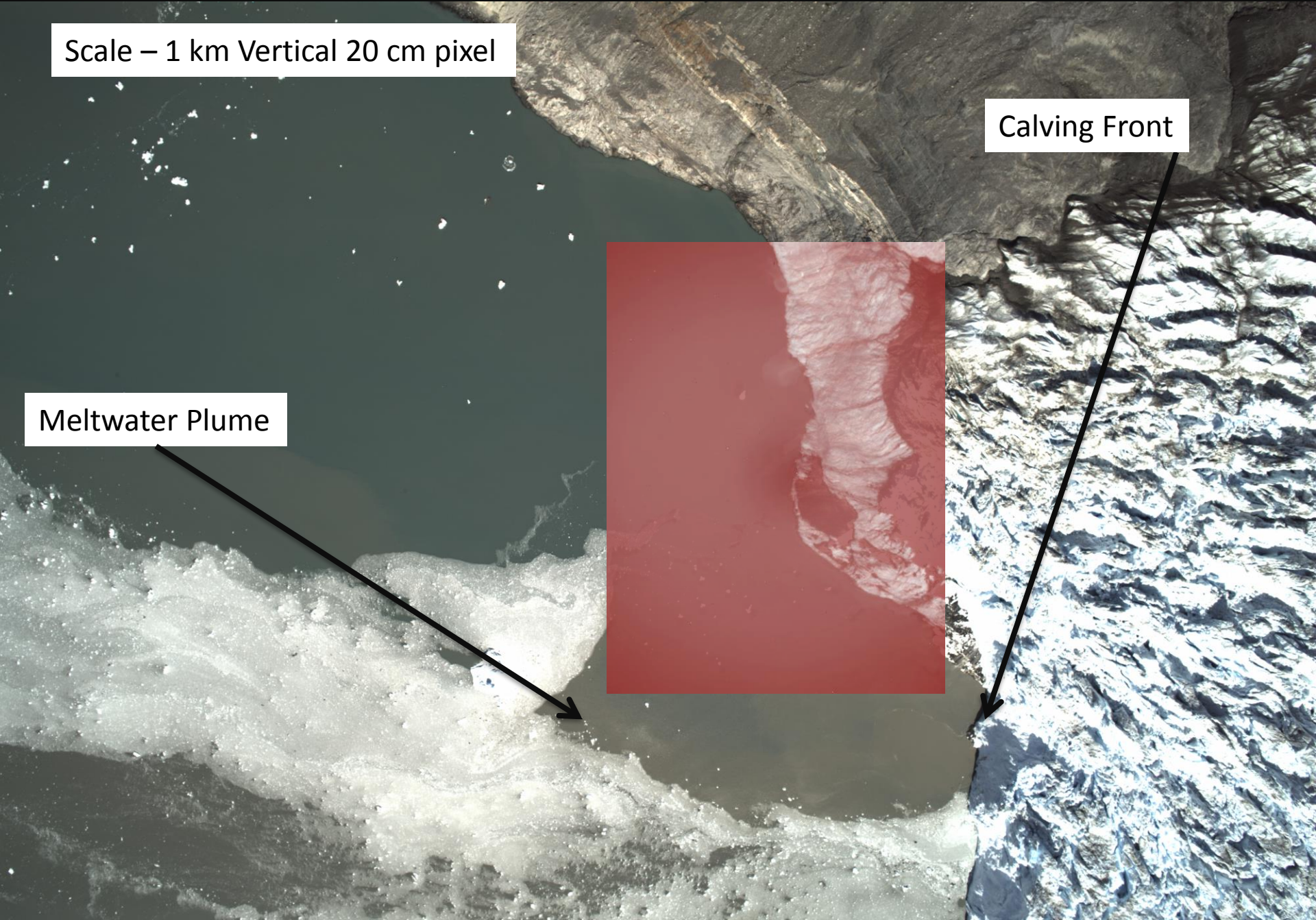
Meltwater Plume



Scale – 1 km Vertical 20 cm pixel

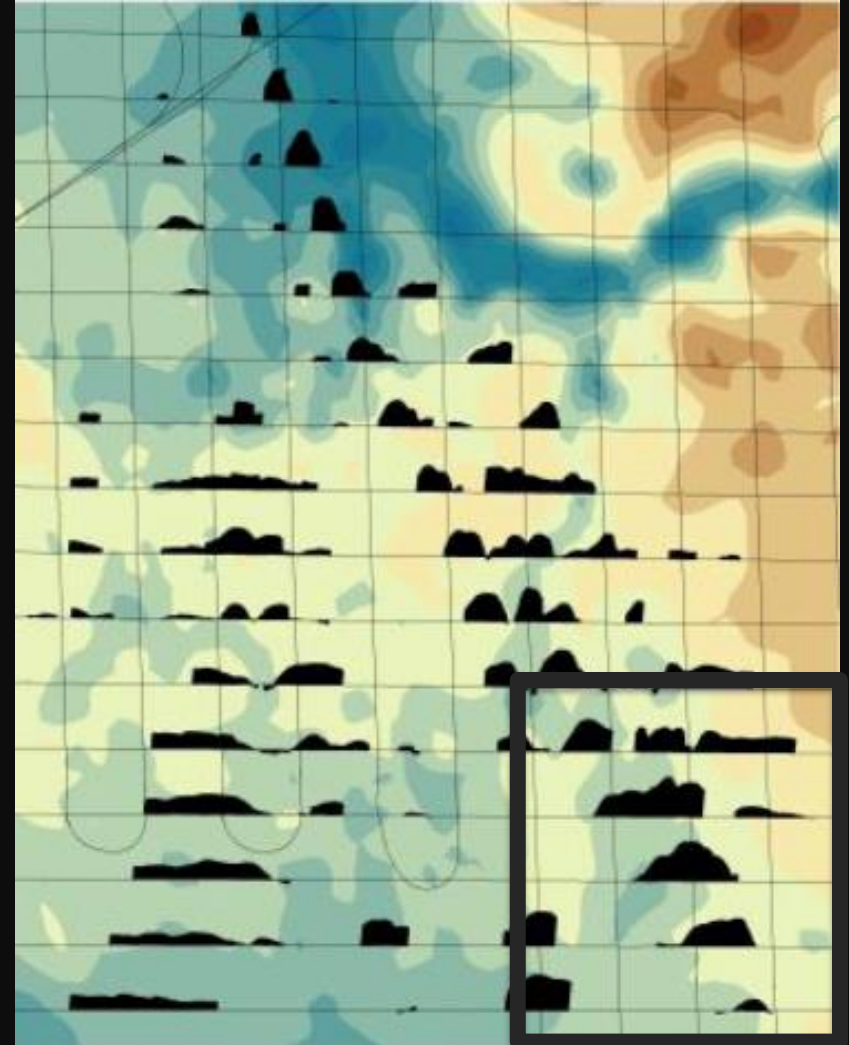
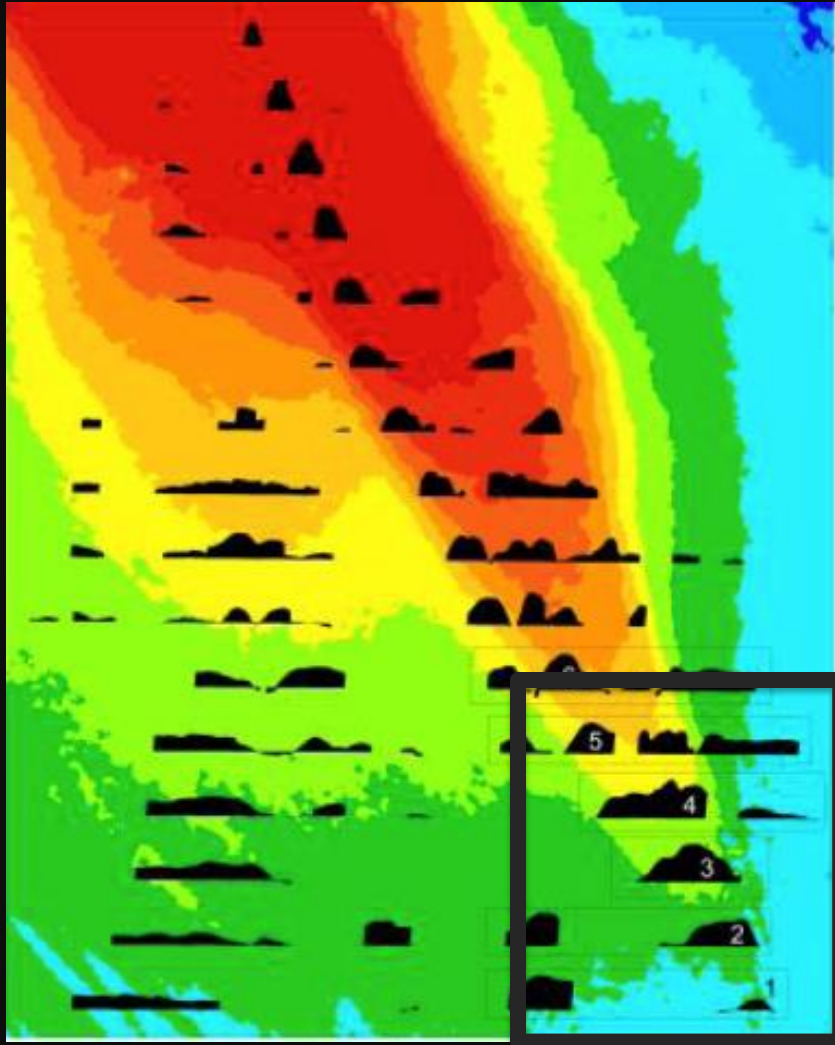
Calving Front

Meltwater Plume

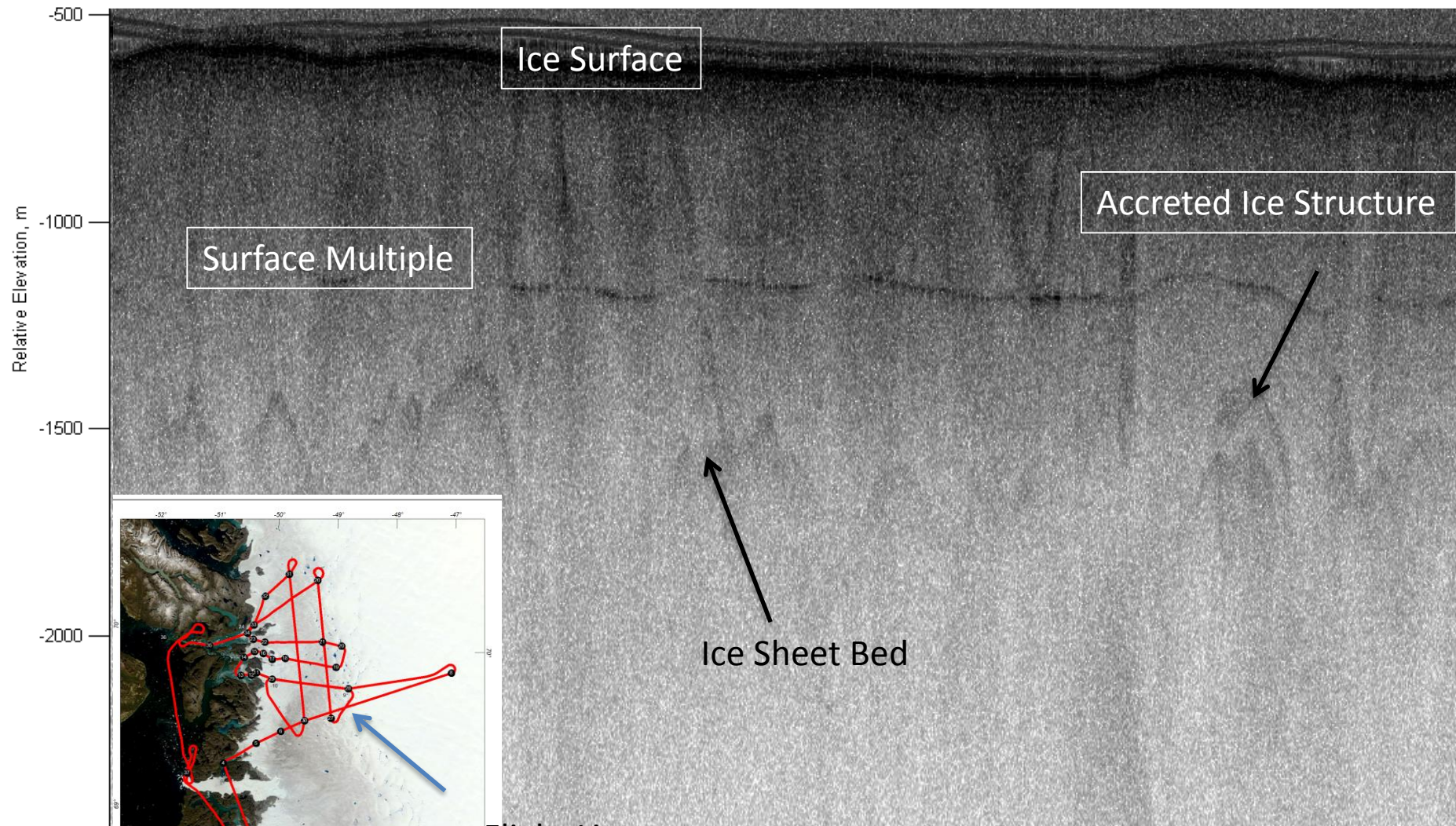


Associated with Onset of Fast Flow

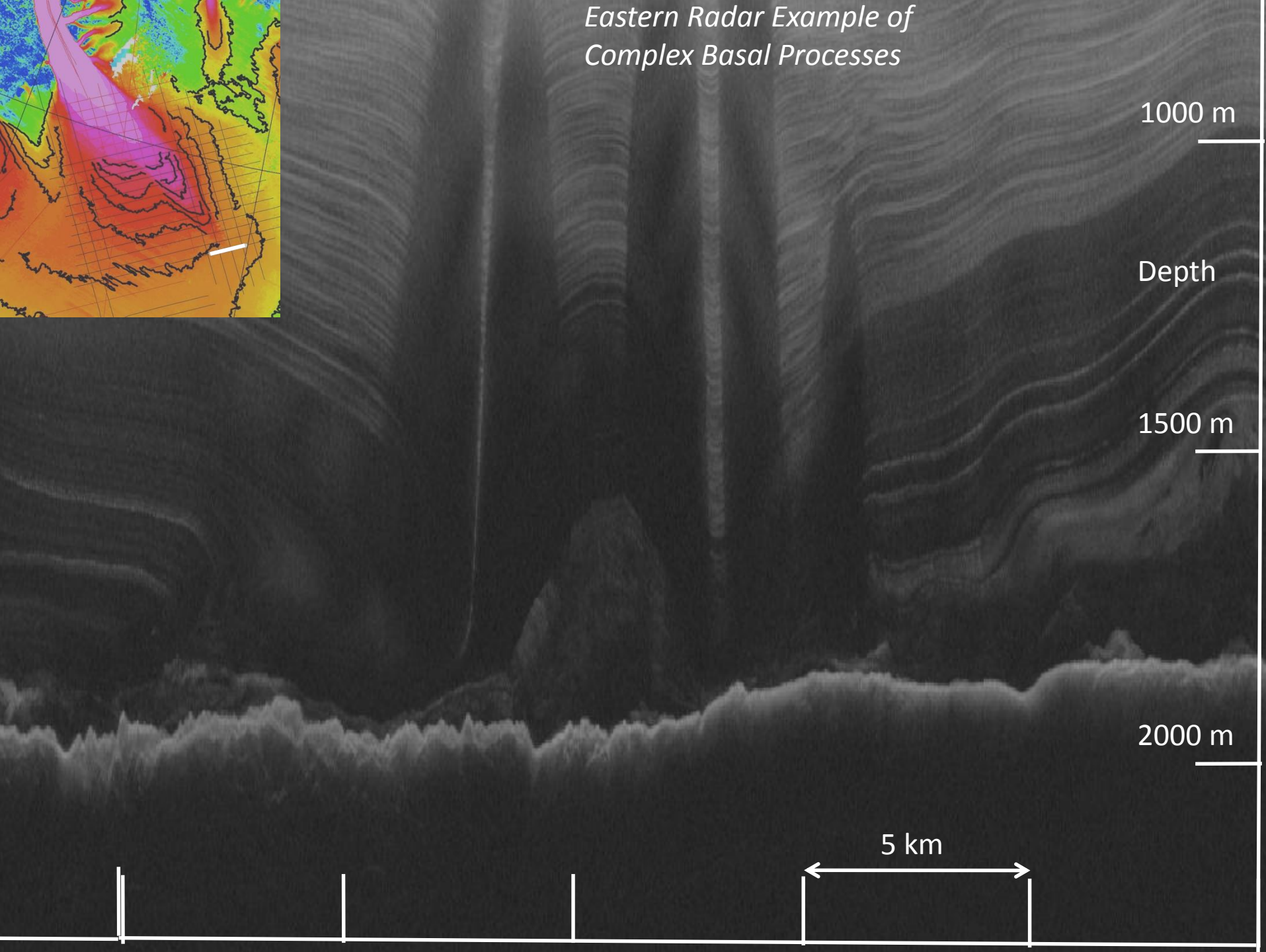
Velocity Bed Topography



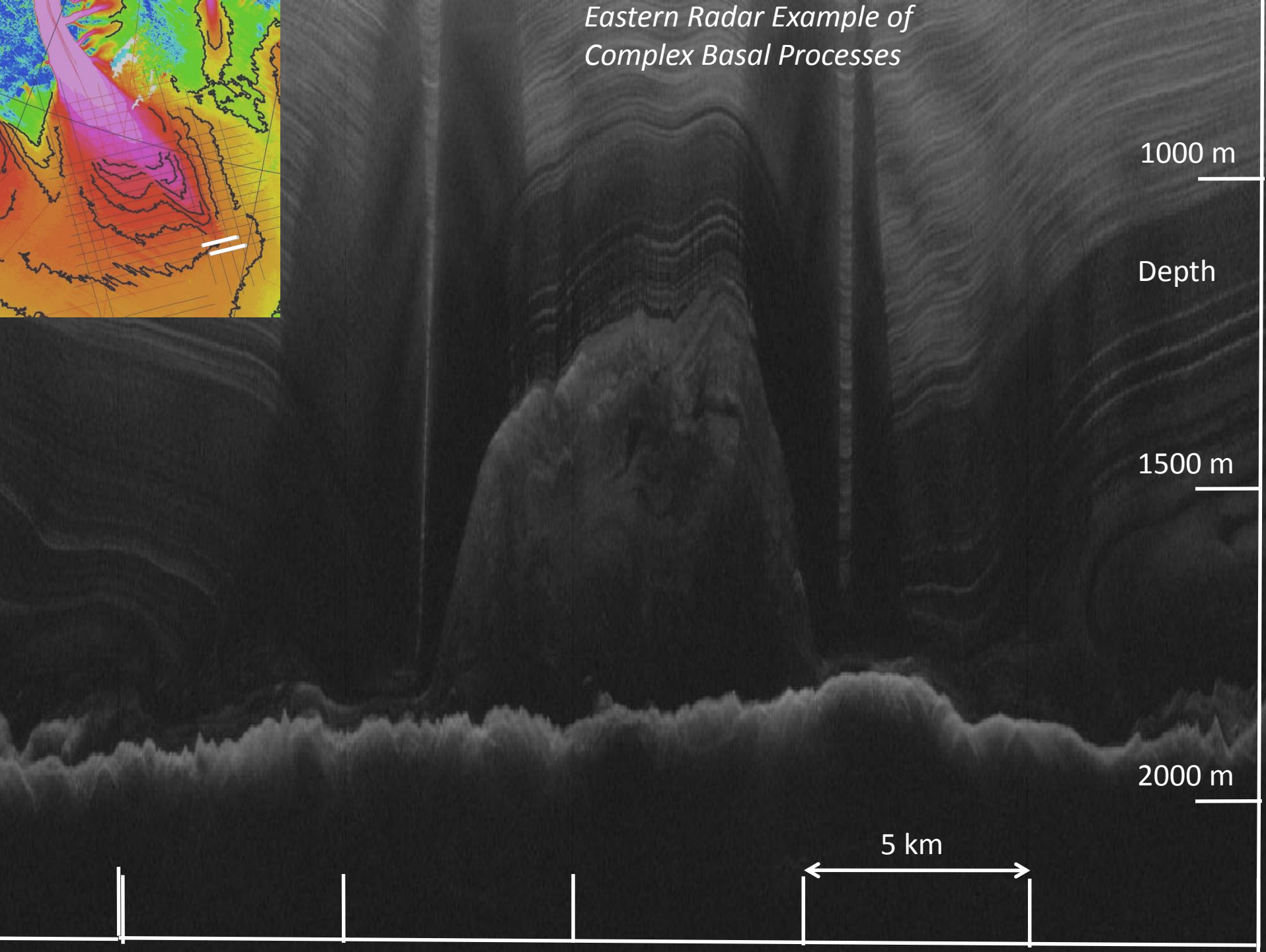
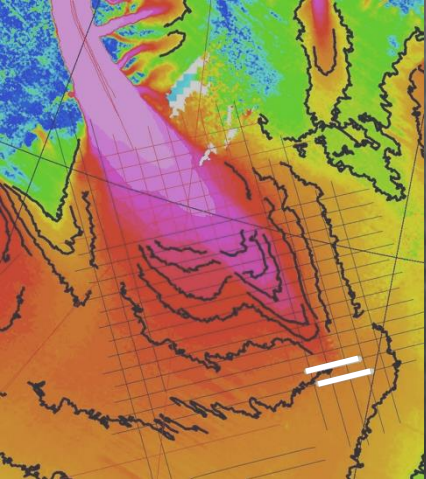
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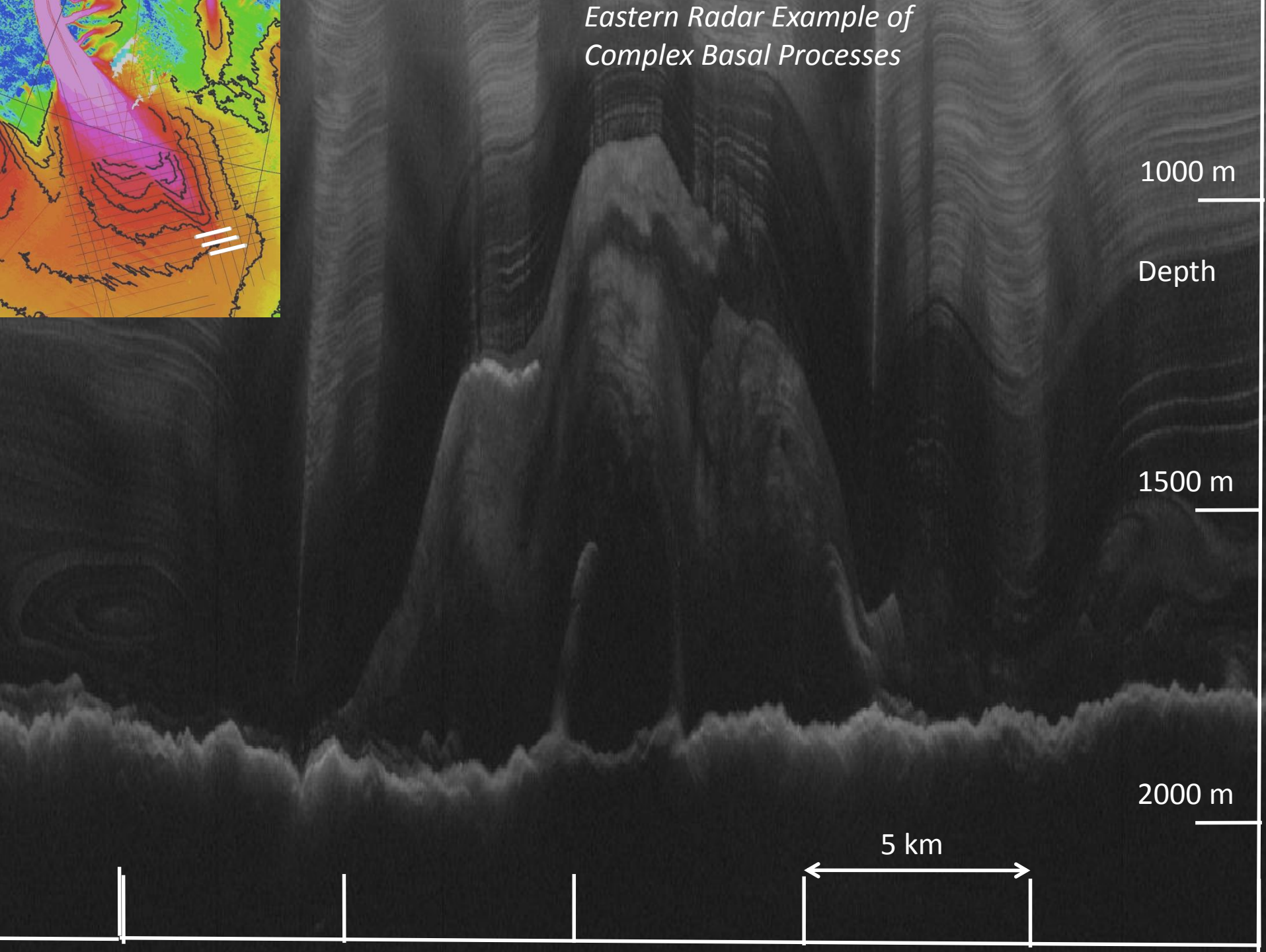
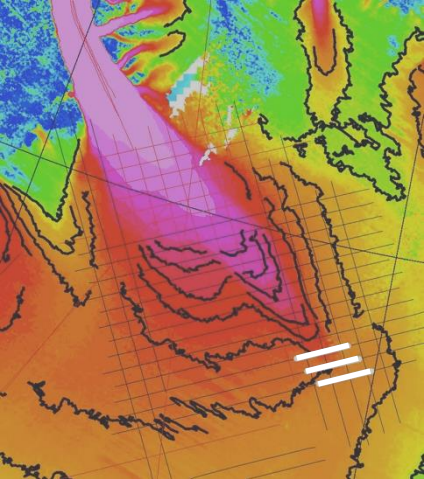
*Eastern Radar Example of
Complex Basal Processes*



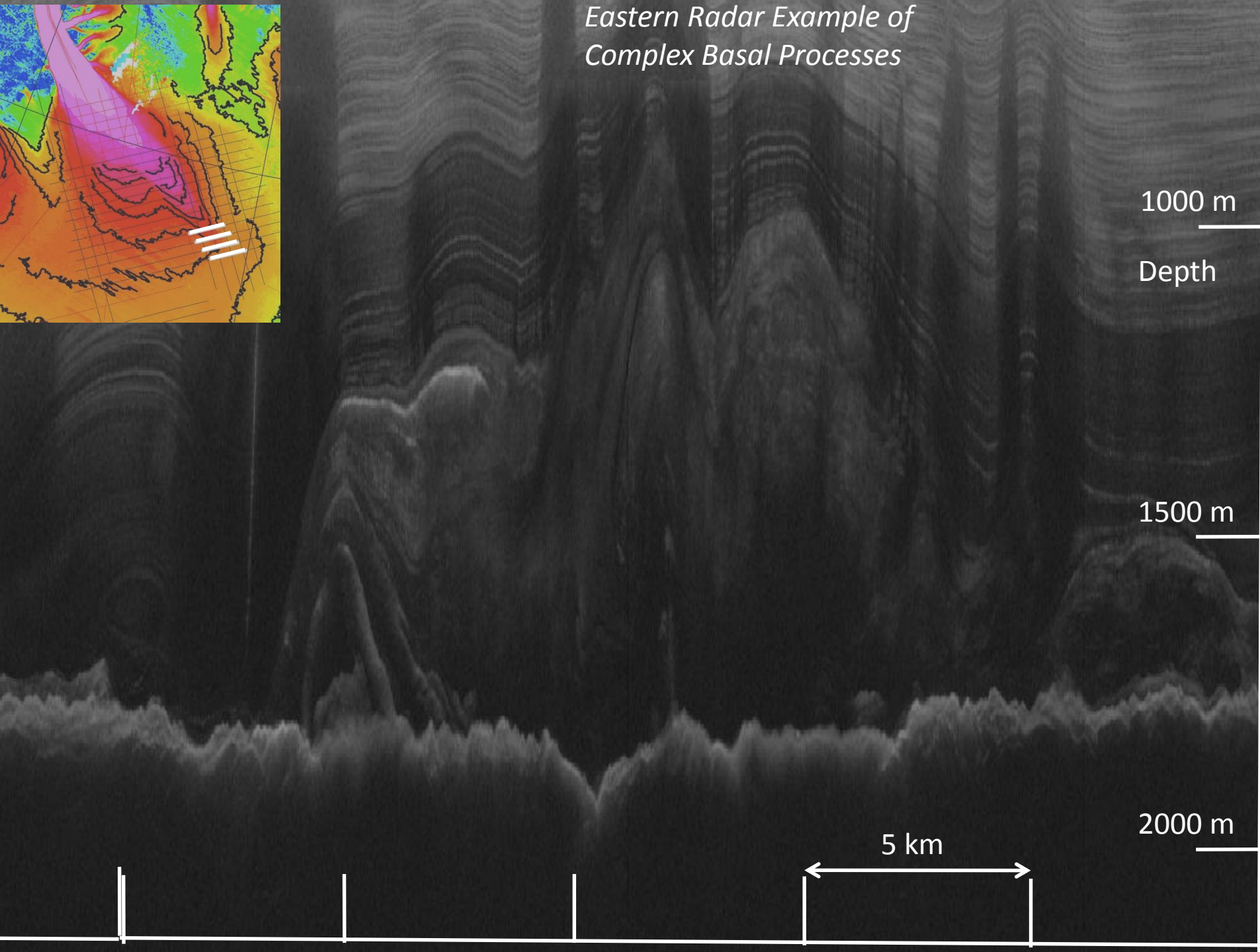
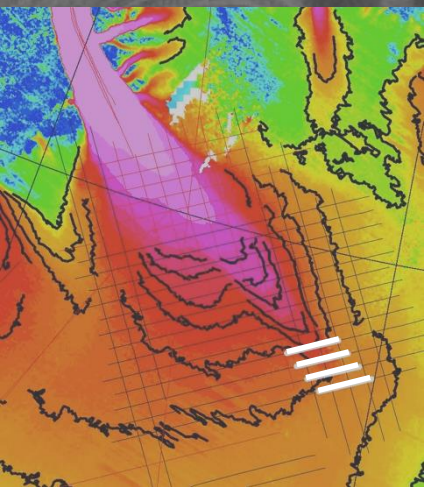
*Eastern Radar Example of
Complex Basal Processes*



*Eastern Radar Example of
Complex Basal Processes*



*Eastern Radar Example of
Complex Basal Processes*



Overview

- Refreezing -Overview–
 - Why does it matter
 - Changes stratigraphy thermal structure and rheology of ice sheet
 - If more water in a warming world --. More refreezing key process
 - What water can refreeze??
 - Any water at the ice sheet base → Lakes, sub glacial water networks “rivers”
 - Where Does the subglacial Water Come From?
 - Basal Melt, Surface Melt, Subglacial Aquifers
- What Does Refrozen Ice Look like?
 - Vostok - Gem Ice
 - Pakitsoq (Greenland) - Black Ice
- Vostok – Slow Freeze-on as ice sheet passes over lake
- Gamburtsev Mountain – Valley Water Networks Feeds Ridgeline Refreezing
- Interior of Greenland – Refreezing and Deformation in flat interior
- Margin of Greenland – Surface Water Feeds Refreezing Along Steep Topography
- Mechanisms
 - Refreezing both supercooling and conductive cooling
 - Often associate or even dominated deformation
- Implication & Conclusions
 - Widespread
 - Paleo Implications → source Heinrich debris
 - Present implications → Likely change rheology of ice sheet both in interior and @ margins Onset and Ice Shelf
 - Future Implications → Likely to increase in a warming world modify ice dynamics @ margins