Subglacial Control on Glacier Flow in Northern Greenland

Beáta Csathó (University at Buffalo, SUNY, Buffalo, NY), C.J. van der Veen (U. of Kansas, Lawrence, KS) Ralph van Frese and Tim Leftwich (The Ohio State University, Columbus, OH), Janos Kiss (ELGI, Hungary), Hyung Rae Kim (NASA/GSFC, Greenbelt, MD) and Alex Braun (U. of Calgary, Canada)

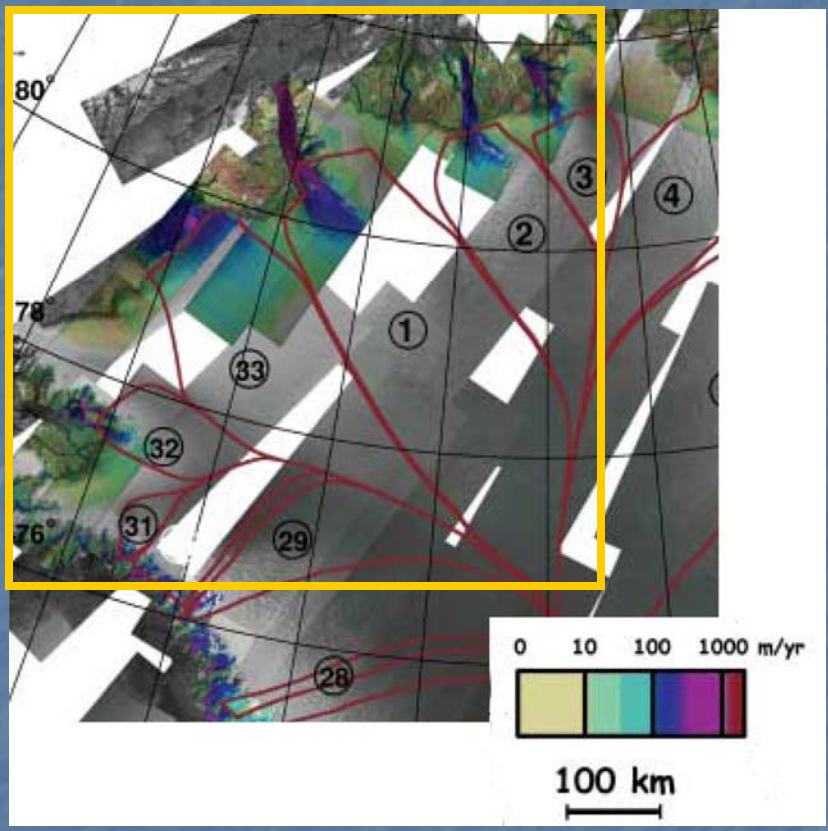
Overview

- Objective: understanding the causes of unusual surface features and subglacial topography in NW Greenland.
- Methodology and results:
  - (1) Mapping shape and distribution of ice sheet features, basal valleys and subglacial hills
  - (2) Estimating crustal thickness from free-air gravity anomaly
  - (3) Reviewing other clues of geothermal conditions and bedrock geology
  - (3) Mapping bedrock lithology from gravity and magnetic field data
- Conclusions and future work

Greenland Ice Sheet, NW Greenland

- Major outlet glaciers: Humboldt (33), Peterman (1), Ryder (2)
- Mass balance and glacial dynamics:
  - The region is close to being in balance and have relatively small accumulation, BUT
  - Very large subglacial melt is measured under the floating tongue of Peterman Glacier
  - A mini-surge has been observed by InSAR over Ryder Glacier
  - Ice piracy is suggested between Humboldt and Peterman

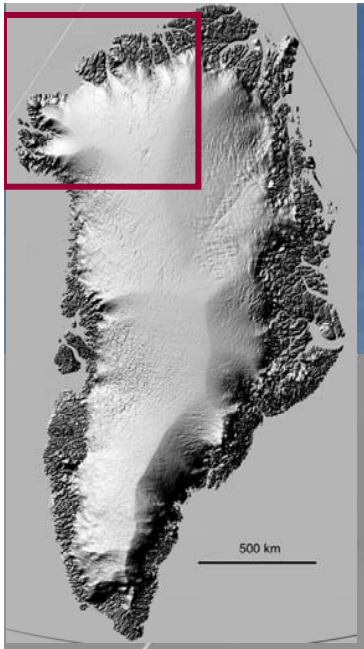
→ Complex and active subglacial hydrologic system!!

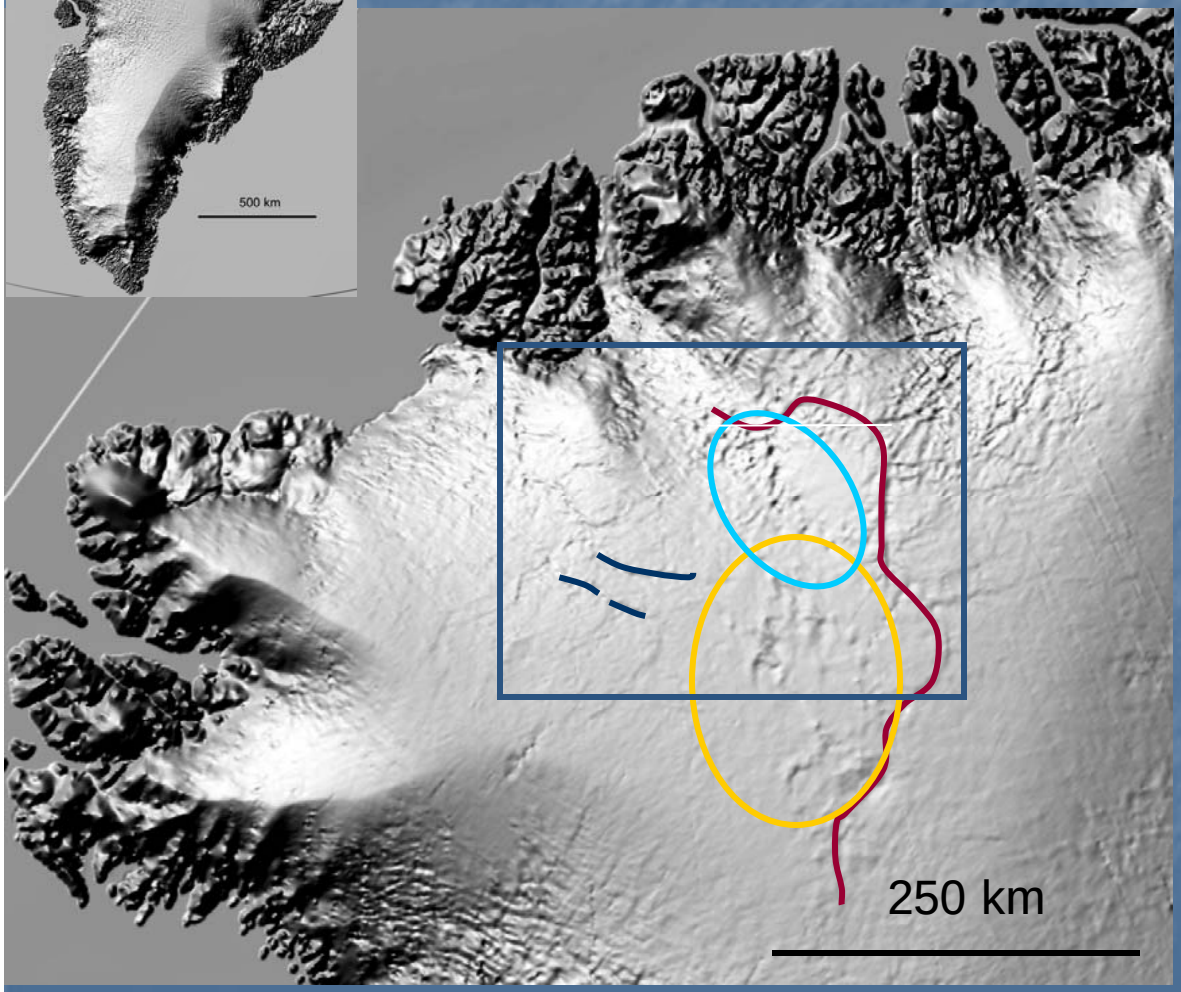


Ice velocities from RADARSAT-1 data, 2000 (Rignot and Kanagaratnam, 2006)

Surface Features in NW Greenland

Shaded relief DEM from photoclinometry, SAR and ICESat altimetry





(1) Onset of Peterman Glacier

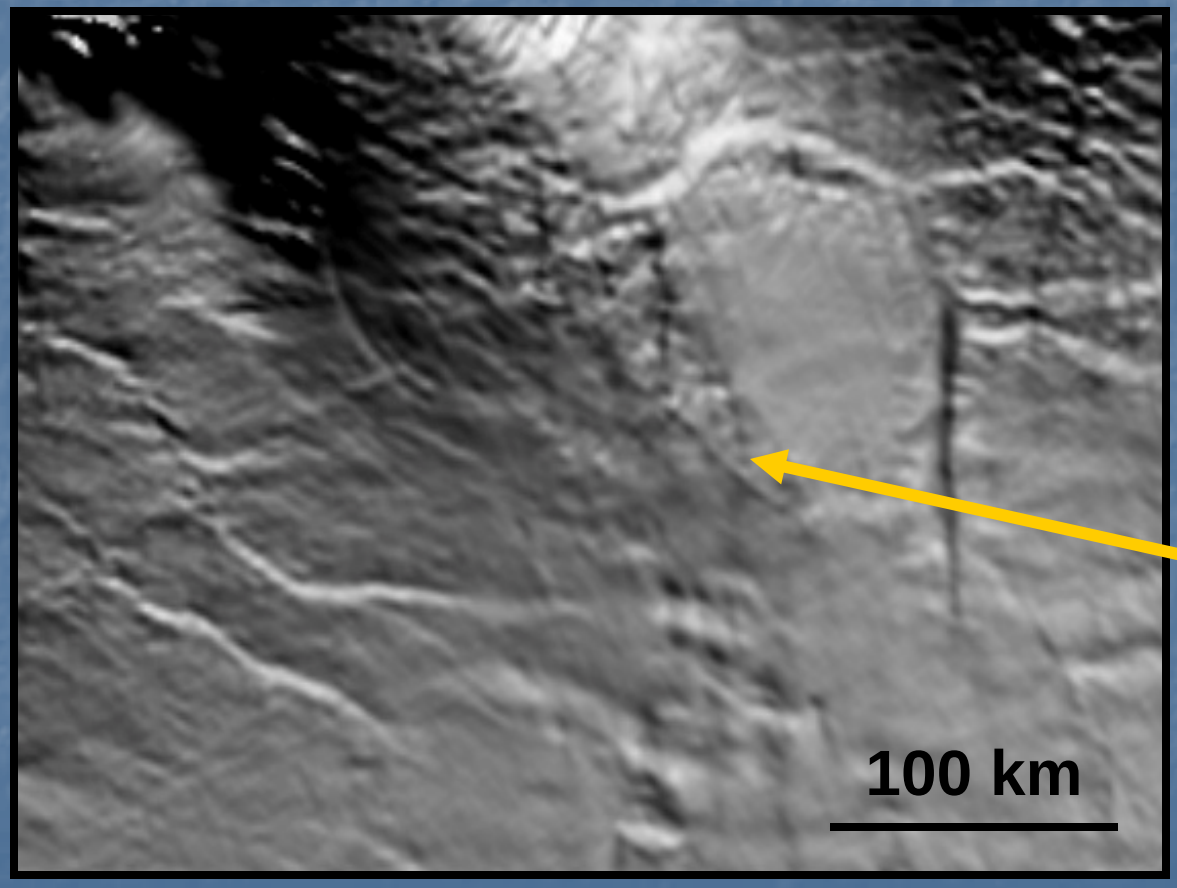
(2) Sinuous surface depression and bedrock channel E of Peterman Glacier was interpreted as an interconnected system of subglacial lakes or water transportation (Ekholm et al., 1998)

(3) Surface features with oblique angles to current flow over Humboldt Glacier

(4) Surface depressions over higher part of Humboldt and Peterman glaciers

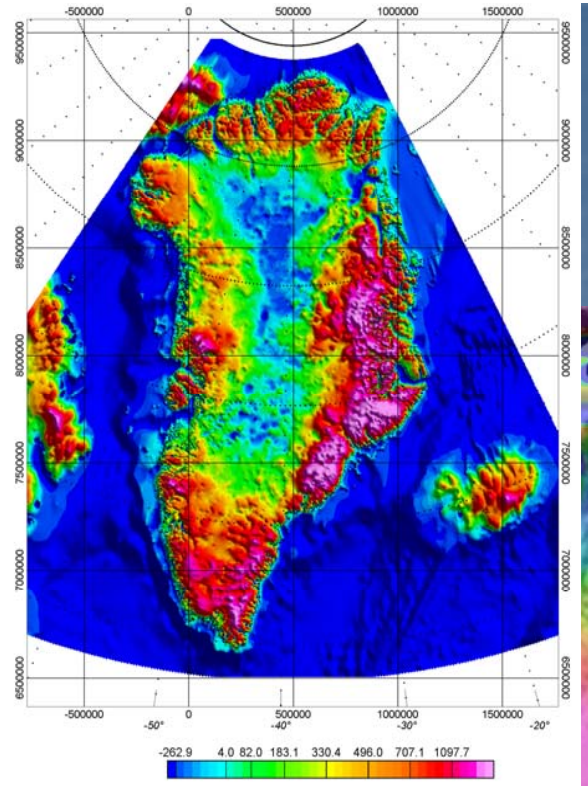
(5) Subglacial hills within (1) and (4) (Legarsky et al., 1998)

Enlarged Features near the Onset of Peterman Glacier



“Discovery” of Tunnel Valleys

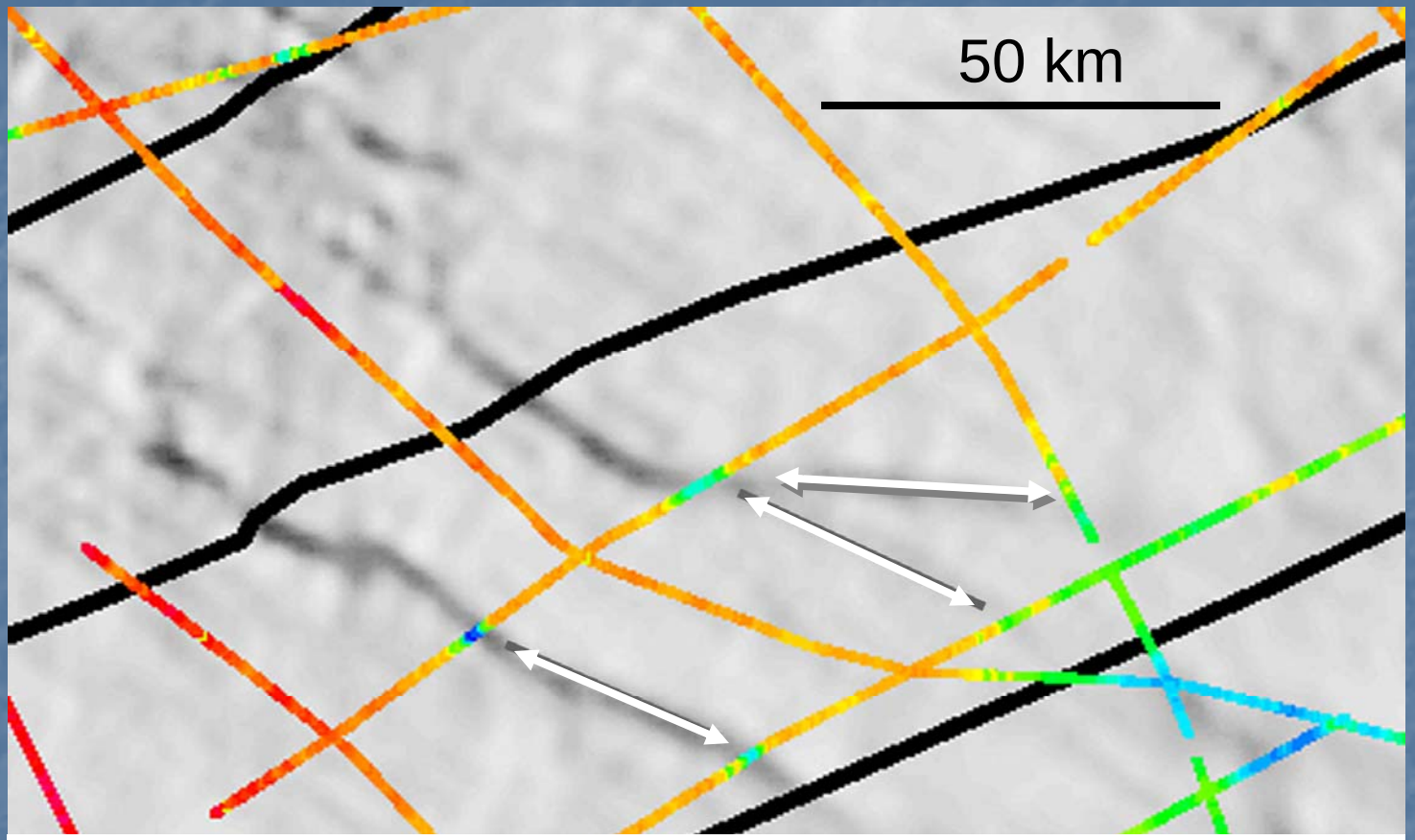
Bedrock DEM (color) and surface DEM (shading)



(Bedrock DEM is From Bamber et al., 2001)

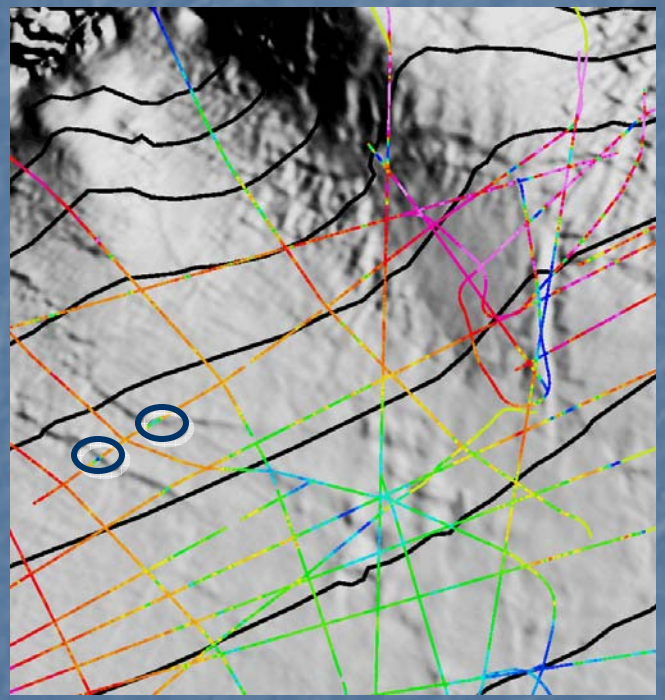
100 km

Color-Coded Bedrock Elevations over Shaded Relief Ice Surface DEM

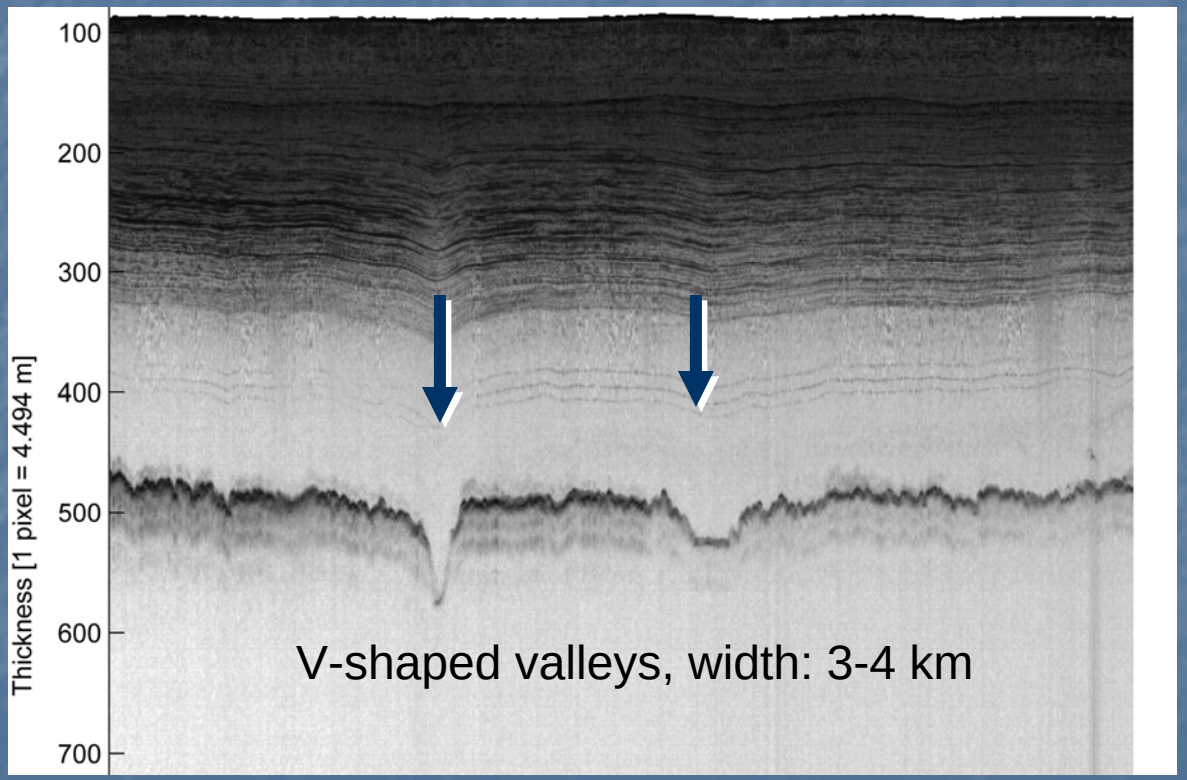


Radio echo sounding data from U. of Kansas (Gogineni et al.)
Interpolation created closed anomalies from small, possibly connected depressions when distance between neighboring profiles is large!!

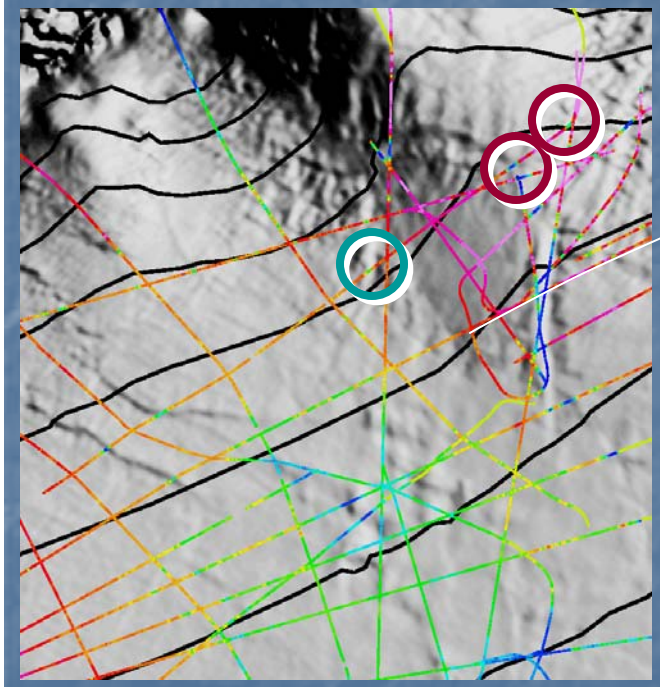
Radio Echo Sounding Profile over Humboldt Drainage Basin

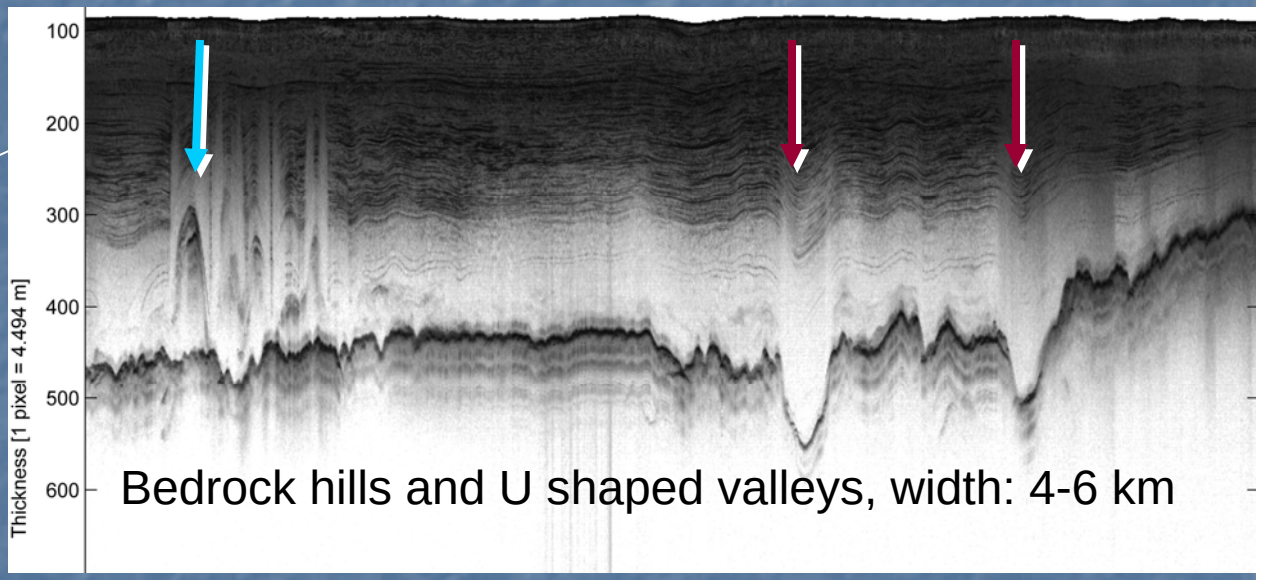


100 km



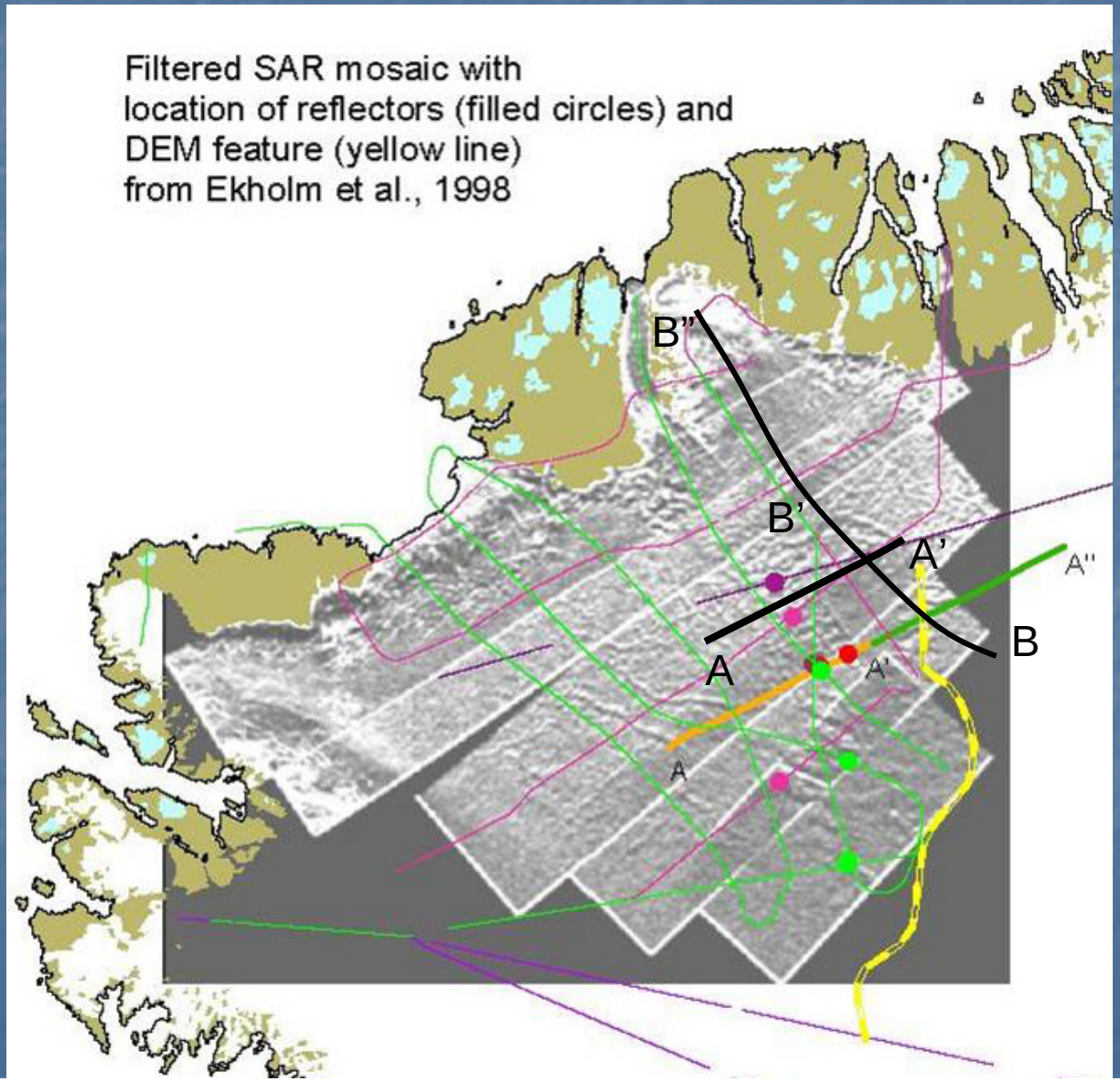
Radio Echo Sounding Profile over Peterman Drainage Basin



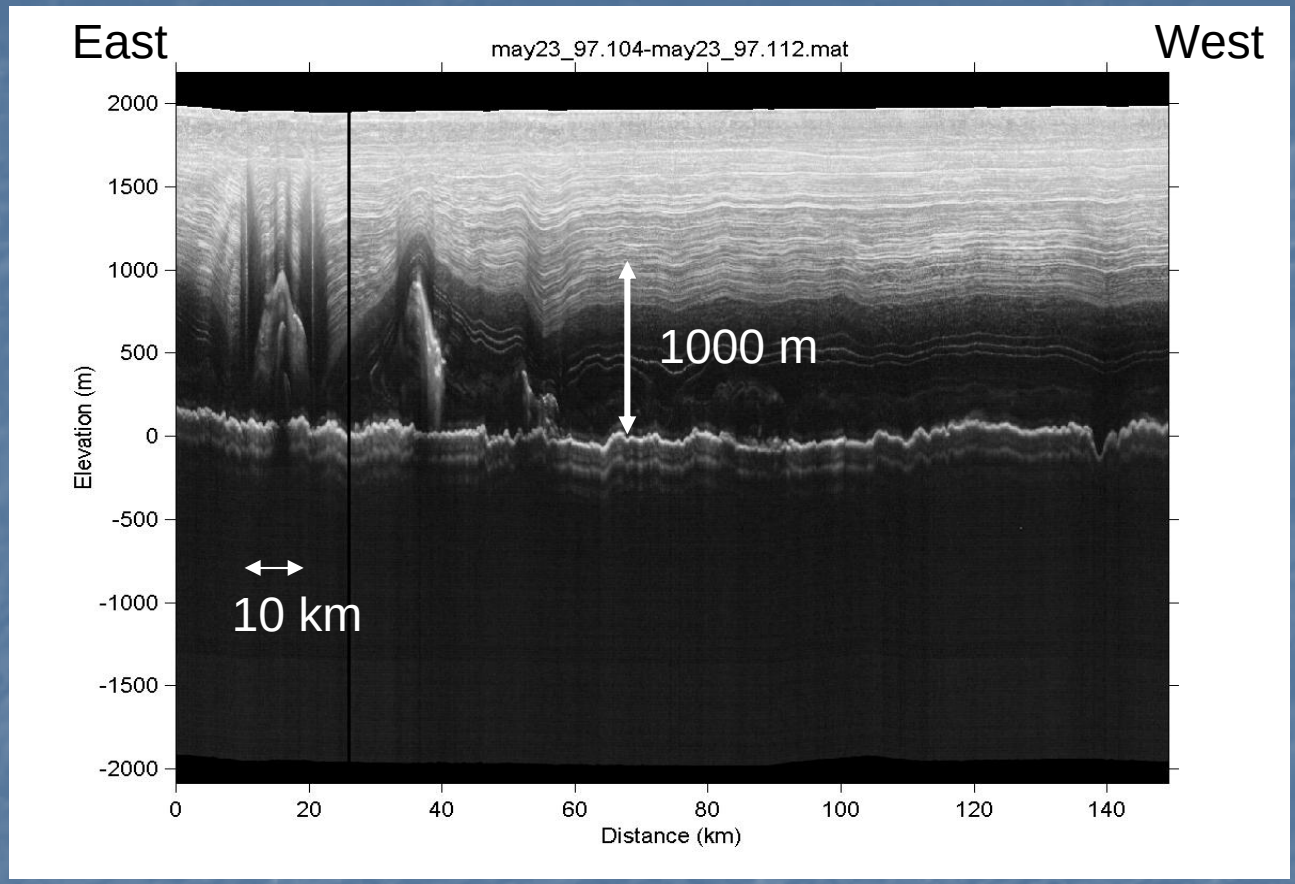


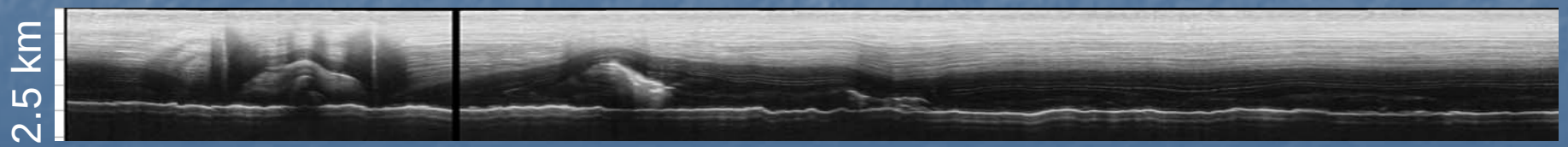
Bedrock hills and U shaped valleys, width: 4-6 km

Profiles over Bedrock “Hills”, Peterman Drainage Basin



Profile Across Peterman Glacier

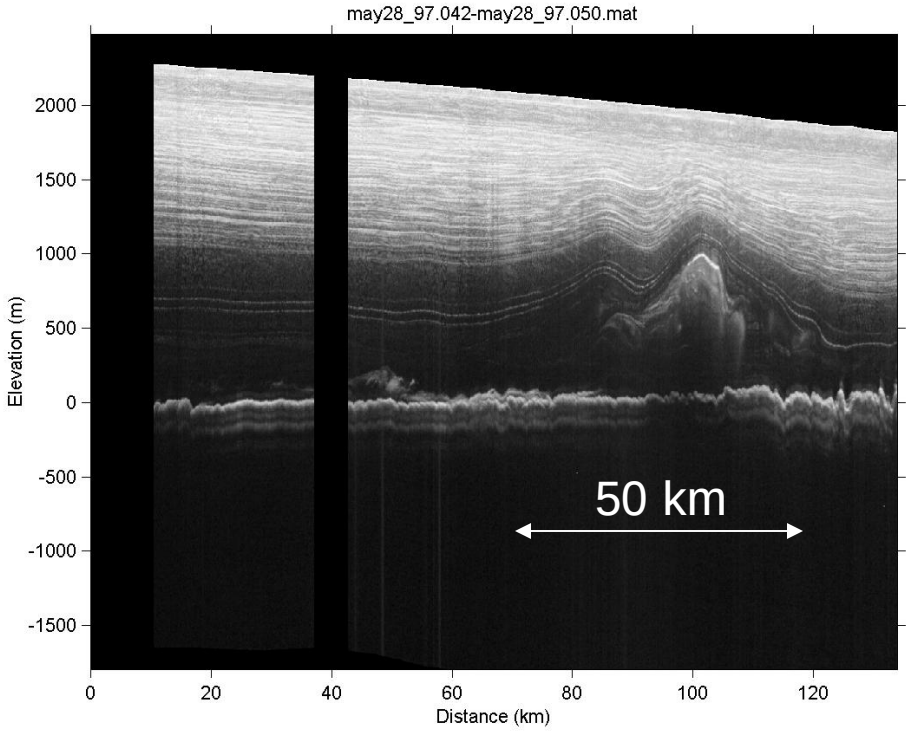


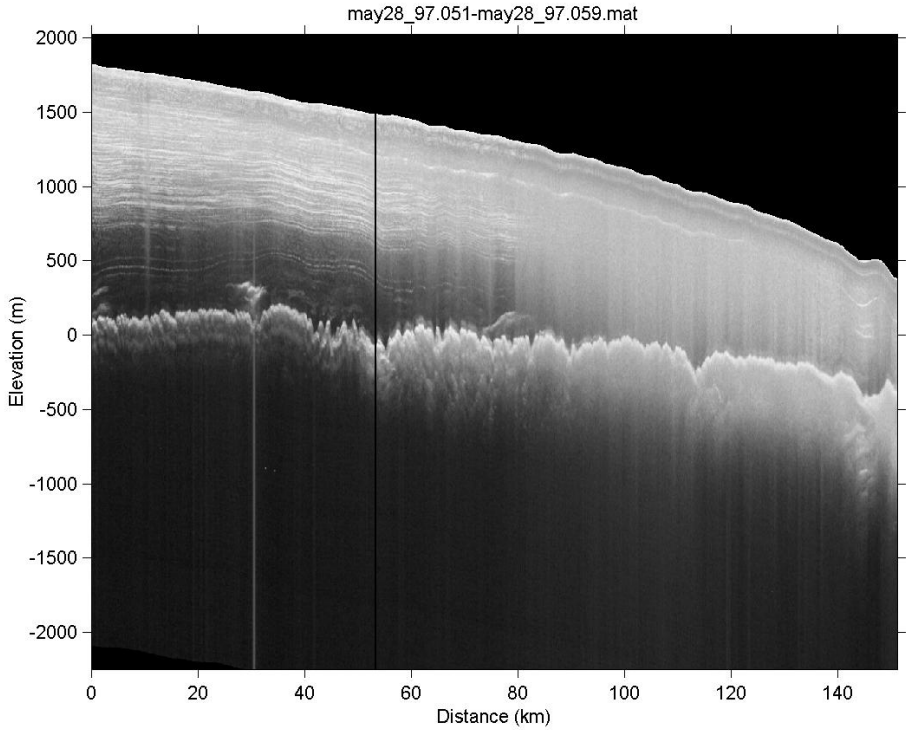


100 km (5:1)

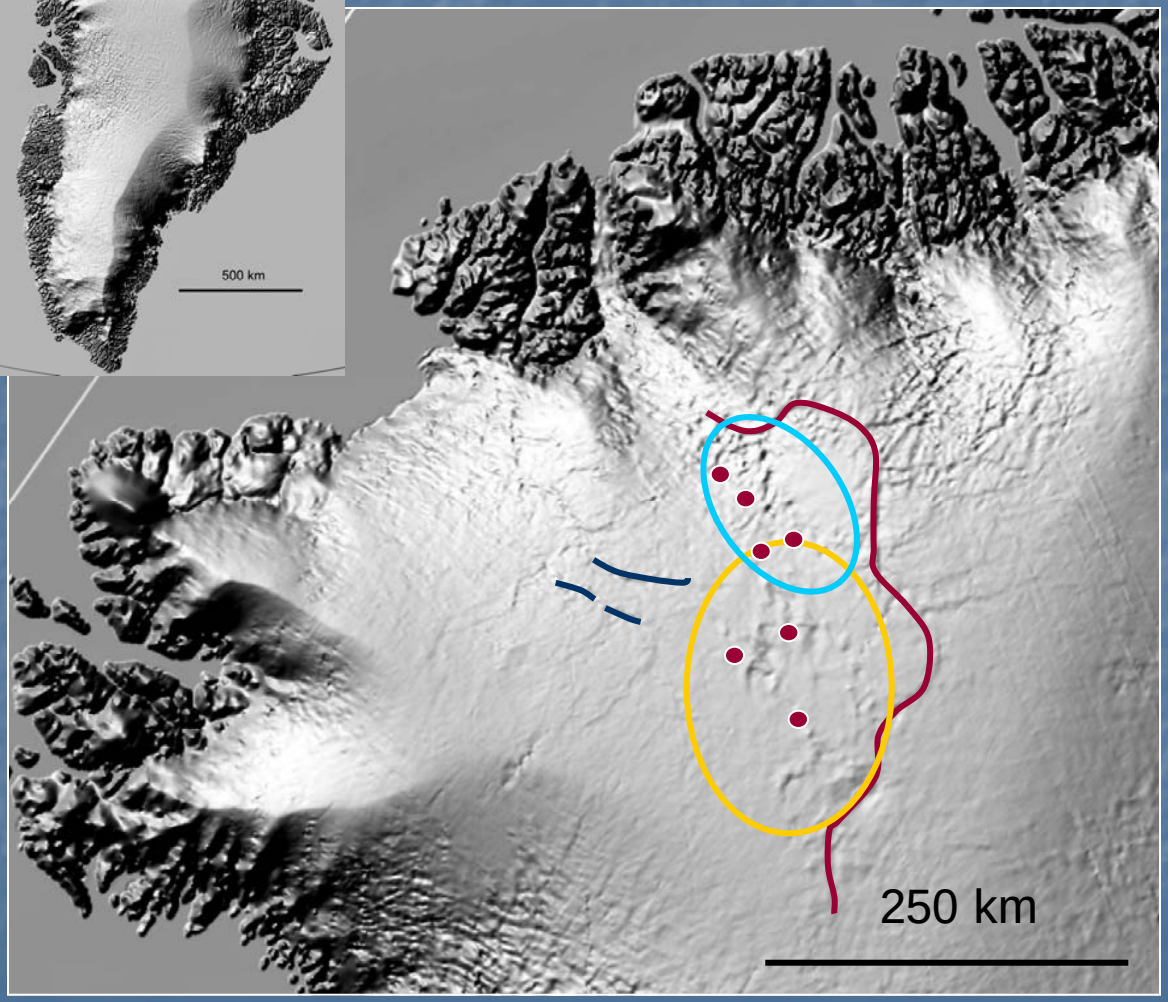
Along Peterman Glacier

B B’ B’ B”





Distribution of Subglacial “Hills”



North: features are aligned along western boundary of the Peterman onset region

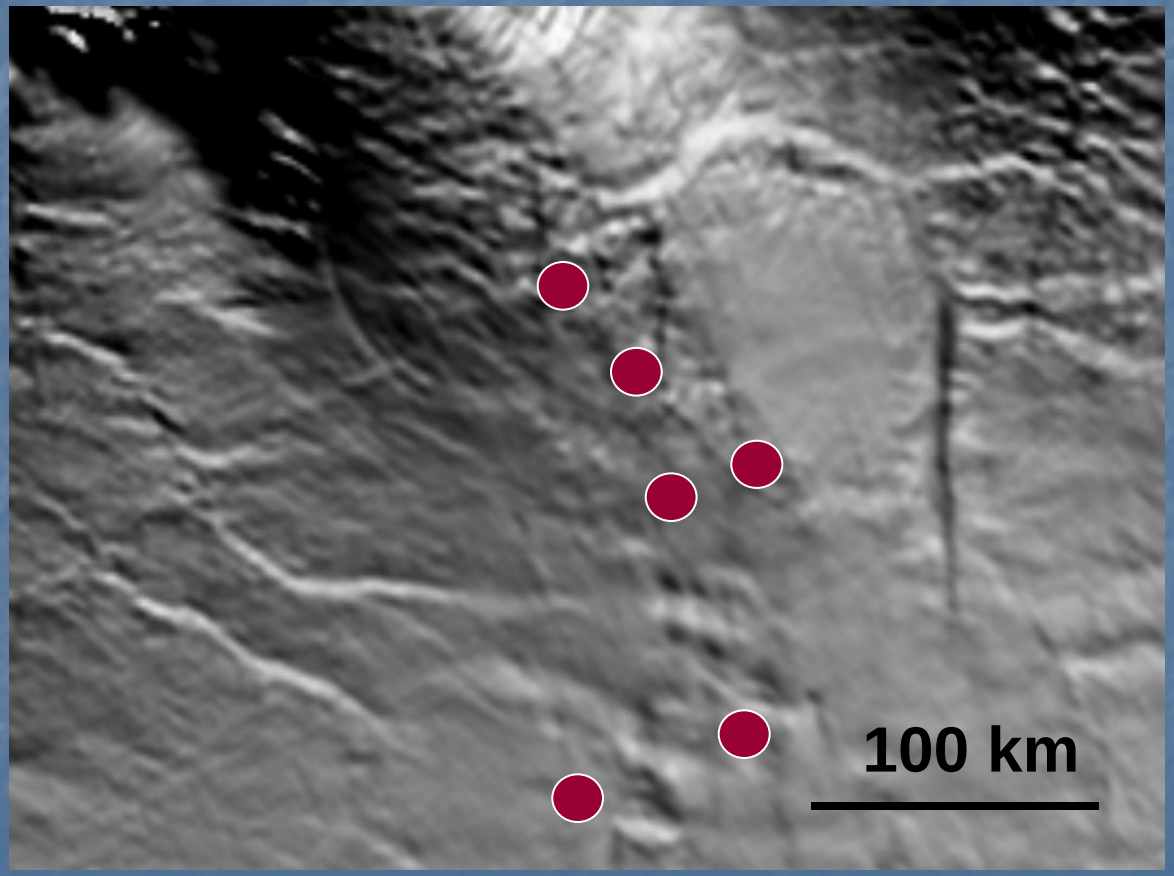
South: features are located in a region where ice flow direction might switch between Humboldt and Peterman Glaciers

Note:

(1) there could be unmapped features

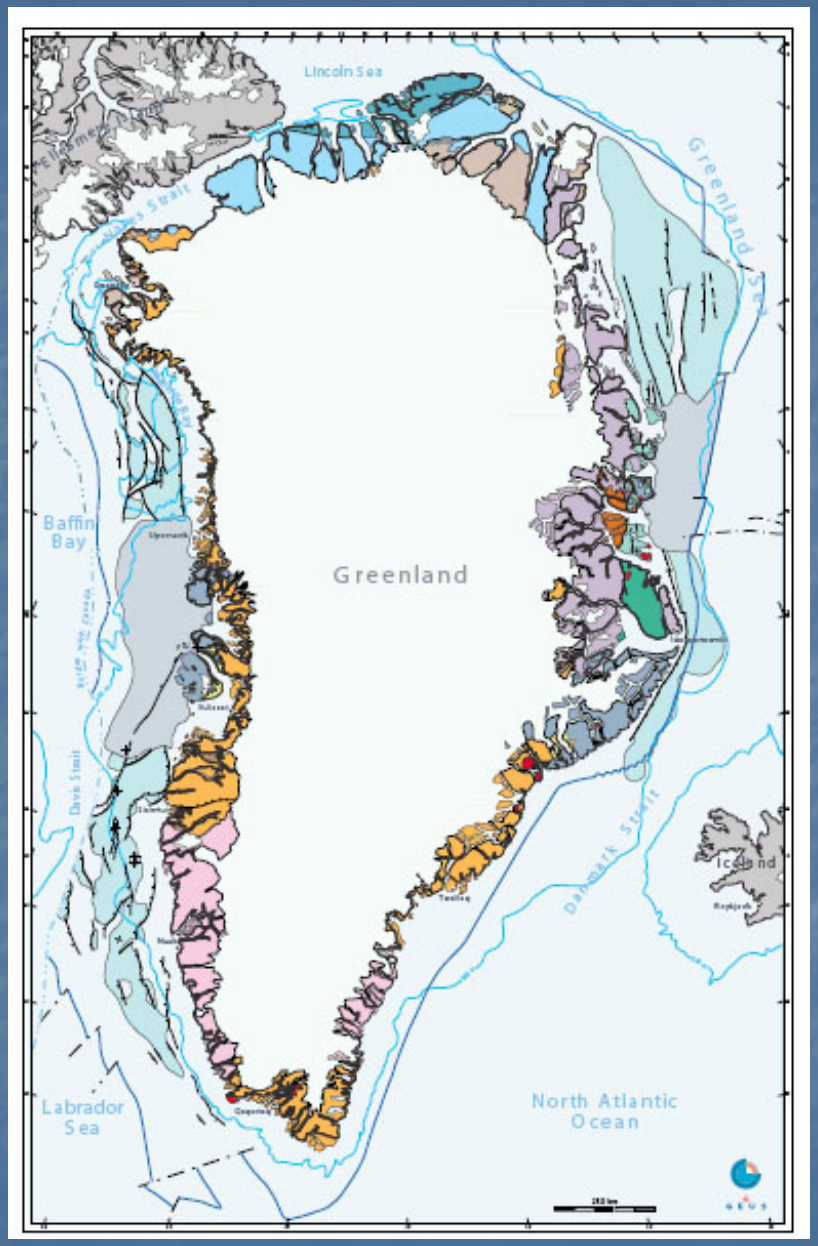
(2) some features might mark elongated ridges

Subglacial Hills over the Onset Region of Peterman Glacier



Bedrock Geology, Geothermal Conditions

- Subglacial geology:
  - Lower Paleozoic Franklinian sedimentary basin in NW and NE
  - Reworked Proteozoic crystalline rocks, outcroping in Victoria Fjord in the middle
  - A large magmatic province, detected by aerogeophysical surveys in central and northern Greenland
- Subglacial volcanism:
  - Glacial volcanic erratics, NOT occuring in outcrops in N Greenland, has been described by Dawes et al., 2000
- Geothermal heatflux:
  - High and spatially variable geothermal flux is estimated at NGRIP (e.g. NGICP members, 2004)
  - Lithospheric thinning and crustal thermal erosion might be related to the Icelandic hotspot track



SEDIMENTARY BASINS OF GREENLAND

Geological Survey of Denmark and Greenland
2000

LEGEND

- Inland Ice
- Lower Tertiary basalts
- Cretaceous – Lower Tertiary sediments of West Greenland (Nuussuaq Basin) and East Greenland (Kangerlussuaq Basin)
- Carboniferous – Lower Tertiary sediments of the Wandel Sea Basin of eastern North Greenland
- Carboniferous – Cretaceous sediments of North-East Greenland basins
- Carboniferous – Cretaceous sediments of the Jameson Land Basin in East Greenland
- Devonian Basin of North-East Greenland
- Shelf / Trough } Lower Palaeozoic sediments of North Greenland (Franklinian Basin)
- Middle–Upper Proterozoic sediments and volcanic rocks
- Caledonian orogenic belt
- Lower Proterozoic orogenic belts
- Archaean craton
- Intrusive complexes; Lower Tertiary in East Greenland, Middle Proterozoic in South Greenland
- Offshore basins with substantial thicknesses of sediments (>~3km)
- Offshore basins where deeper sedimentary successions concealed by Lower Tertiary basalts
- Landward limit of proven oceanic crust
- Extensional fault
- Compressional fault, thrust
- Transform fault
- Site of exploration well

Map of major structural-statigraphical units of Northern Greenland

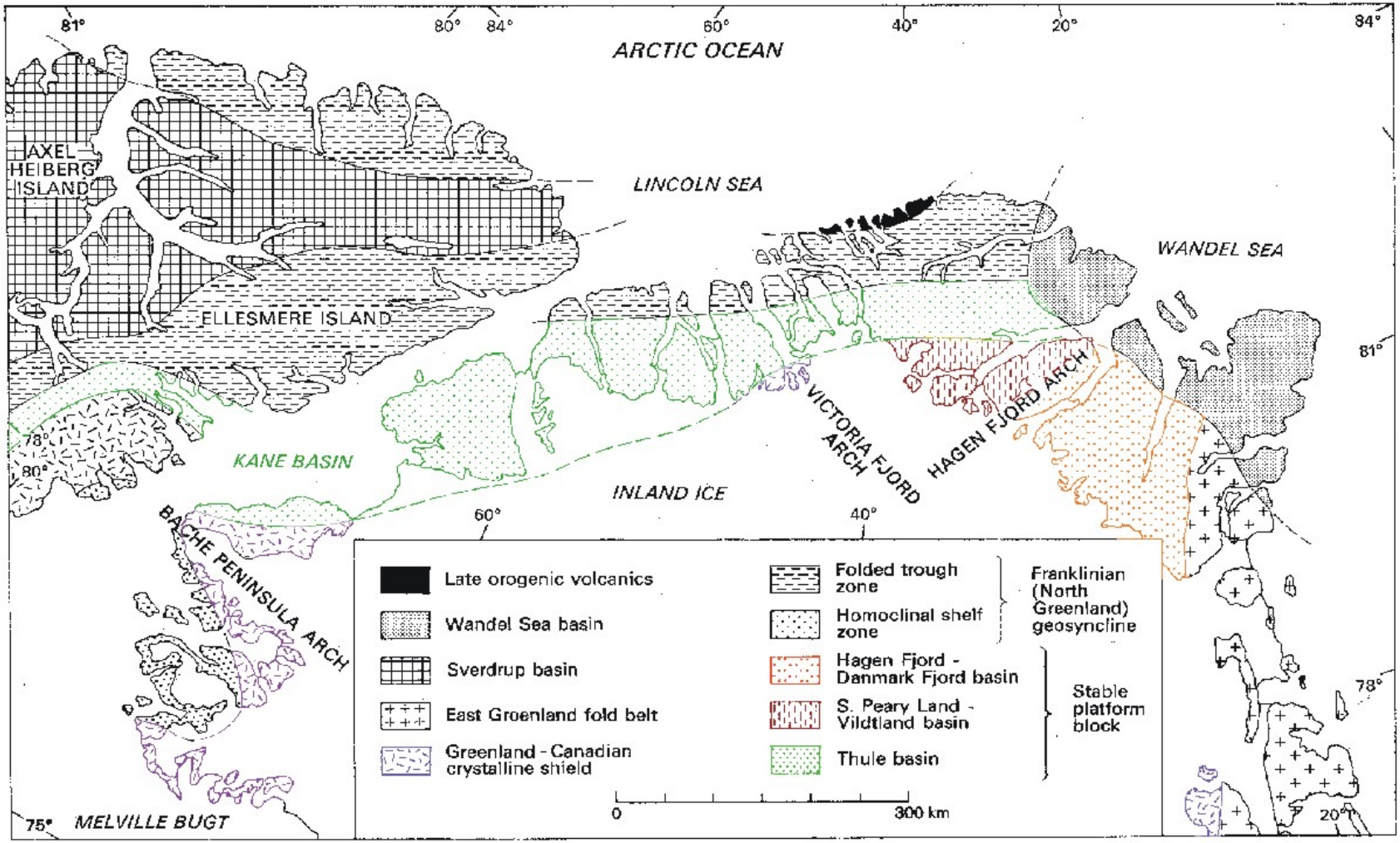
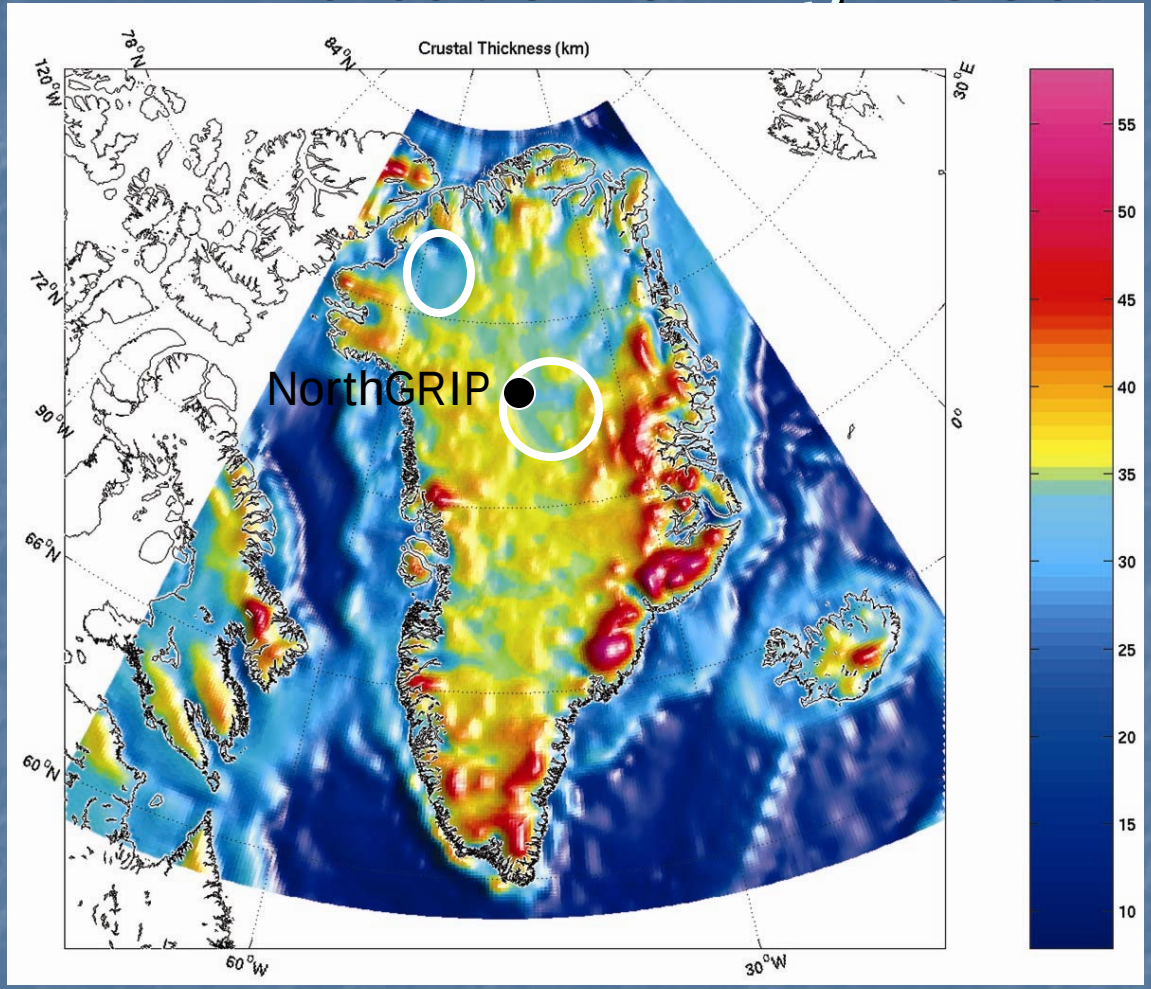
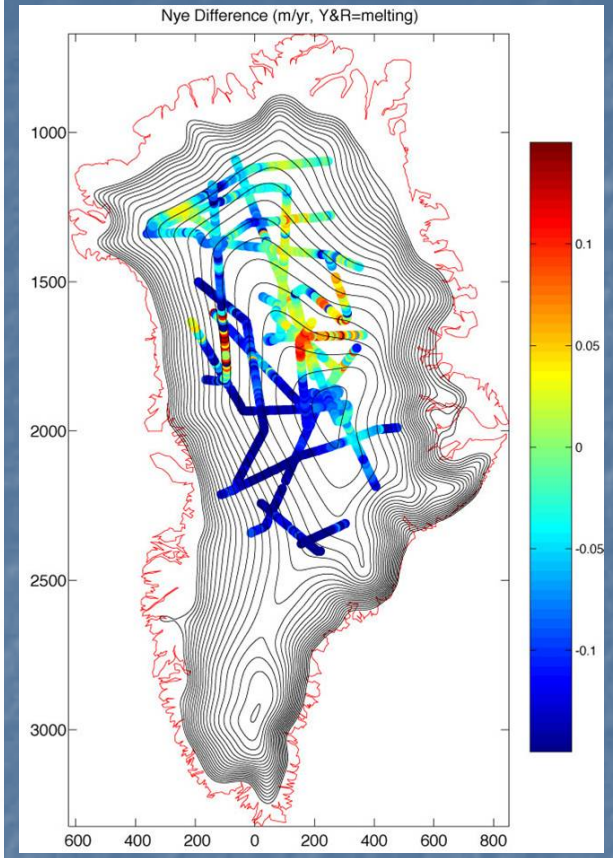


Fig. 222. Map showing the main structural–stratigraphical units of northern Greenland and adjacent Arctic Canada (modified from Dawes & Soper, 1973).

Comparison of Crustal Thickness and Indication of High Geothermal Heatflux

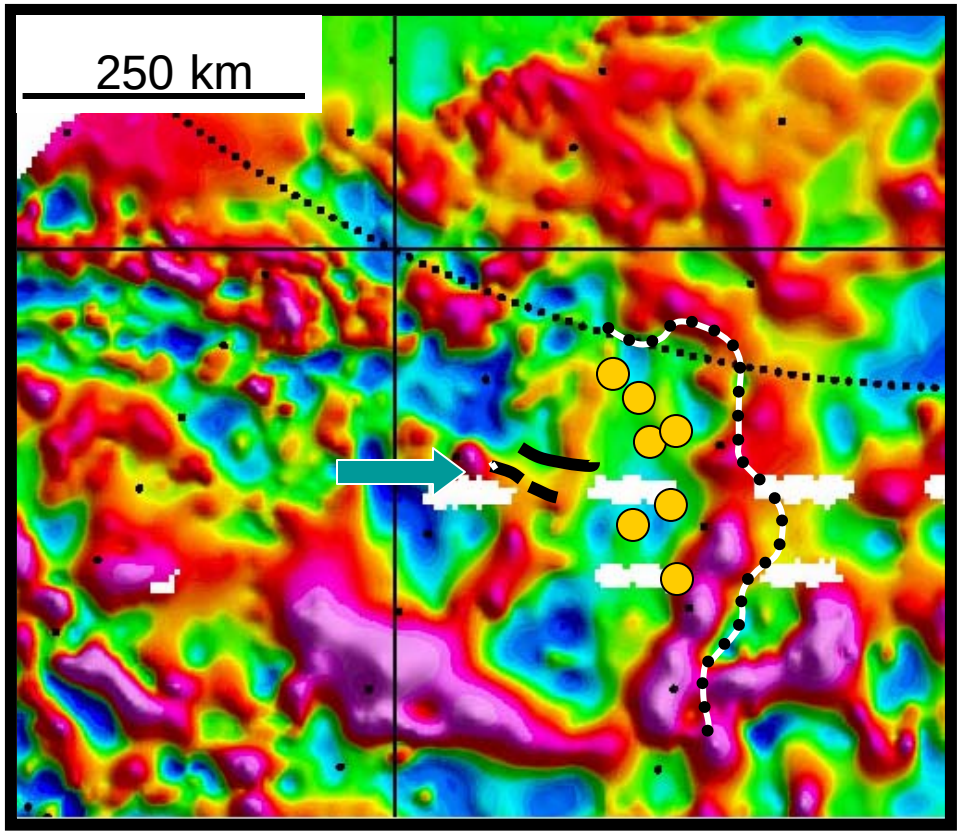


Crustal thickness Computed from Free-Air Gravity Anomalies (Braun et al., submitted)



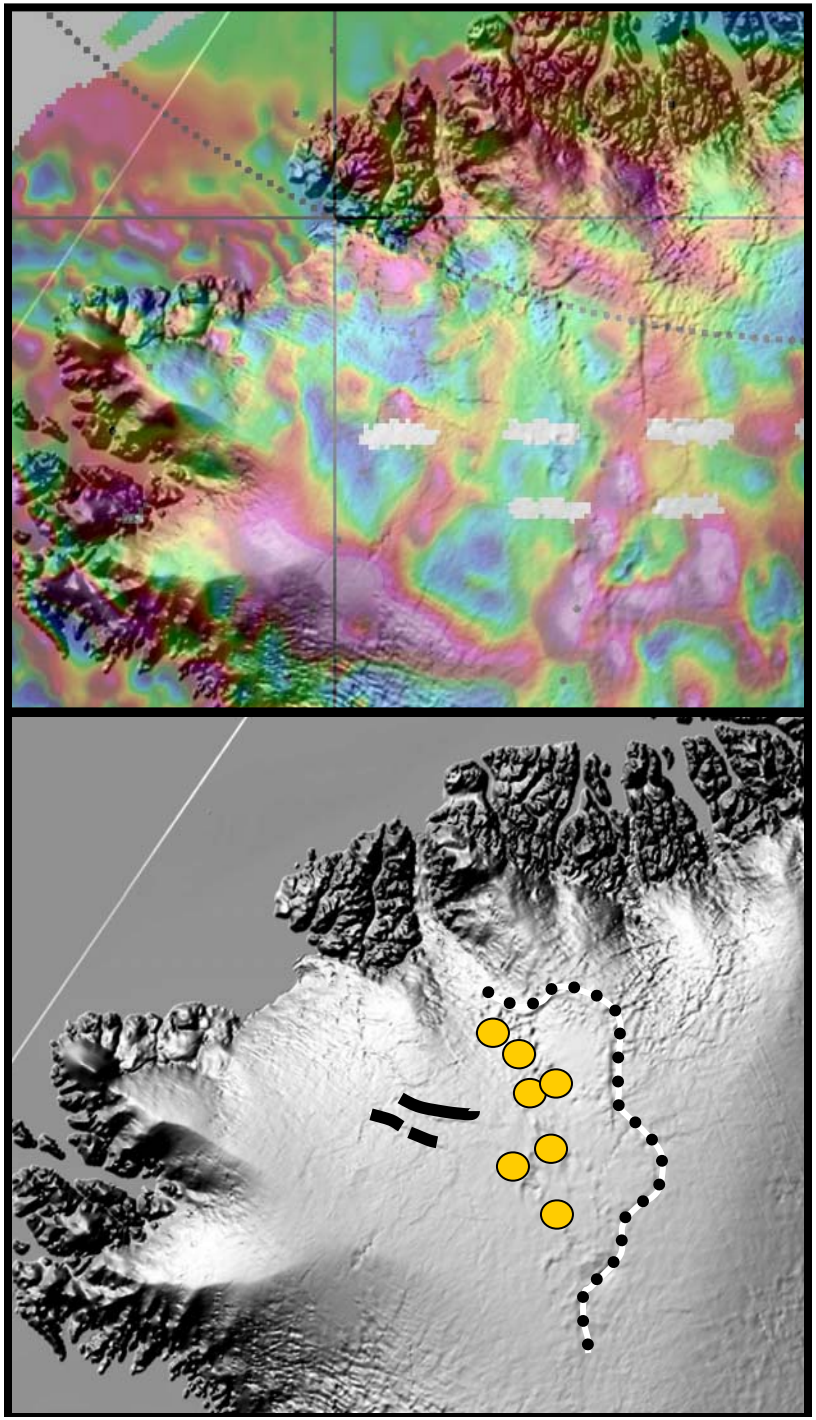
Subglacial melt mapped from Internal layer thickness (Fahnestock, personal com.)

Total Field Magnetic Map (nT)

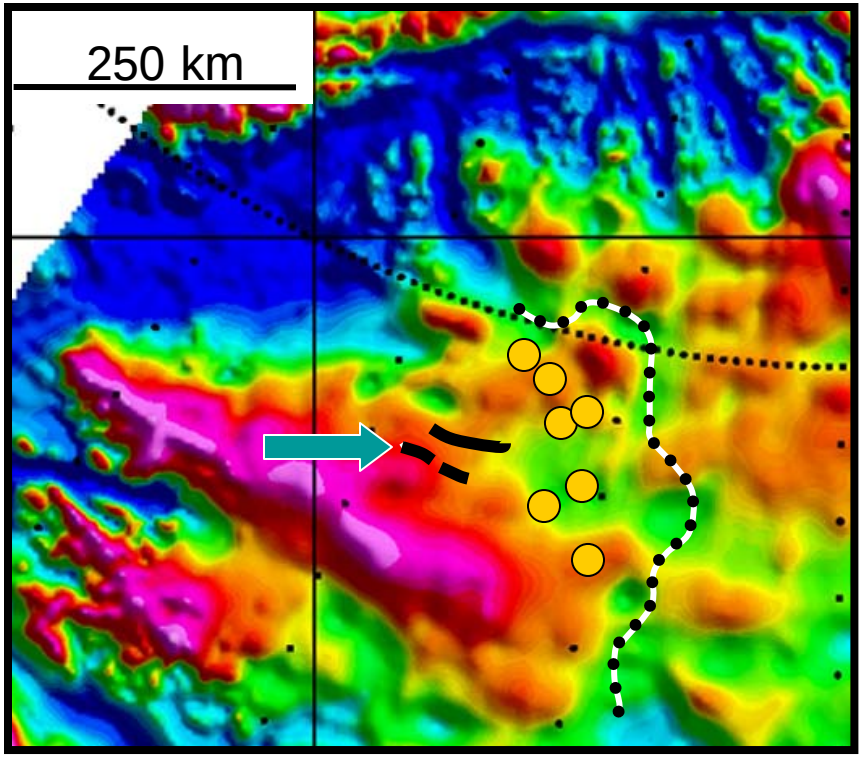


-314.2 -129.3 -67.3 -25.4 16.4 55.9 108.3 236.7

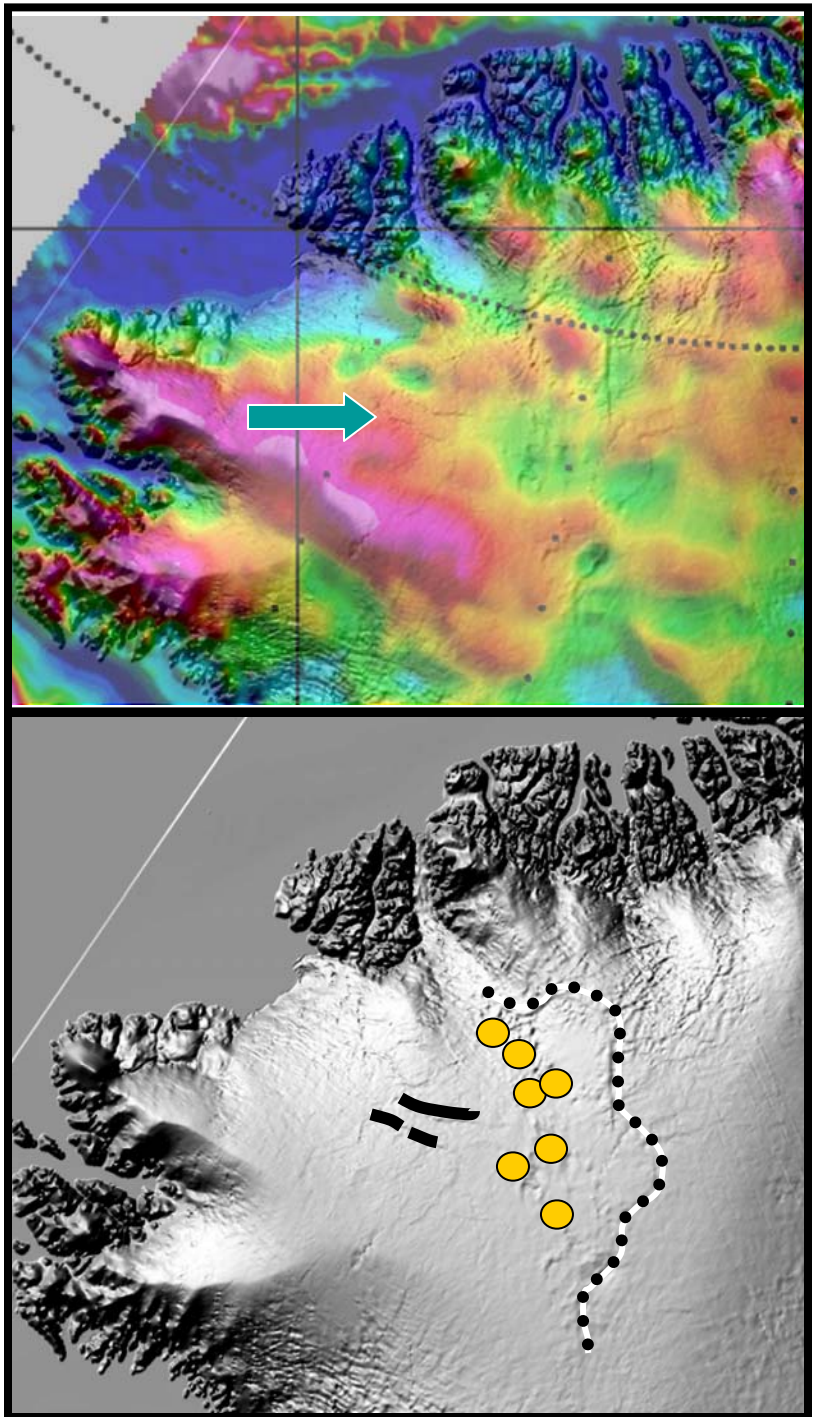
Data from Verhoef et al., 1996



Free-Air Gravity Anomaly Map (mgal)



Data from J. Brozena and R. Forsberg



Conclusions

- Glacial-geological conditions in NW Greenland are similar to those observed on WAIS, since NW Greenland is characterized by thin crust, a large sedimentary basement, high and spatially variable geothermal heat flux, large magnetic anomalies and a complex hydrological system.
- Bedrock geology controls the southern extent of Humboldt glacier and possibly the onset of streaming flow on Peterman Glacier

Conclusions (cont)

- Bedrock hills are interpreted as volcanoes, possibly erupted subglacially
- Elongated subglacial depressions are interpreted as tunnel valleys created by sudden release of melt water, selective linear erosion (Humboldt) and active glacier erosion (curvilinear feature E of Peterman)
- Subglacial volcanic activity could contribute to important glacial dynamic processes, such as mini-surges of Ryder Glacier and observed high melt rate of the floating tongue of Peterman Glacier and therefore it has important implications for the mass balance and stability of the ice sheet
- Future work: a lot …..

Acknowledgements

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