The Northeast Greenland Ice Stream

Richard Alley, Sridhar Anandakrishnan, Byron Parizek, David Pollard and Nathan Stevens (alphabetically)

December 15, 2014

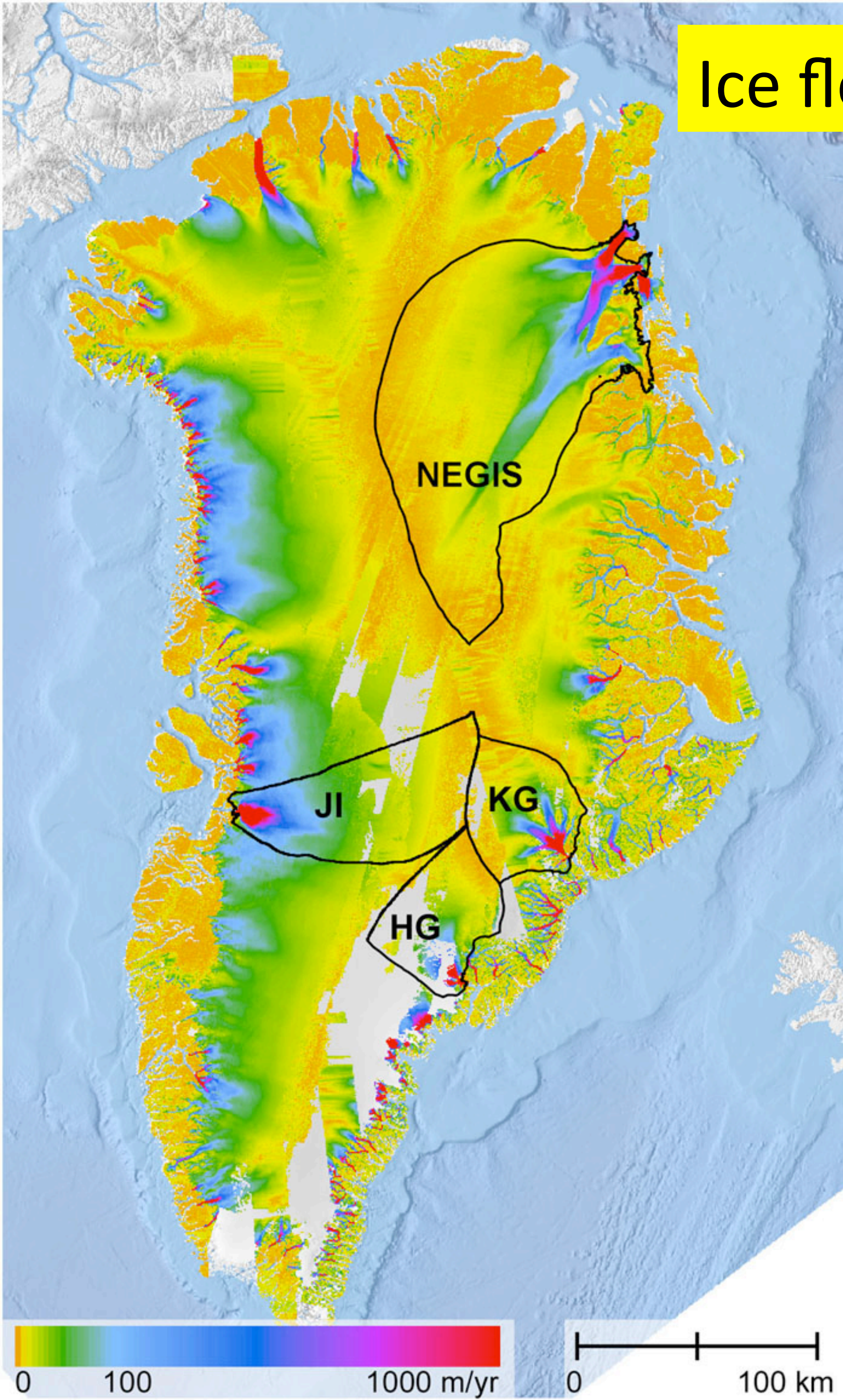
Please note: I work for Penn State University,
And help UN IPCC, NRC, etc.,
But I am not representing them, just me.

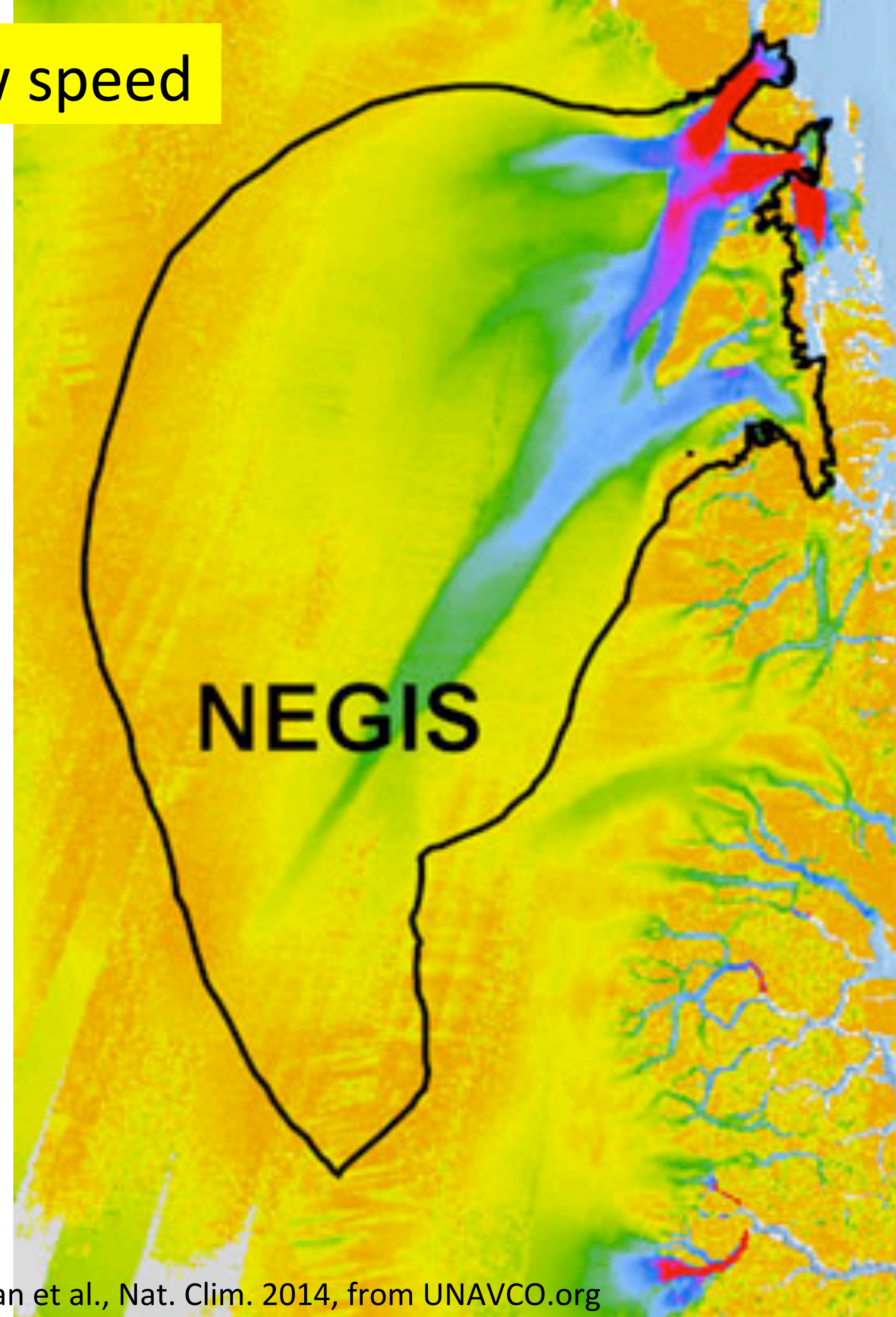
NSF CRESIS PENNSTATE NASA G. Comer Foundation earth VOICE

Penn State effort addresses two-way interactions between big ice sheets and volcanism, through observations and modeling

This picture is Mt. Erebus in Antarctica, but one early focus is Northeast Greenland Ice Stream (NEGIS)

Ice flow speed





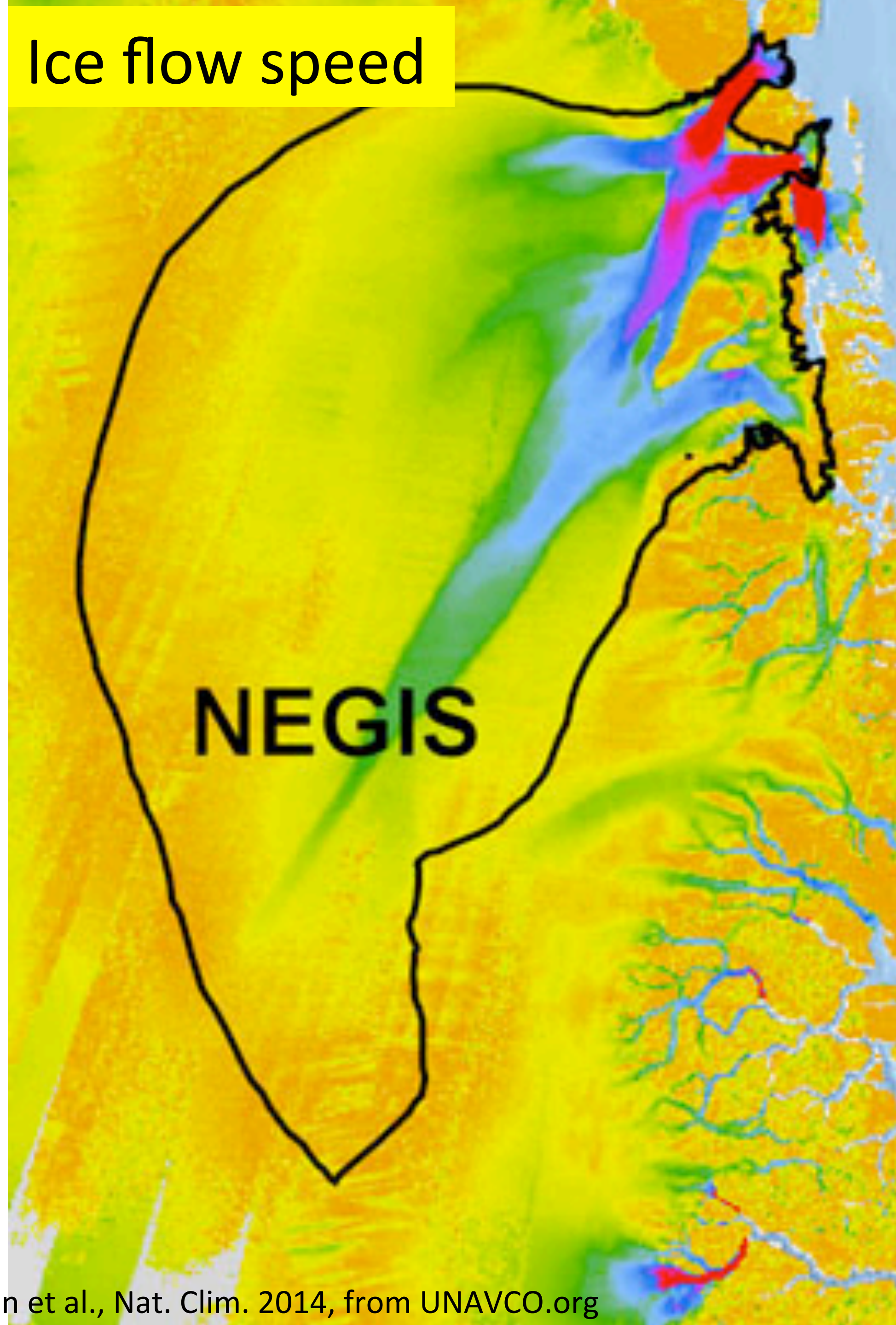
Khan et al., Nat. Clim. 2014, from UNAVCO.org

A unique ice stream:

→Extends almost to divide (others start far downstream)

→Starts narrow and widens (flow converges into others)

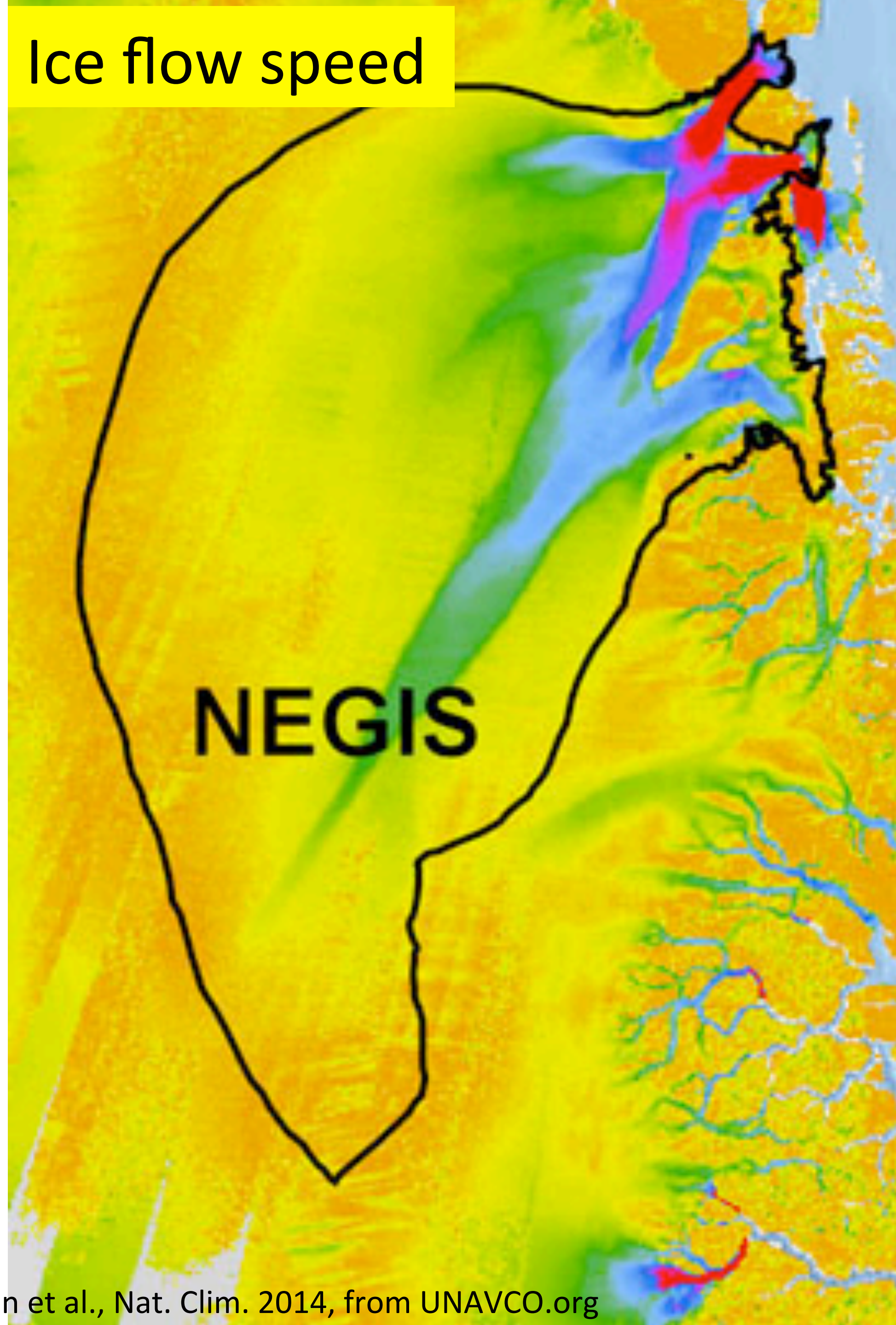
→All ice crosses shear margin (flow into head of others)



Khan et al., Nat. Clim. 2014, from UNAVCO.org

Penn State effort:

→Sridhar directed field work
→Field work including Knut Christianson, Leo Peters, Kiya Riverman, Atsu Muto
→Models by Byron and Dave
→Proposal for major international effort including ice core, and solid-Earth as well as glaciological geophysics
→I help a bit on papers
→Three published this year:



Khan et al., Nat. Clim. 2014, from UNAVCO.org

Dilatant till facilitates ice-stream flow in northeast Greenland

Knut Christianson[a,b,*], Leo E. Peters[c], Richard B. Alley[c], Sridhar Anandakrishnan[c], Robert W. Jacobel[b], Kiya L. Riverman[c], Atsuhiro Muto[c], Benjamin A. Keisling[d,b]

Earth and Planetary Science Letters 401 (2014) 57–69

Basal conditions and ice dynamics inferred from radar-derived internal stratigraphy of the northeast Greenland ice stream

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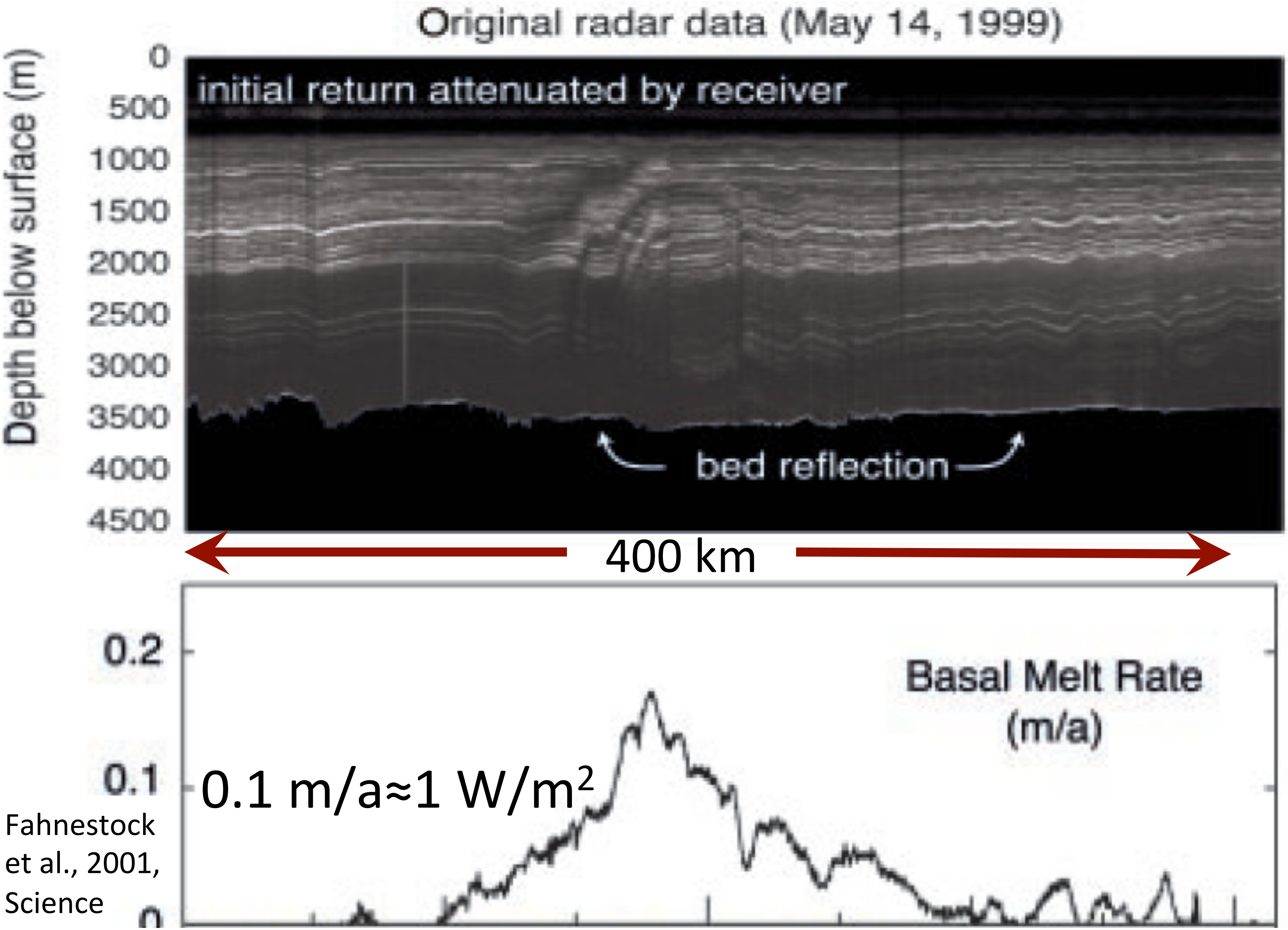
Initial results from geophysical surveys and shallow coring of the Northeast Greenland Ice Stream (NEGIS)

The Cryosphere, 8, 1275–1287, 2014
www.the-cryosphere.net/8/1275/2014/
doi:10.5194/tc-8-1275-2014

P. Vallelonga[1], K. Christianson[2,3], R. B. Alley[4], S. Anandakrishnan[4], J. E. M. Christian[3], D. Dahl-Jensen[1], V. Gkinis[1], C. Holme[1], R. W. Jacobel[3], N. B. Karlsson[1], B. A. Keisling[3,5], S. Kipfstuhl[6], H. A. Kjær[1], M. E. L. Kristensen[1], A. Muto[4], L. E. Peters[4], T. Popp[1], K. L. Riverman[4], A. M. Svensson[1], C. Tibuleac[1], B. M. Vinther[1], Y. Weng[1], and M. Winstrup[1]

Overview (with prior studies esp. M. Fahnestock & I. Joughin):

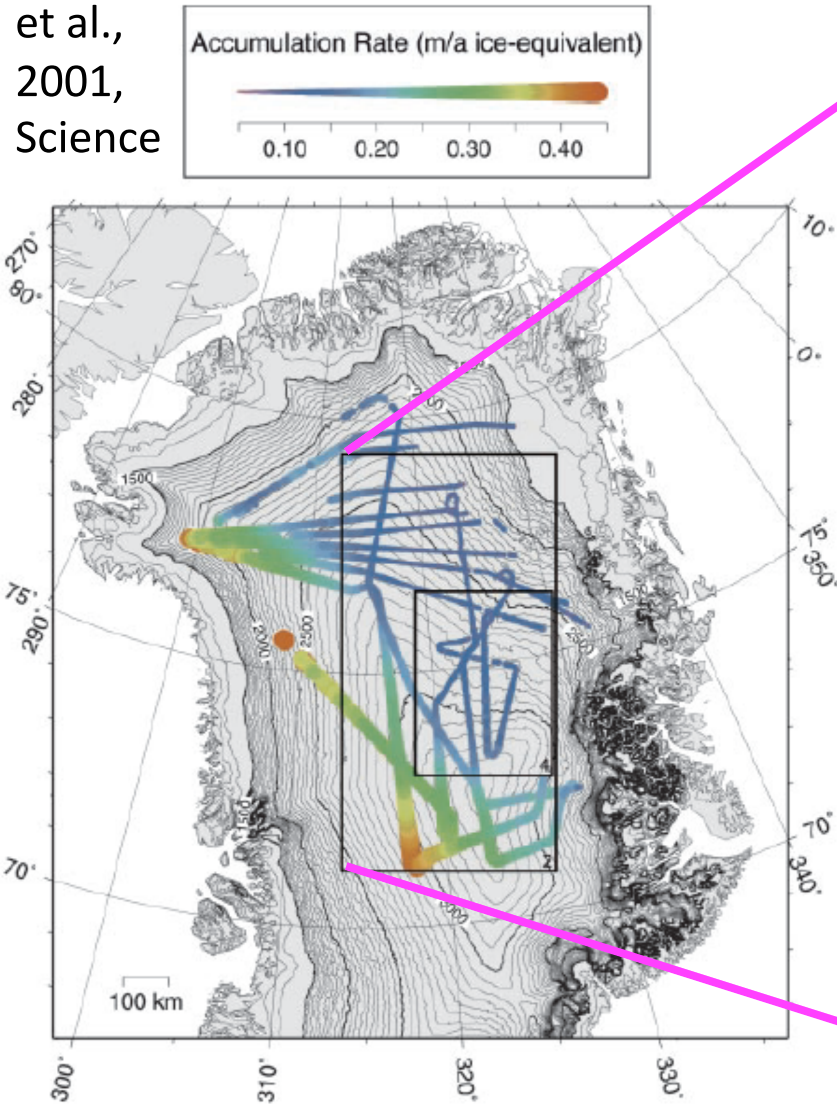
→ NEGIS starts at a geologically hot place (1-2 W/m^2, with widespread 100-200 mW/m^2, including along upper part of NEGIS), with gravity low and anomalously rough bed

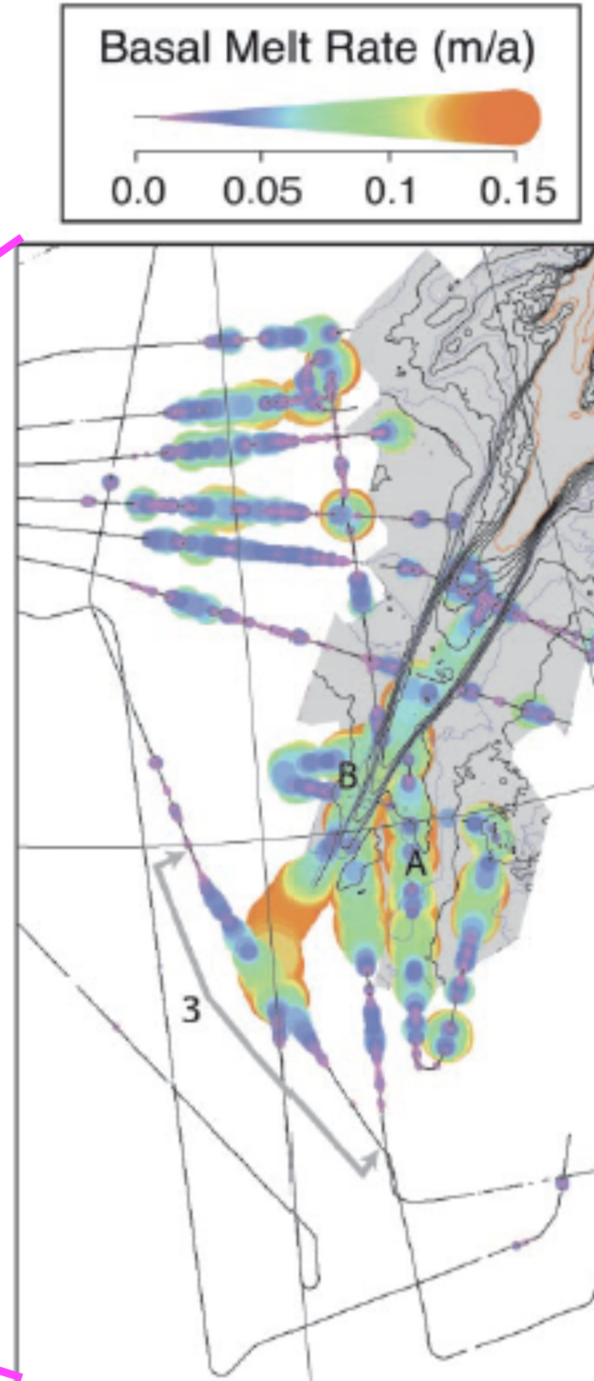


Fahnestock et al., 2001, Science

0.1 m/a melt=1 W/m^2, plus conduction into ice (~0.1 W/m^2)

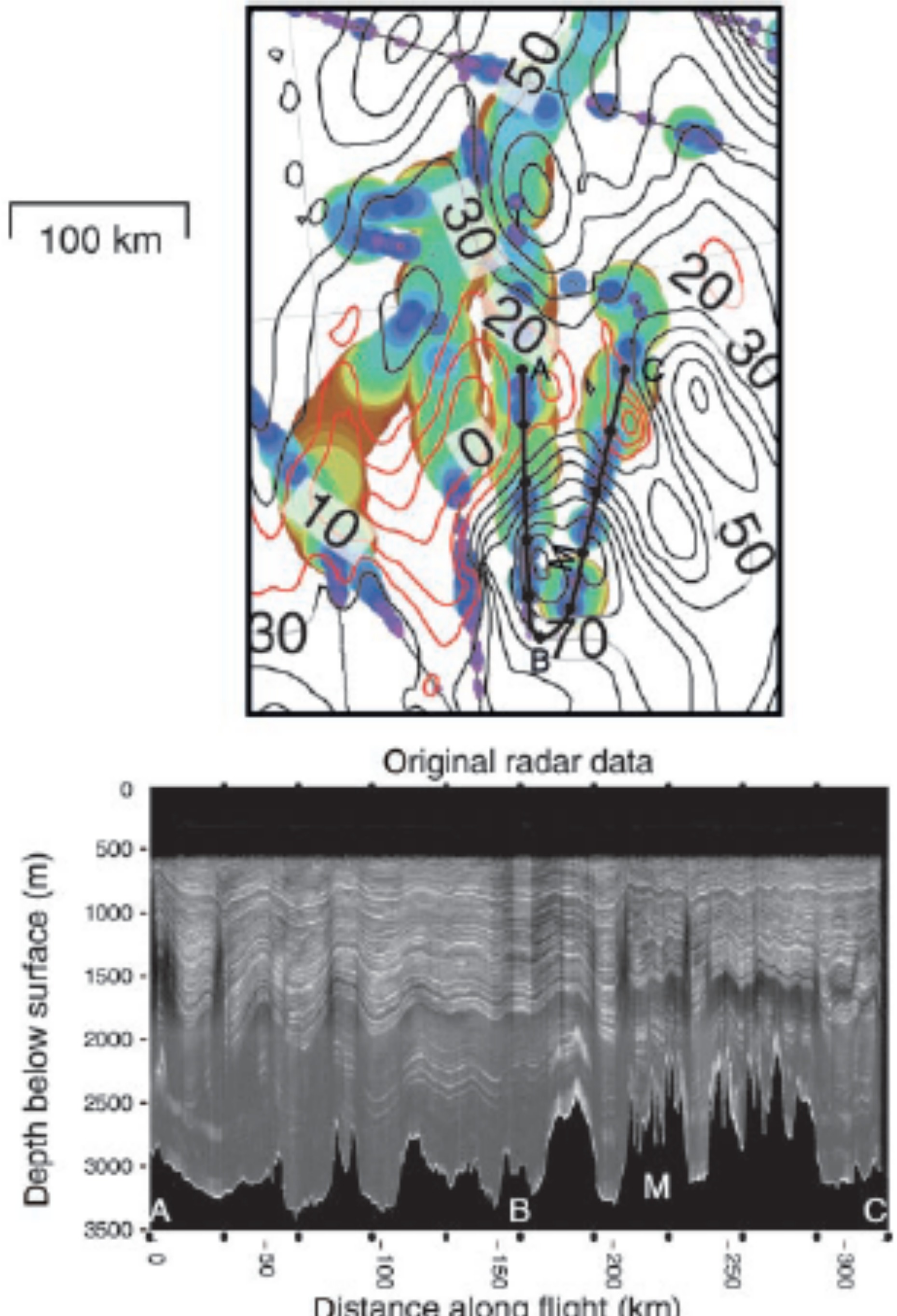
Fahnestock et al., 2001, Science





Fahnestock et al., 2001, Science

Fig. 4. Relation between airborne gravity measurements and basal melt rate. Contour interval 10 mgal, (red ≤ 20 mgal, black ≥ 30 mgal). Note the strong correspondence between the 30 to 50 mgal low in the free-air gravity data and the area of rapid basal melting. The bottom plot is the radar profile along the (A-B-C) black section of flight line (round black distance marks), which crosses several GAP flights. The radar profile shows several mountains that rise abruptly from the bed in this area; most notably the one labeled M (located at the gravity high in the area) and the next edifice to the north. Both of these features show rougher bed topography than anything else observed along this or most of the other profiles. This suggests a poorly eroded feature that is likely younger than its surroundings.



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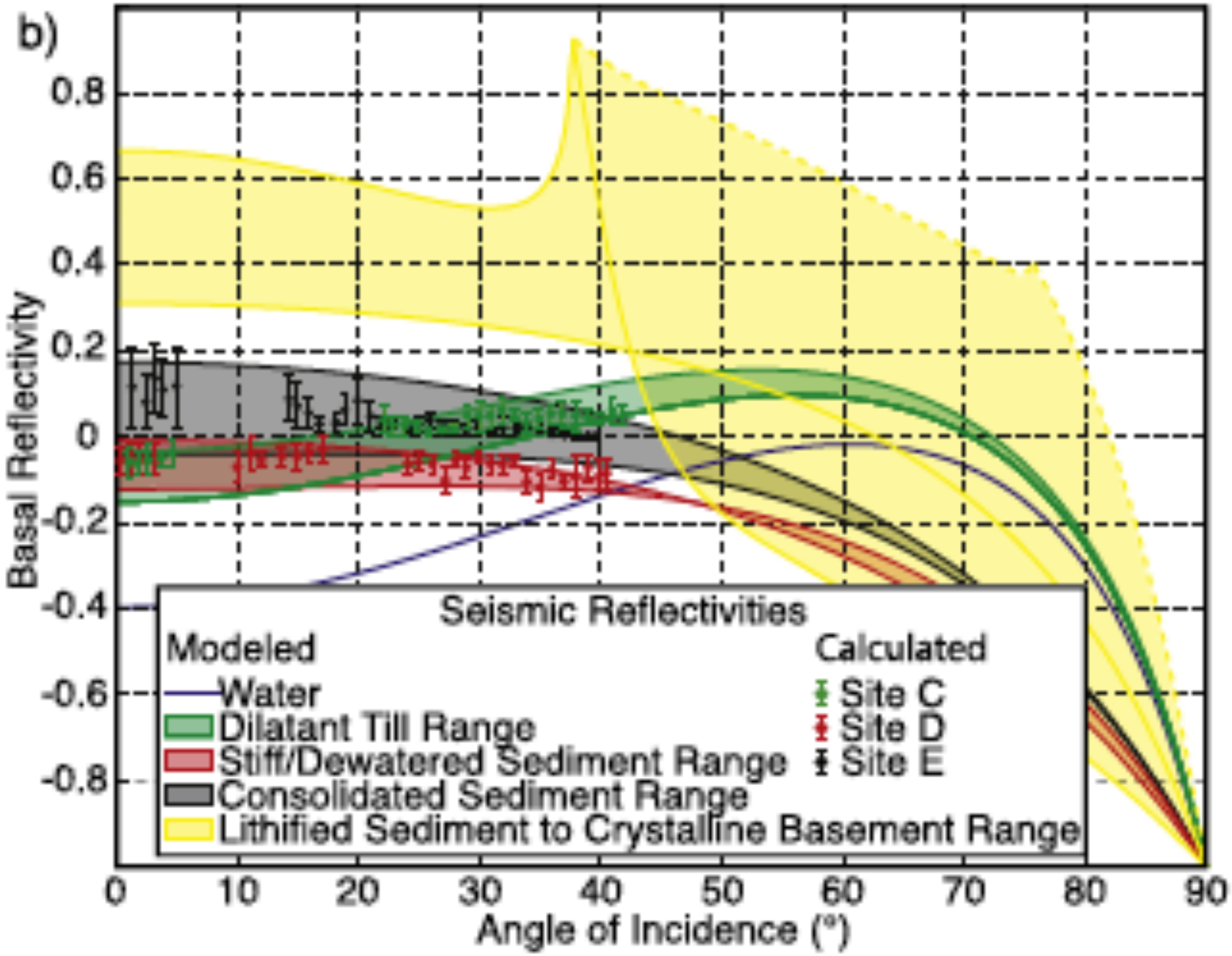

Seismic AVO analysis (Leo Peters, Sridhar)—Soft till in ice stream, somewhat stiffer outside, stiffest in part of shear margin where basal hydropotential gradient causes divergent water flow

Fig. 8. Seismic amplitude variation with offset (AVO) analysis. a) AVO gather at site D. b) Modeled reflectivities for water (blue), dilatant till (green), dewatered till (red), consolidated sediments (black), and lithified sediments to crystalline basement (yellow) are given; the solid lines mark the bounds for each potential subglacial bed type. The circles, with error bars, give the calculated reflectivities of the ice-bottom seismic reflection from sites C (green), D (red), and E (black) (Figs. 2, 5–6). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

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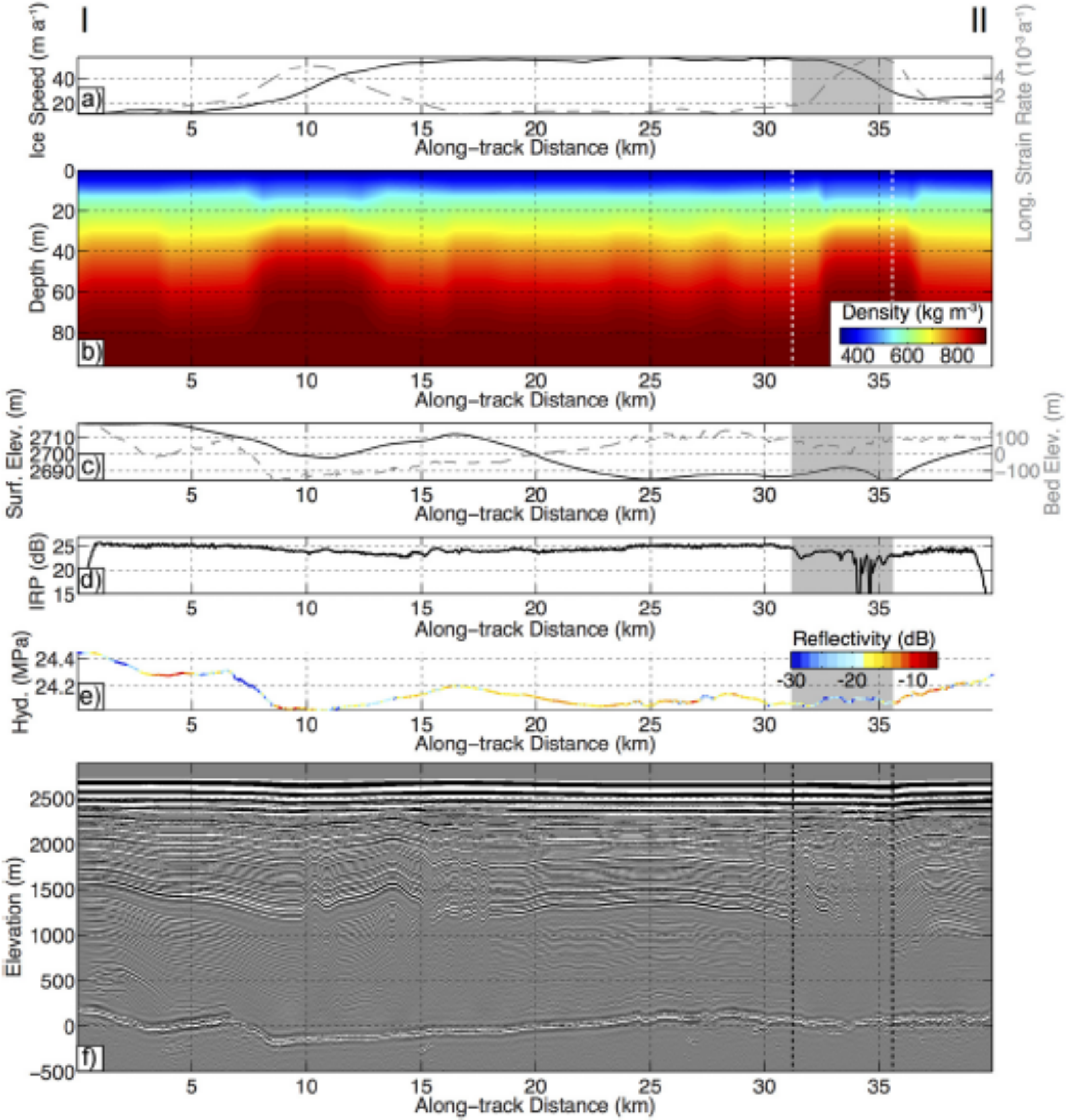
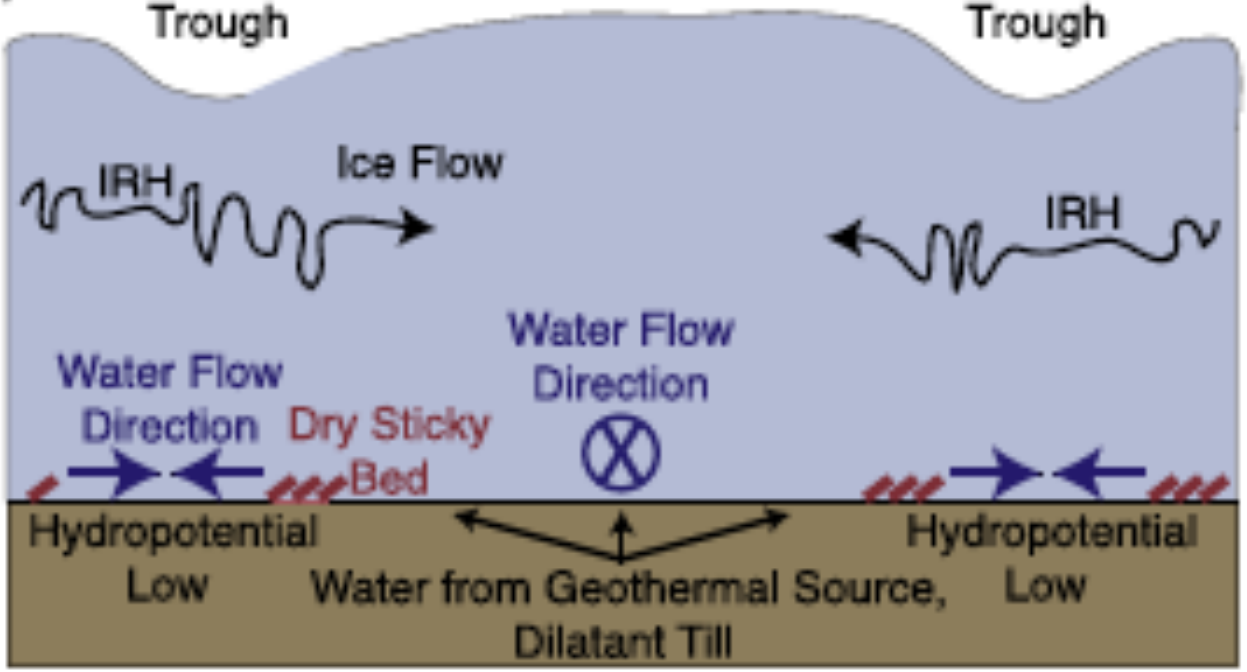
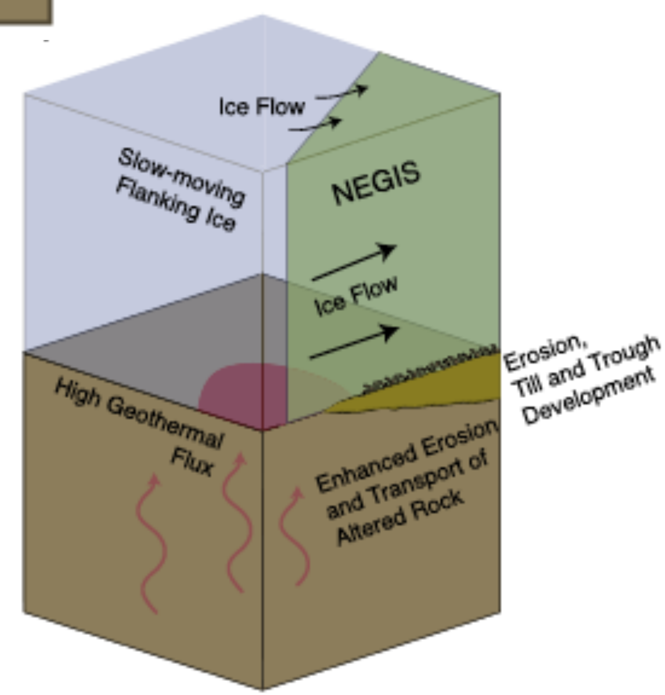
→ The point-source of lubricating water causes the ice stream to be "self-limiting" with sticky flanking zones


I
II
Ice Speed (m a⁻¹)
Long. Strain Rate (10⁻³ a⁻¹)
a)
b)
Depth (m)
Density (kg m⁻³)
400 600 800
c)
Surf. Elev. (m)
Bed Elev. (m)
d)
IRP (dB)
e)
Hyd. (MPa)
Reflectivity (dB)
-30 -20 -10
f)
Elevation (m)
Along–track Distance (km)

a)


Shear-margin Trough
Central Ice Stream
Shear-margin Trough
IRH
Ice Flow
IRH
Water Flow Direction
Water Flow Direction
Dry Sticky Bed
Hydropotential Low
Water from Geothermal Source, Dilatant Till
Hydropotential Low


Ice Flow
Slow-moving Flanking Ice
NEGIS
Ice Flow
Erosion, Till and Trough Development
High Geothermal Flux
Enhanced Erosion and Transport of Altered Rock

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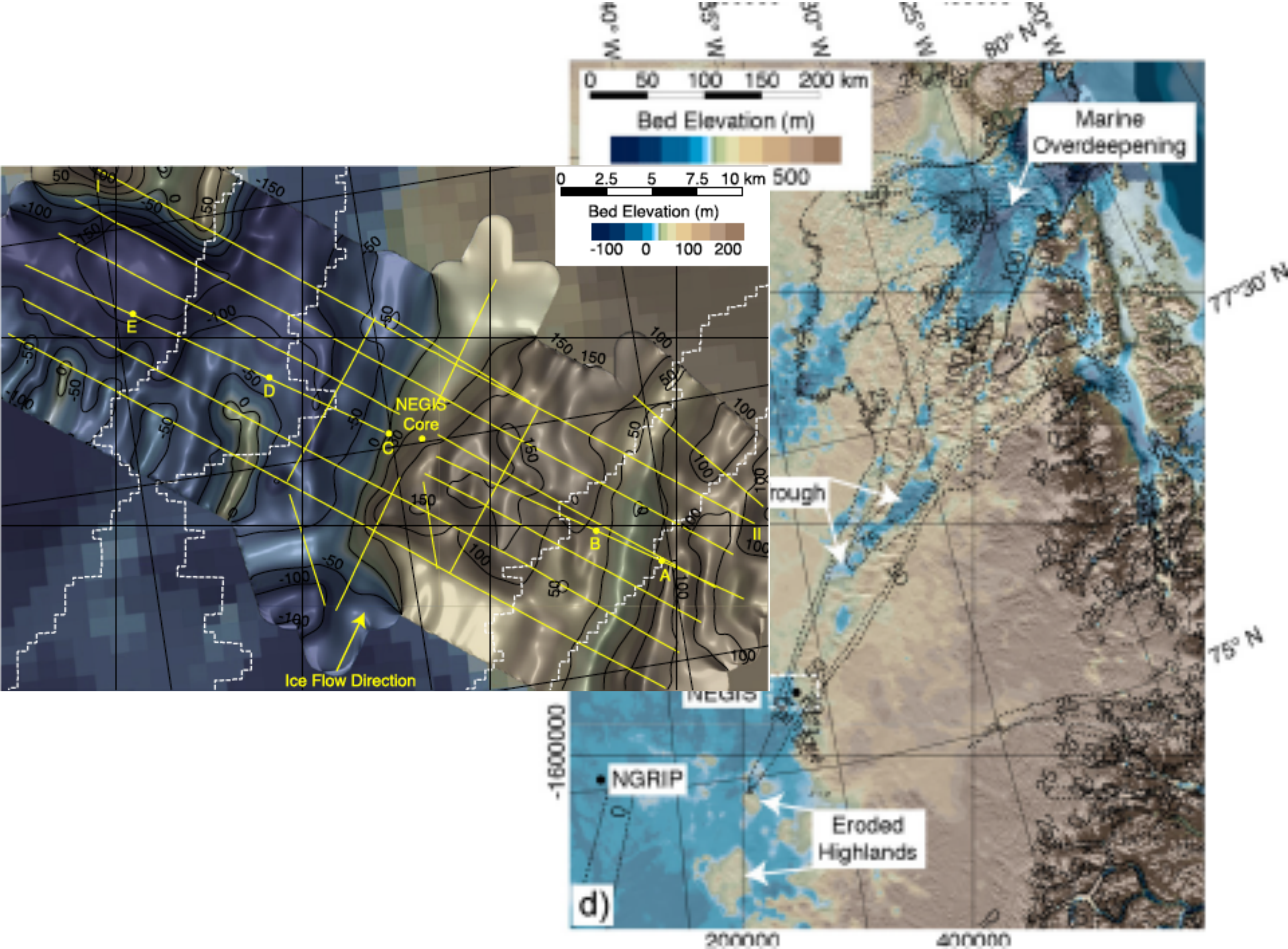
→ Till suggests an erosional source, but there isn't much of a basal trough eroded under NEGIS


0 2.5 5 7.5 10 km
Bed Elevation (m)
-100 0 100 200
E
D
C
NEGIS Core
B
A
I
II
Ice Flow Direction
0 50 100 150 200 km
Bed Elevation (m)
500
Marine Overdeepening
77°30' N
75° N
rough
NEGIS
NGRIP
Eroded Highlands
d)
-1600000
200000
400000

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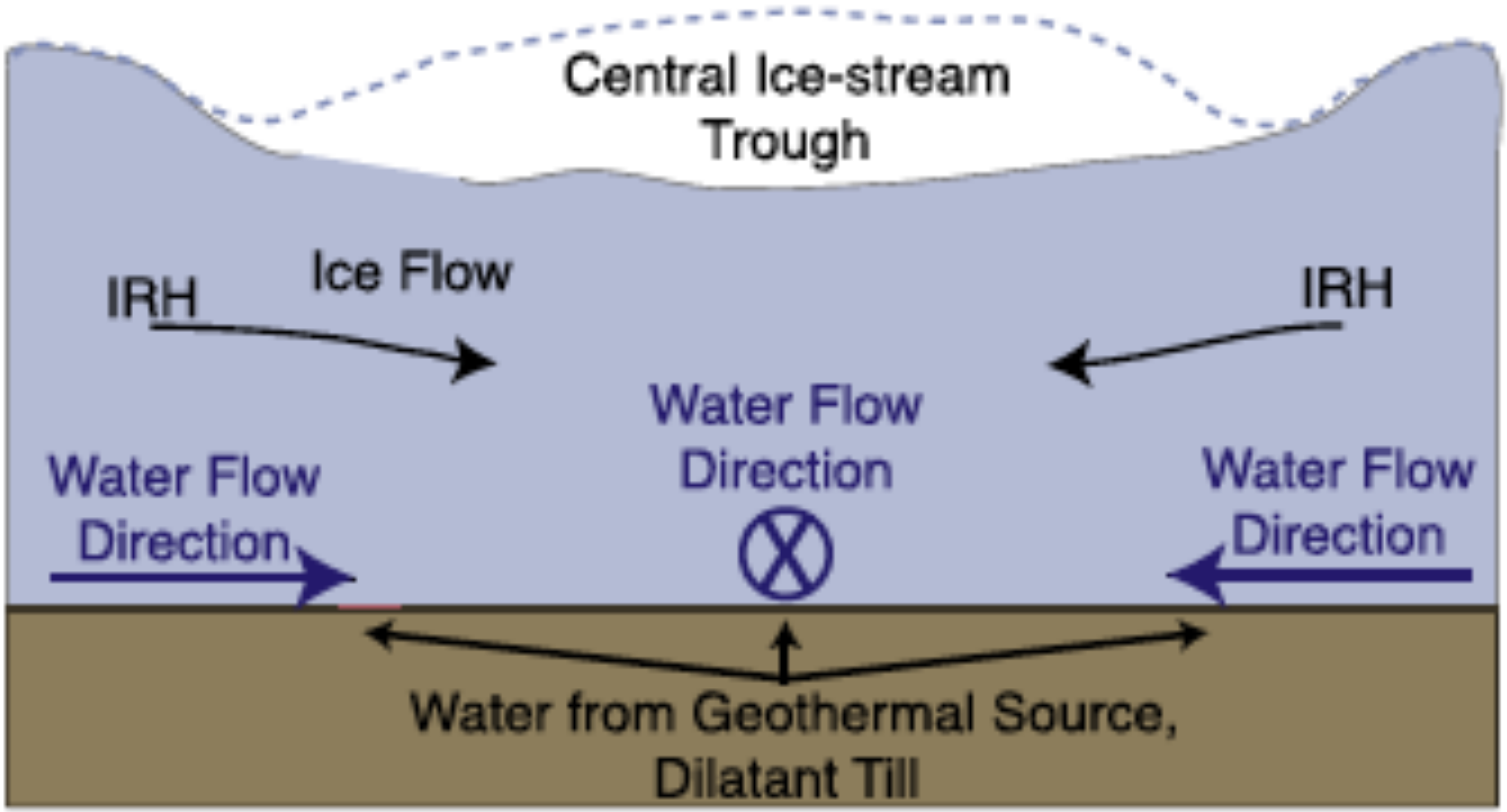
→ With enough coastal forcing, NEGIS might allow easier inflow of ice, and draw down a lot of the ice sheet

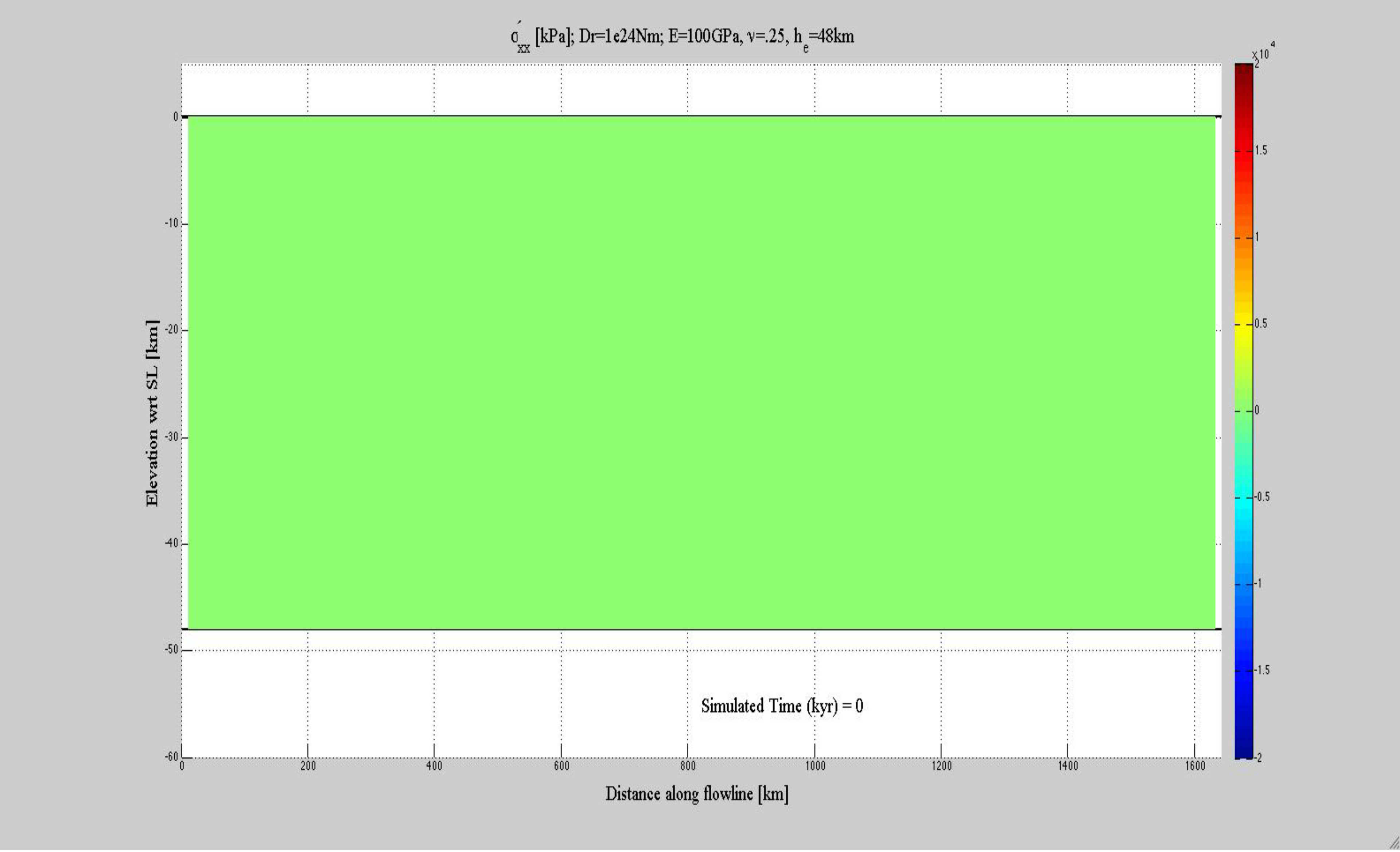


If coastal thinning were to propagate inland, and lower the center of the ice stream, then the hydrological-potential reversals at the margins that now restrict ice inflow would be lost, which might lead to rapid ice-sheet drawdown through NEGIS.

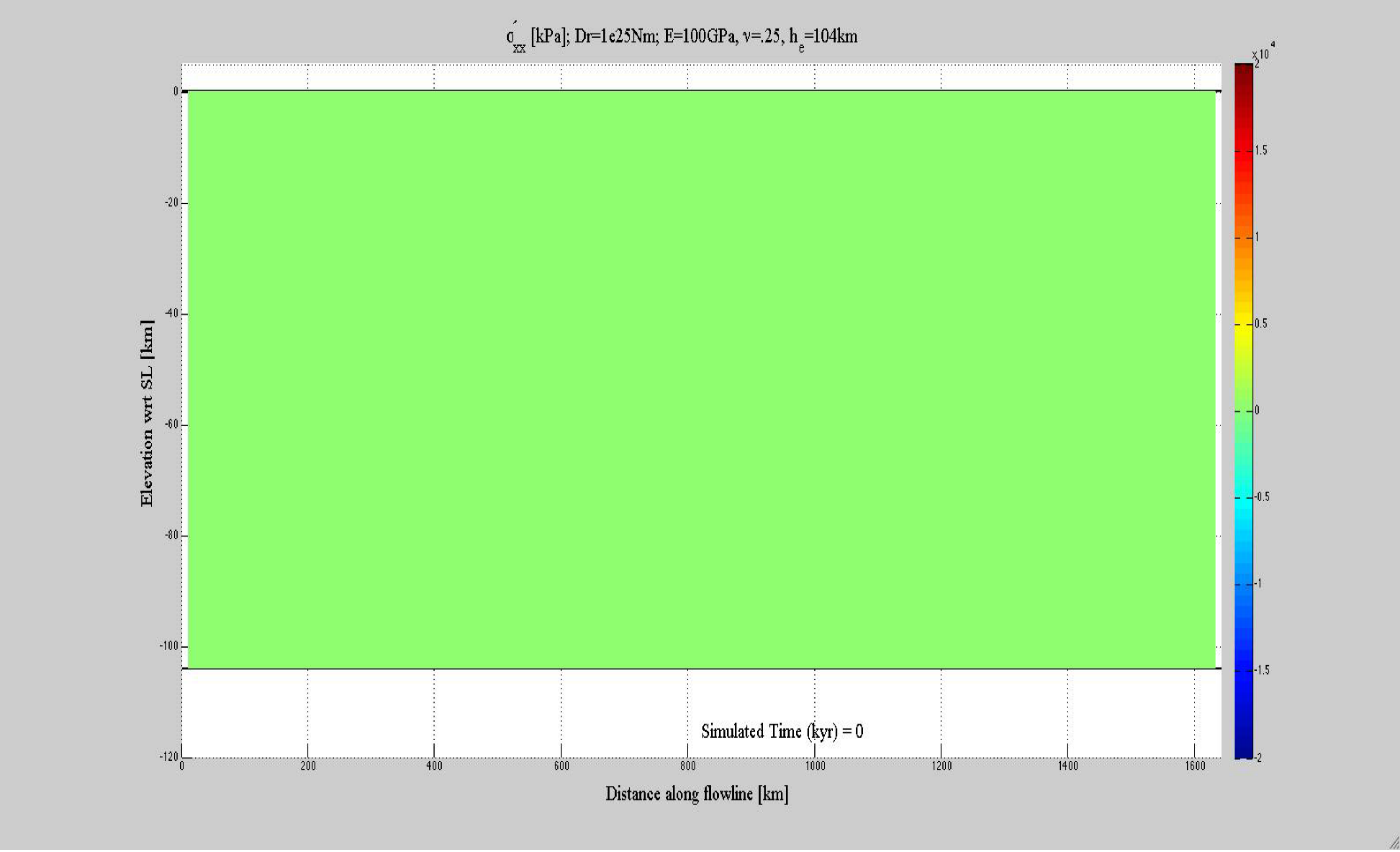
Back at the geological control…

- → Maybe suggestion of nonsteadiness in mismatch between widespread till and no major basal trough
- → But, this work shows geology controls unique setting
- → The big international NEGIS proposal would focus geophysical research on the hot spot
- → And, we're still working on modeling the system
- → Paper in preparation (a student project…)
- → Ice sheet loading and unloading during large changes flexes crust, creating very large stresses that enable upward motion of deep melt

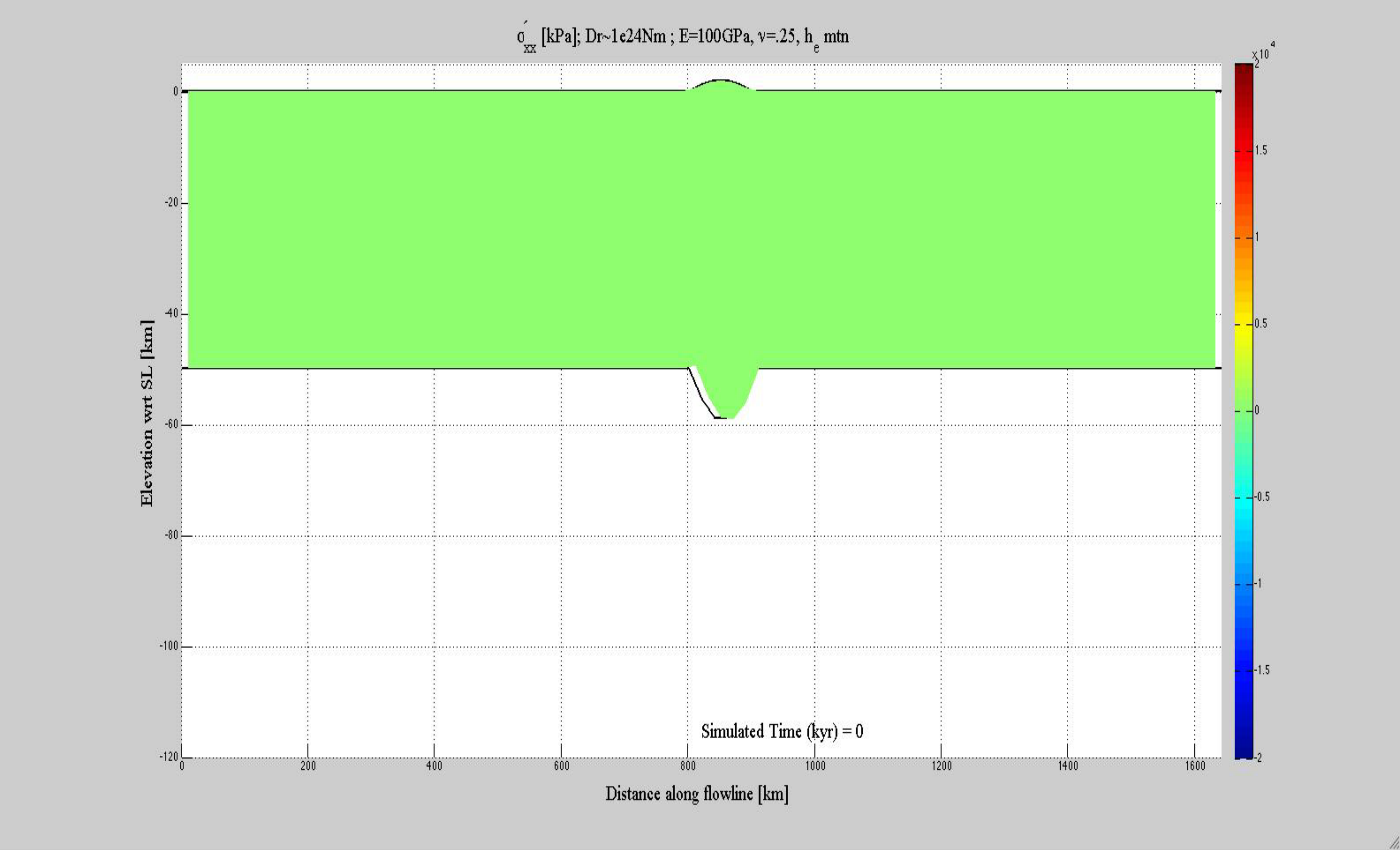
"Standard" run—48 km elastic lithosphere, 10^{24} Nm



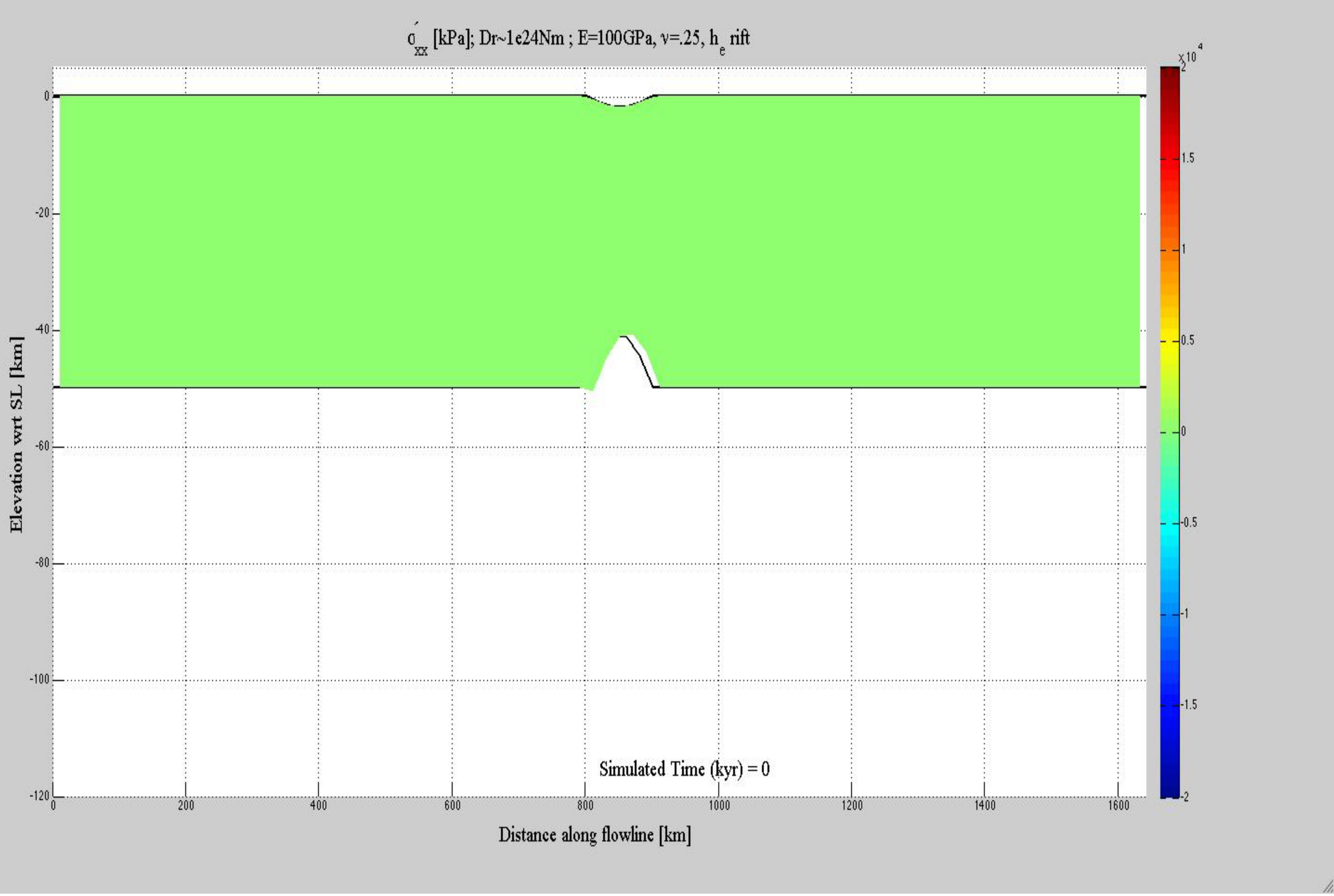
“Stiff” run—104 km elastic lithosphere, 10^{25} Nm



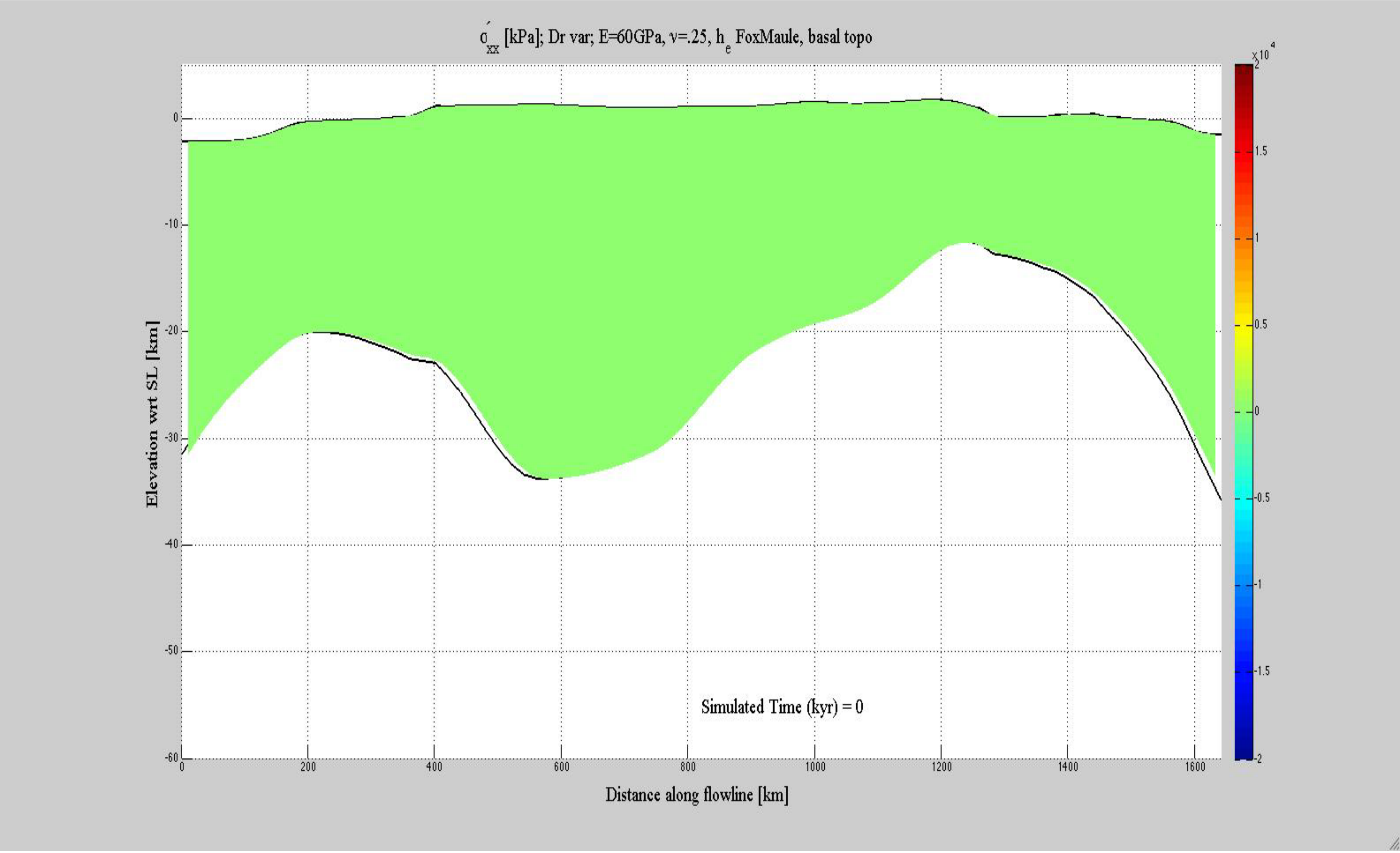
"Standard" run with mountain

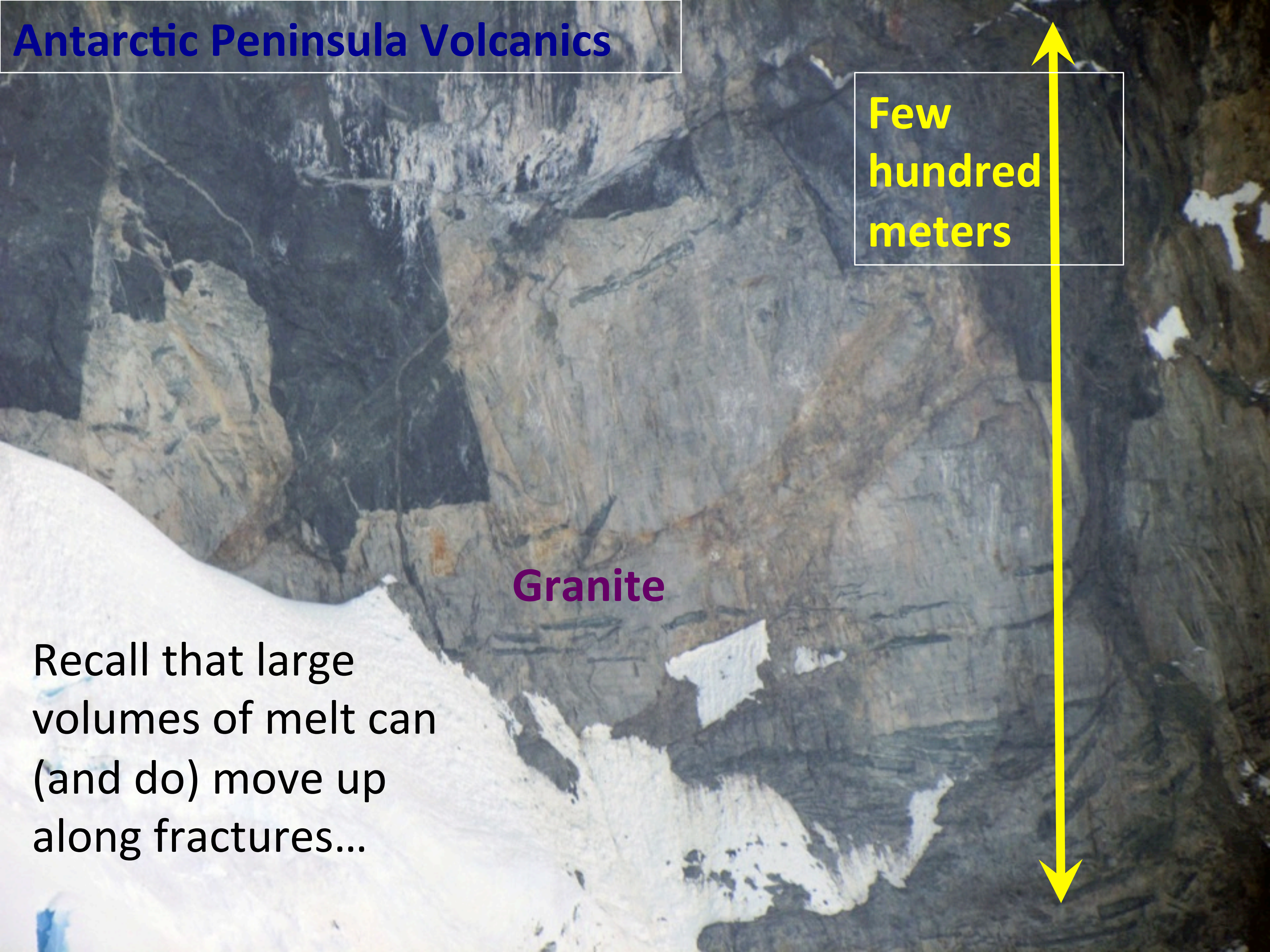


"Standard" run with rift



Fox Maule Greenland lithosphere (satellite magnetics)




Antarctic Peninsula Volcanics
Few hundred meters
Granite
Recall that large volumes of melt can (and do) move up along fractures…

Lots of work to do (and some already done)

→ Byron guiding Nate in the first look at this

→ Dave has already made runs for Antarctica as well as Greenland looking at stresses

→ Customizing to particular places (such as Sridhar's volcanics?) may be important

→ We will be very surprised if ice-sheet fluctuations have not notably modulated proximal and subglacial volcanism, and increased that volcanism when averaged over ice-age cycles