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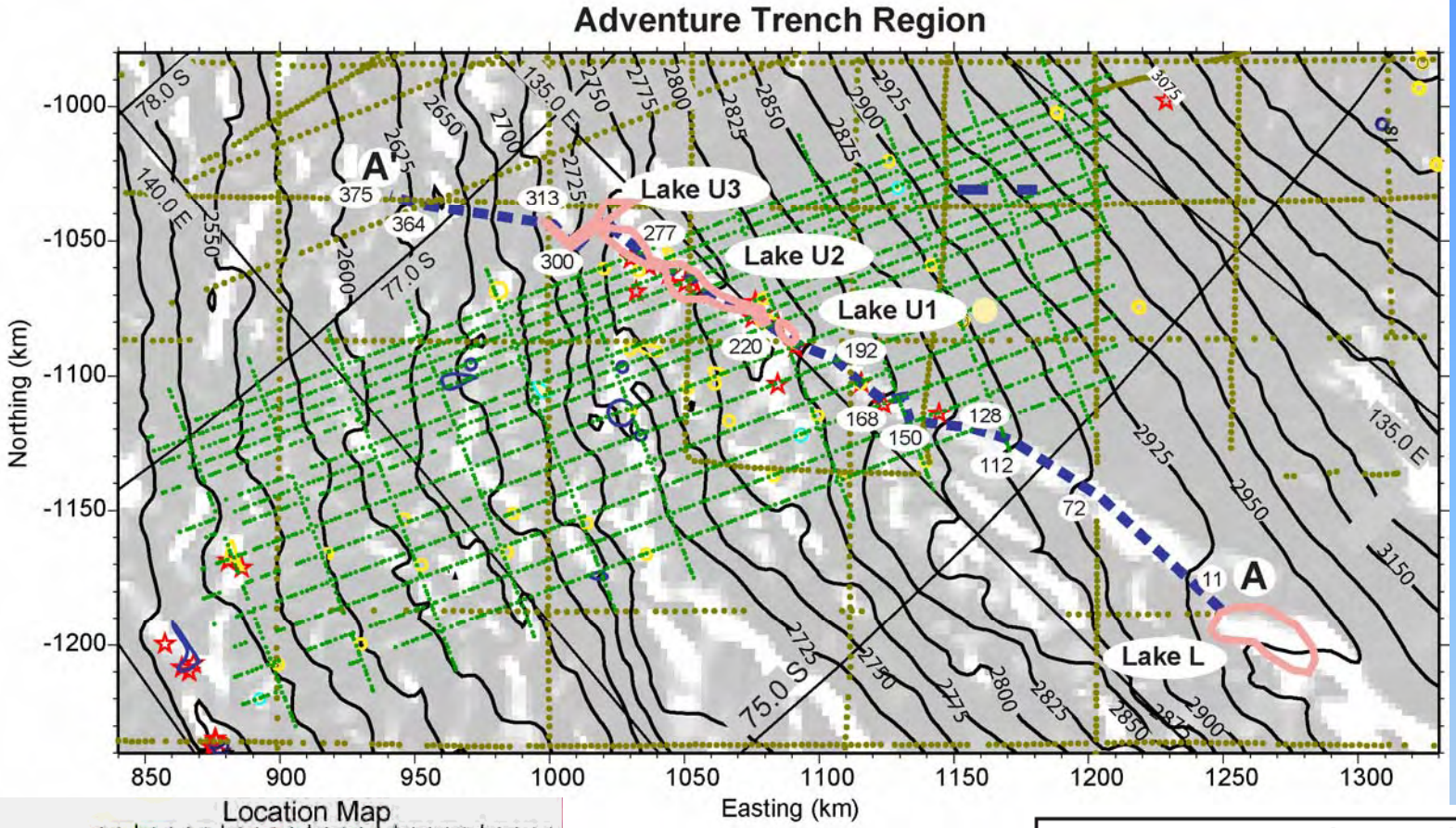
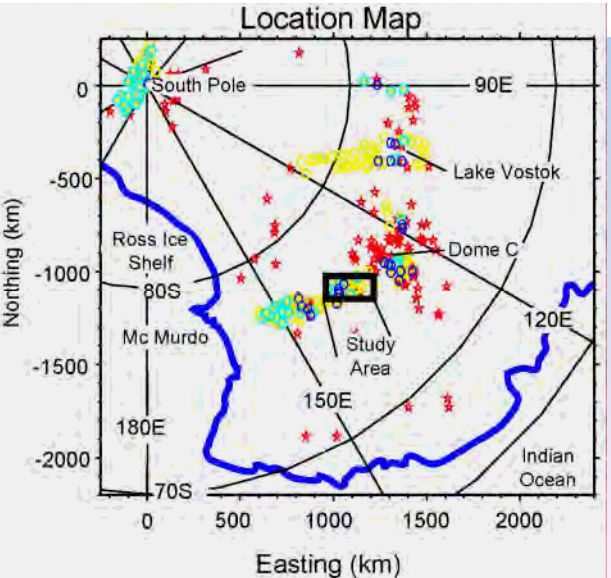
Modeling the transport of subglacial discharge: A case study from Adventure Trench

Sasha Peter Carter, Donald D. Blankenship, Duncan A. Young, Matthew E. Peters, John W. Holt, and Martin J. Siegert

Outline

- Adventure Trench Region and data availability
- Satellite observations of subglacial discharge
- The joint application of satellite altimetry and radar sounding
- Mass budget
- Flow mechanisms
- Implications / Conclusions



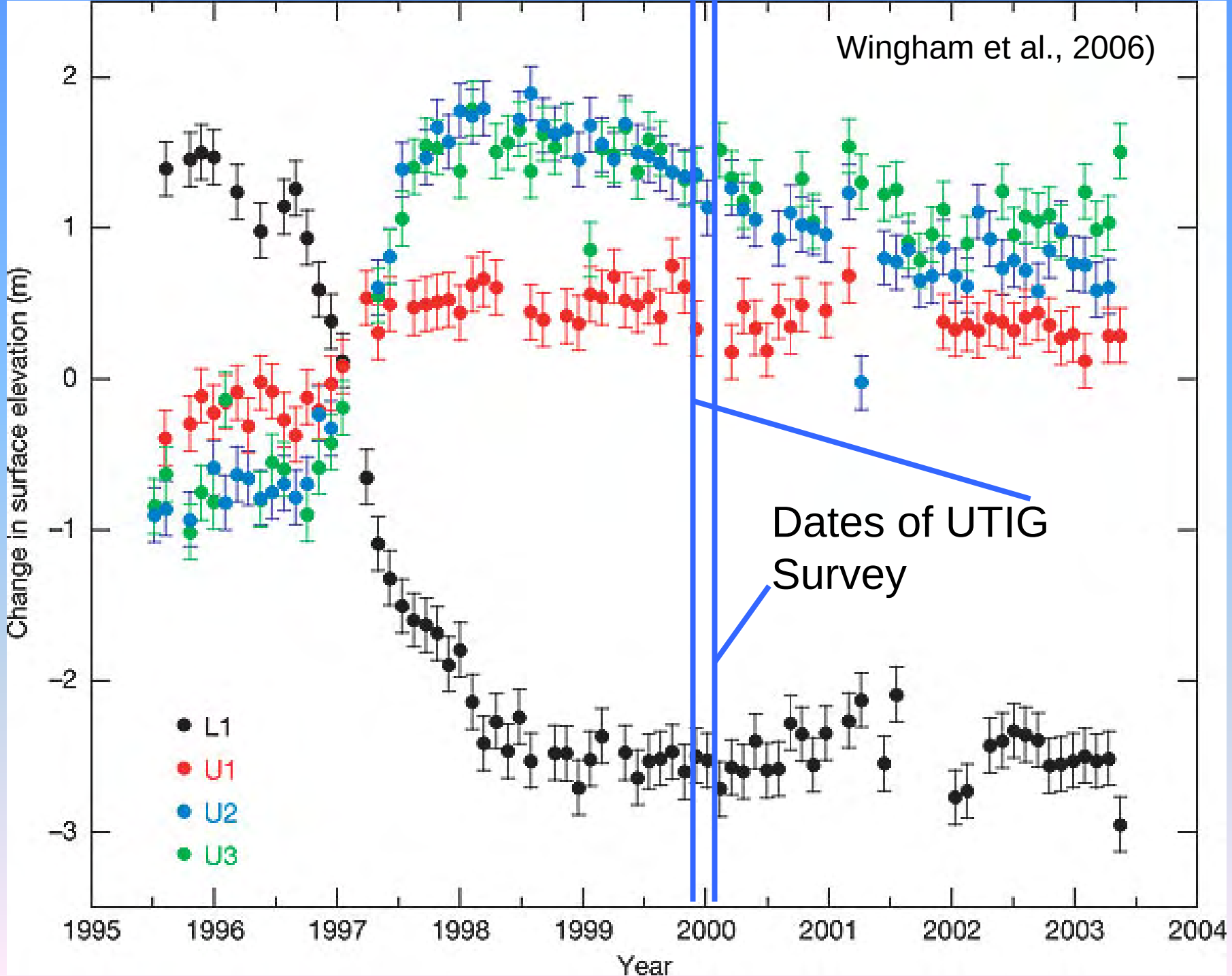


(Carter et al., Submitted)

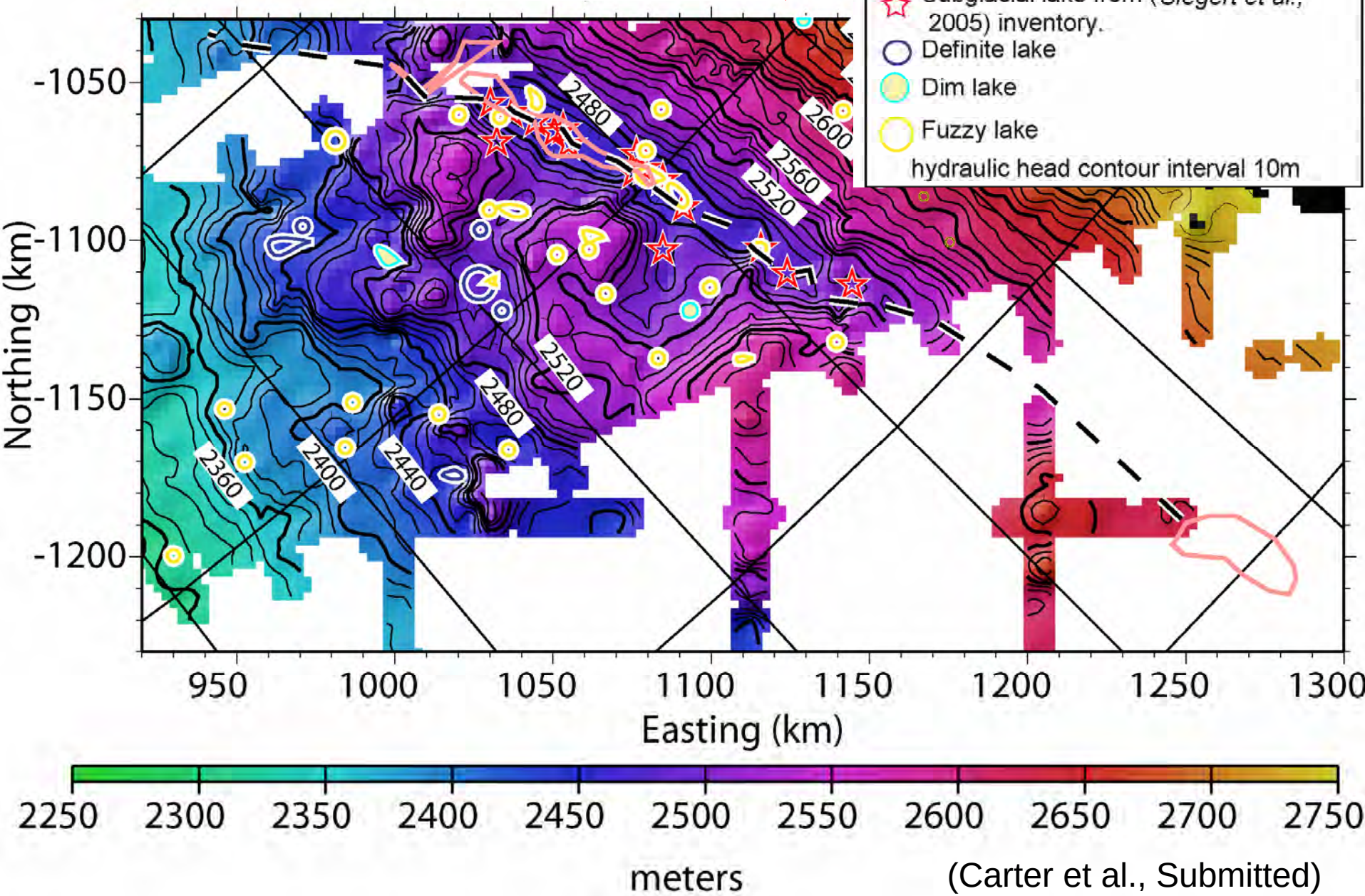
Legend

- UTIG 1999 / 2000 data coverage
- SPRI/NSF/TUD 1971 / 1975 data coverage
- Lake associated with 1996-1999 outburst
- Inferred path of 1996-1999 outburst
- Subglacial lake from [*Siegert et al.*, 2005] inventory.
- Definite lake
- Dim lake
- Fuzzy lake
- (112) Distance along A - A' (See Figure 4)

Surface elevation contour interval 25m


Wingham et al., 2006)
Dates of UTIG Survey
Change in surface elevation (m)
Year
L1
U1
U2
U3
2
1
0
−1
−2
−3
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004

Hydraulic Head

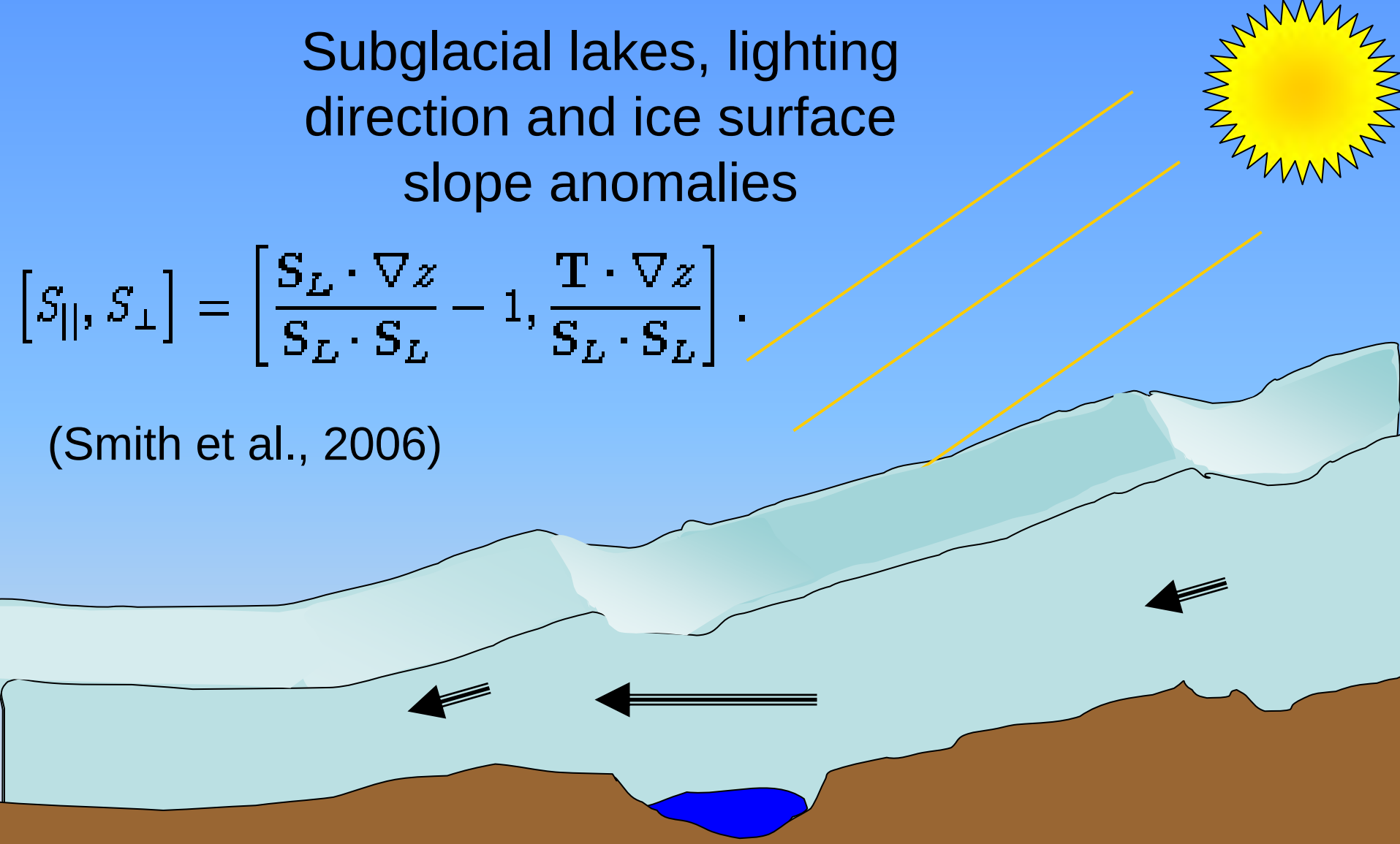


(Carter et al., Submitted)

Subglacial lakes, lighting direction and ice surface slope anomalies

$$\left[S_{||}, S_{\perp}\right] = \left[\frac{\mathbf{S}_L \cdot \nabla z}{\mathbf{S}_L \cdot \mathbf{S}_L} - 1, \frac{\mathbf{T} \cdot \nabla z}{\mathbf{S}_L \cdot \mathbf{S}_L}\right].$$

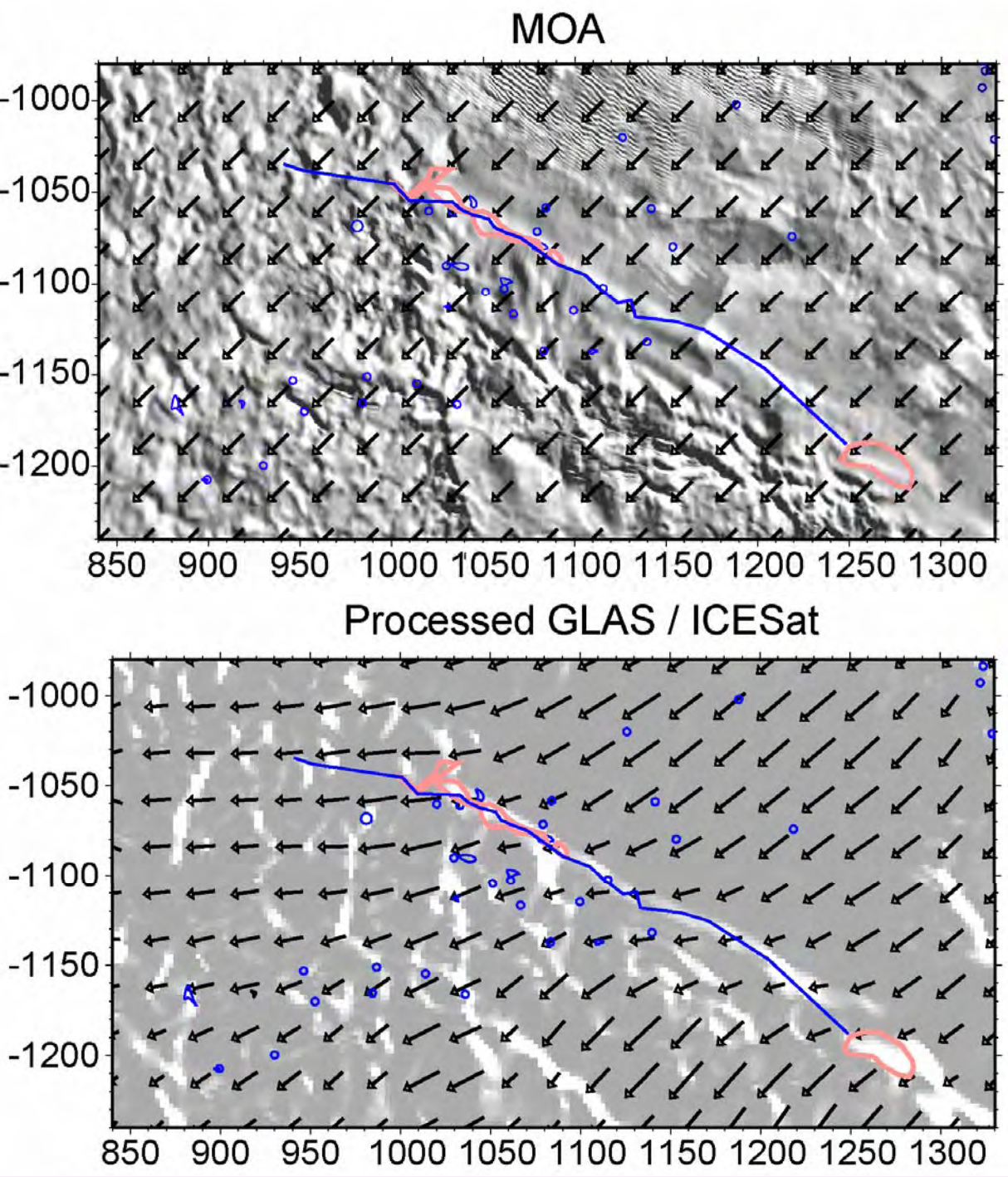
(Smith et al., 2006)



ICESAT DEM (DiMarzio et al., 2007)

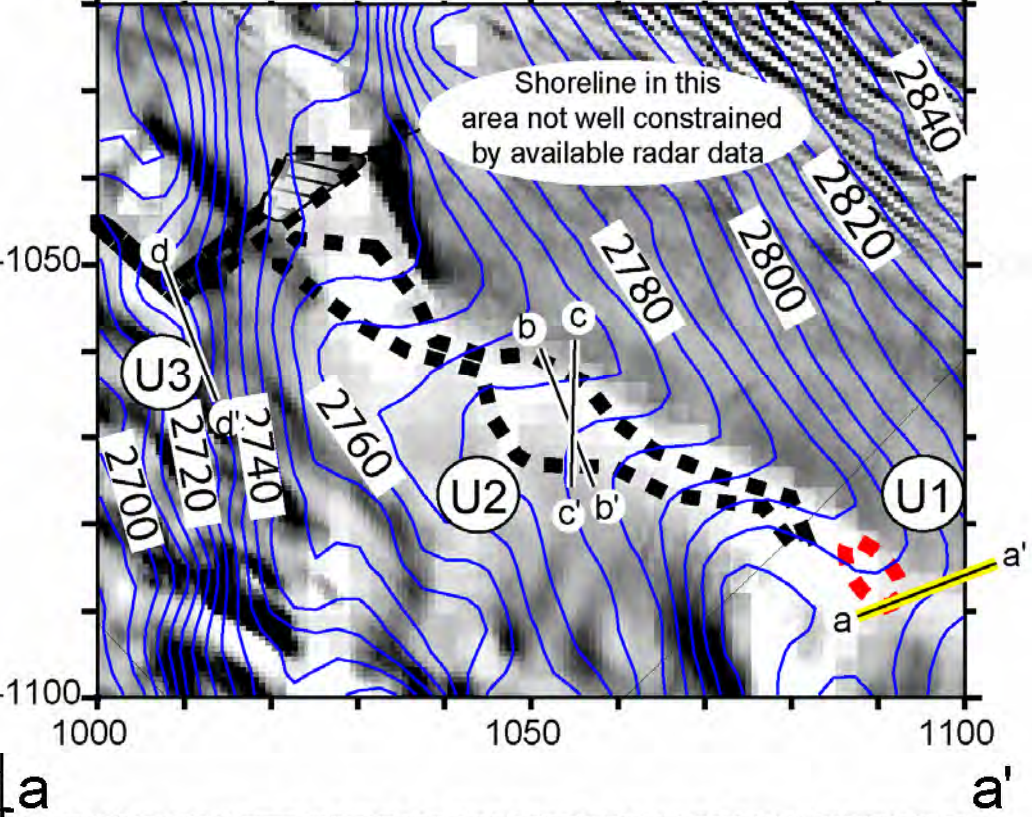
or RAMP DEM (Liu et al., 2001)

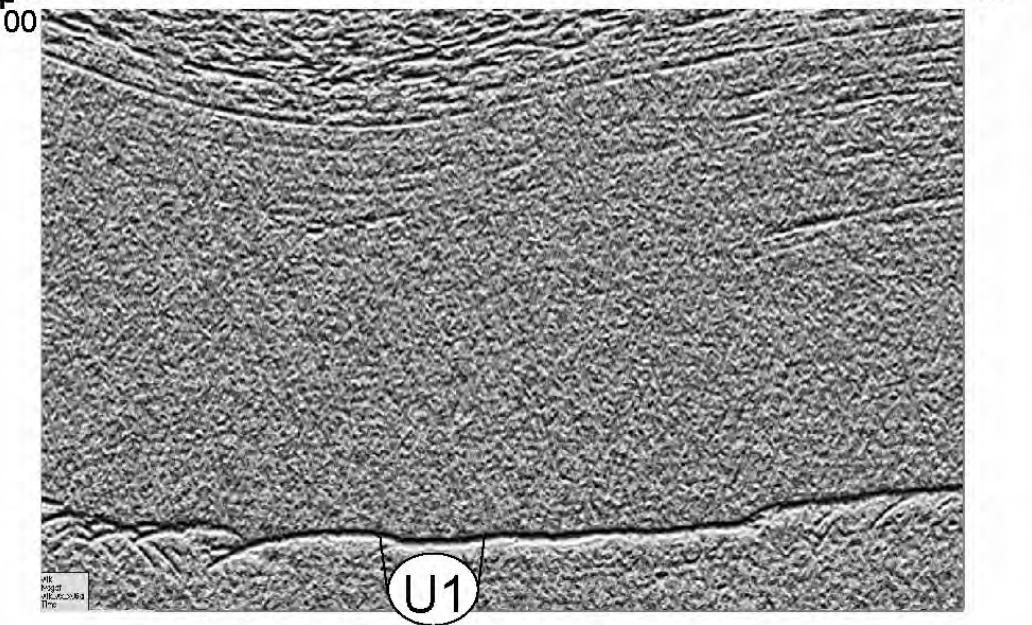
(Carter et al., Submitted)



- Slope anomaly processing quantifies the “shiny” flat depressions observed in MOA and ERS-1 and does not depend on slope azmuth.
- Builds upon techniques developed by Robinson 1964, Ridley and Siegert 1998, and Bell et al., 2006, 2007 for locating subglacial lakes from surface data.
- All that is flat is not lakes.

(Carter et al., Submitted)





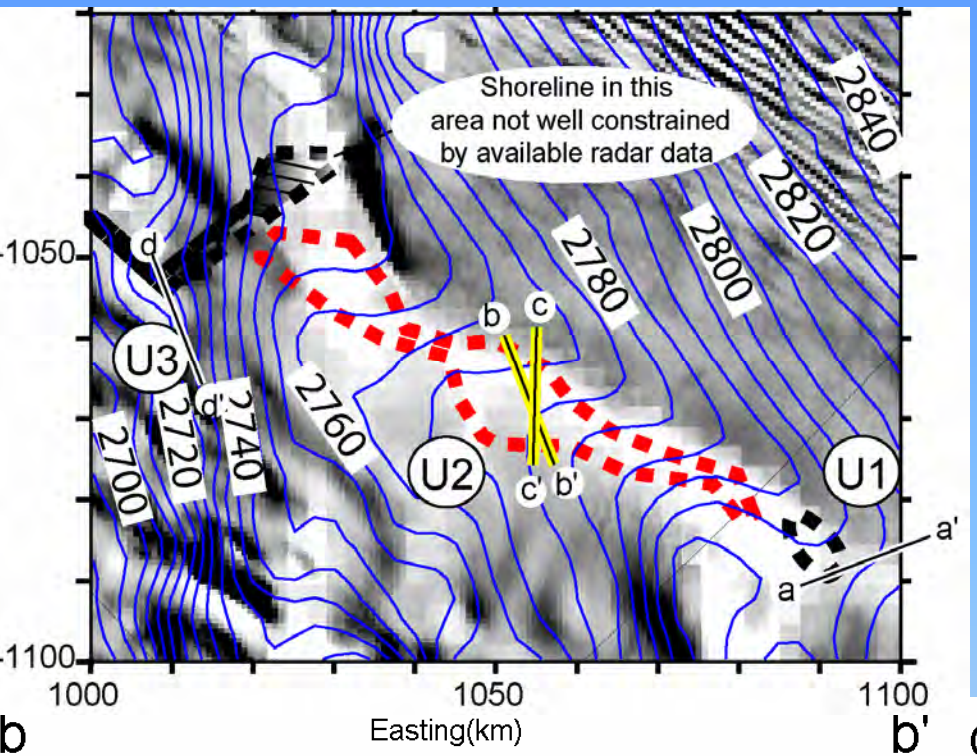
U1

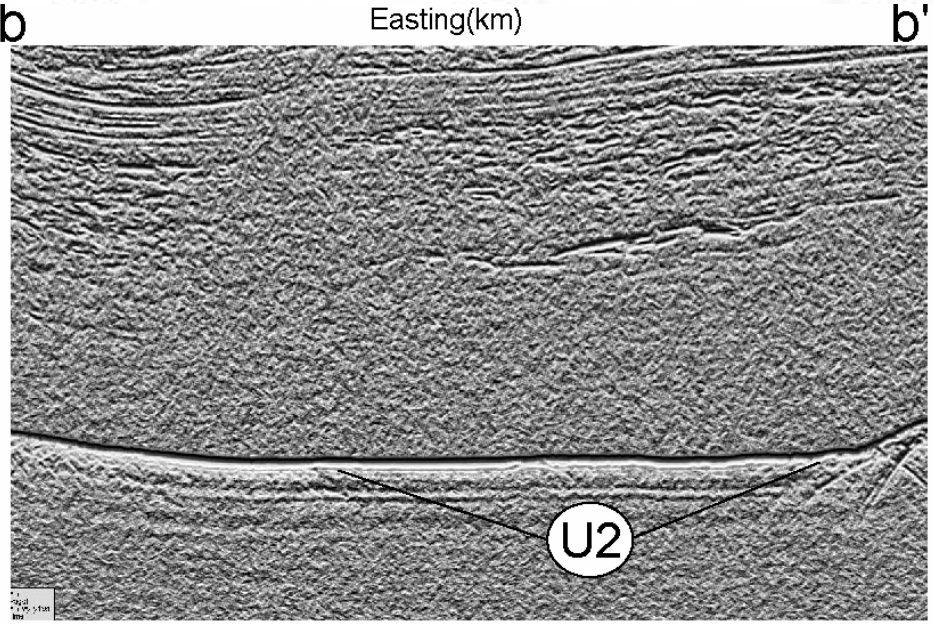
- 31 ± 3 km^2
- Fuzzy lake: shallow and swampy
- Received 0.03 km^3 at 1 m^{3}s^{-1}
- 1% of mass budget

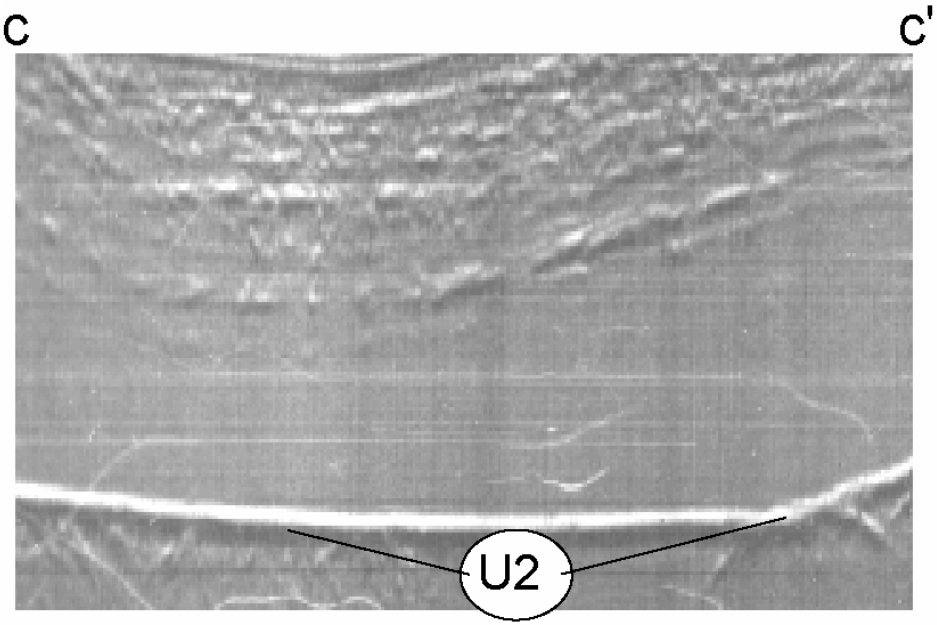
(Carter et al., Submitted)

U2

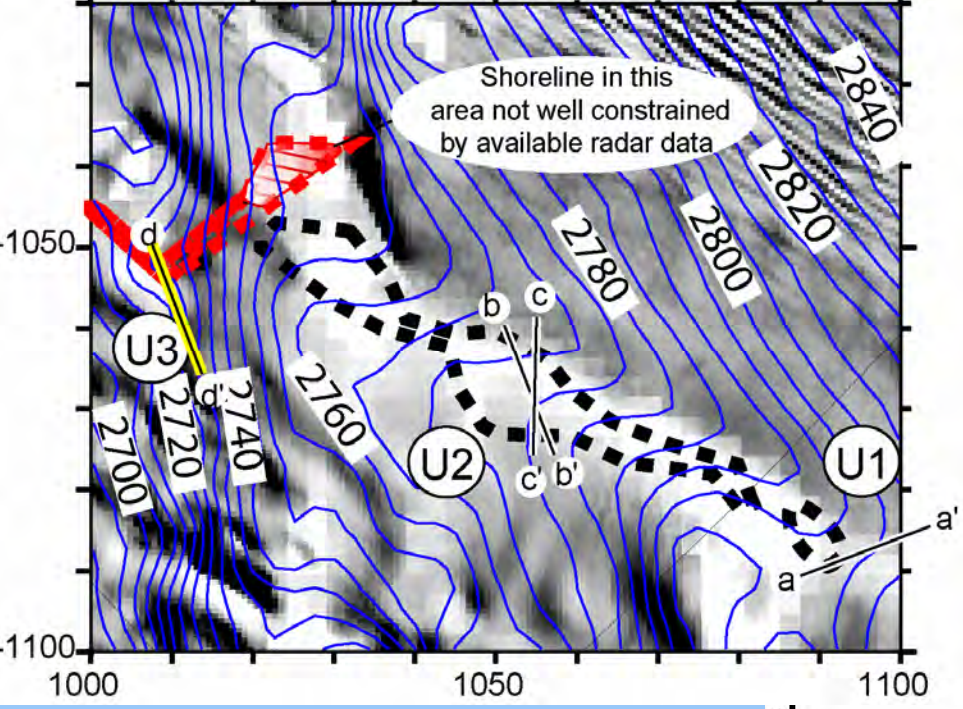
- 368 ± 72 km^2
- Definite lake: may be deep in some areas.
- Appears to have held water before 1996.
- Received 0.91 km^3 at ~48 m^{3}s^{-1}
- ~40% of mass budget
- Surface deflated in subsequent years indicating leakage





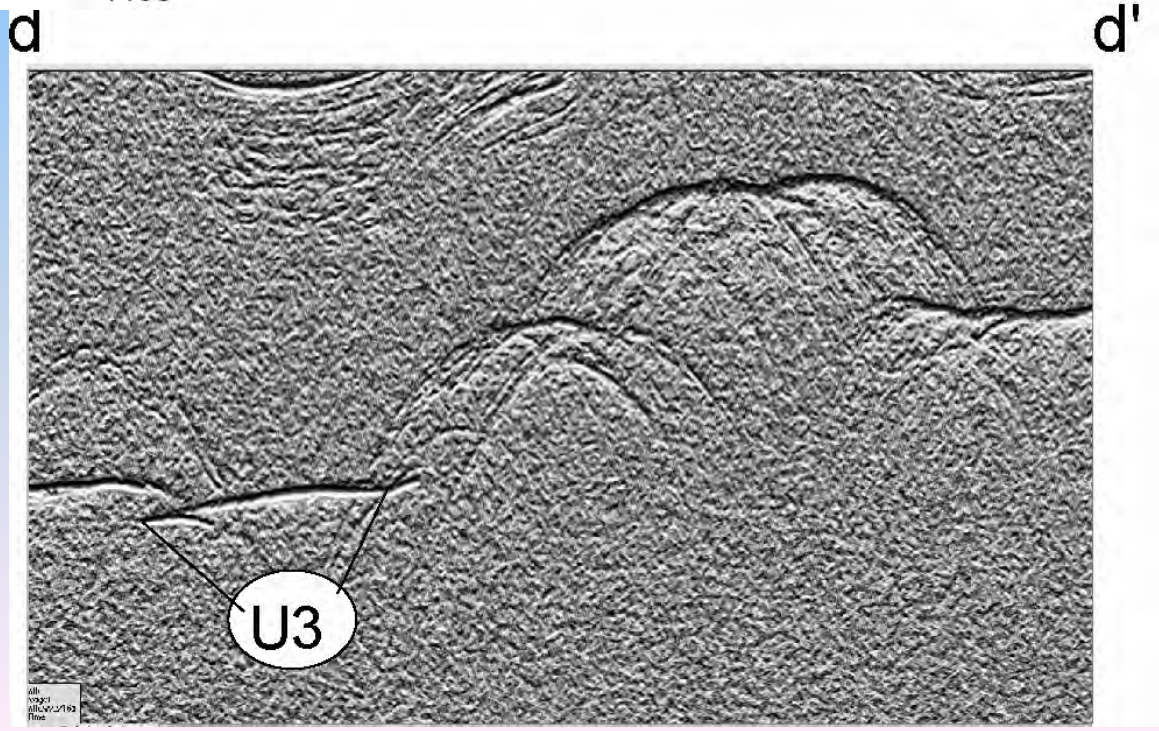


1999 (Carter et al., Submitted) 1974

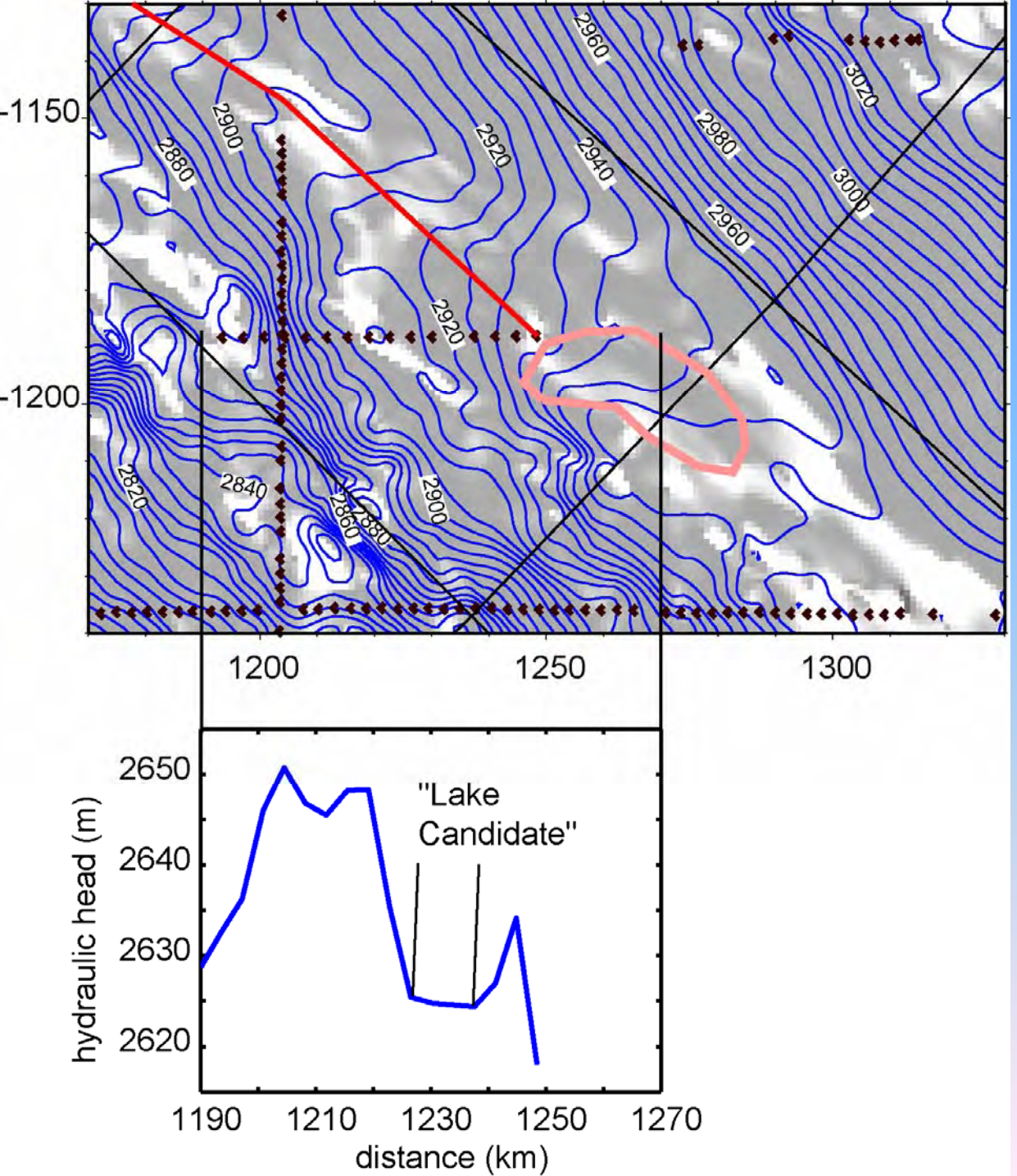


U3

- 64 ± 37 km^2
- Steep topography adjacent to lake interfered with detection and classification
- Received 0.14 km^3 at 7 m^{3}s^{-1}
- ~6% of mass budget
- Coverage is less dense and uncertainty greater for this lake



(Carter et al., Submitted)

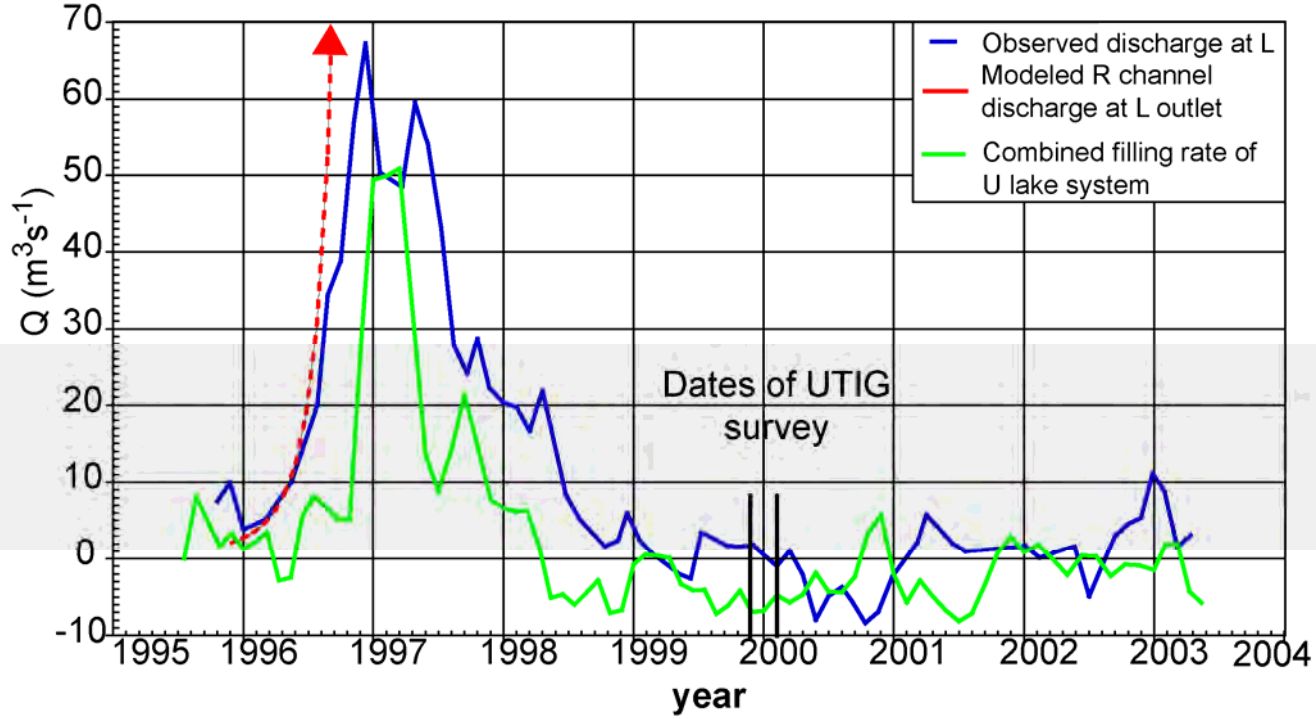


L

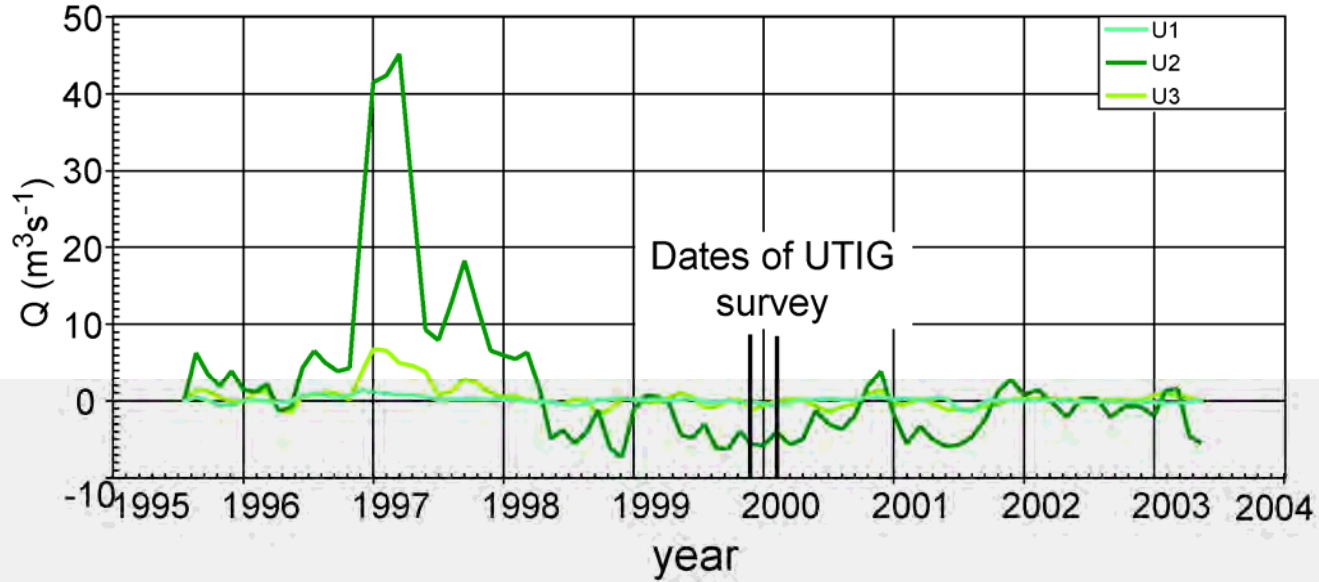
- 600 ± 100 km^2
- Identified by surface motion (Wingham et al., 2006)
- Also identifiable by surface anomaly
- Hydropotential on nearby 1972 flight line shows hydraulically flat spot

(Carter et al., Submitted)

A) Filling and draining rates of Adventure Trench Subglacial Lakes 1995-2003



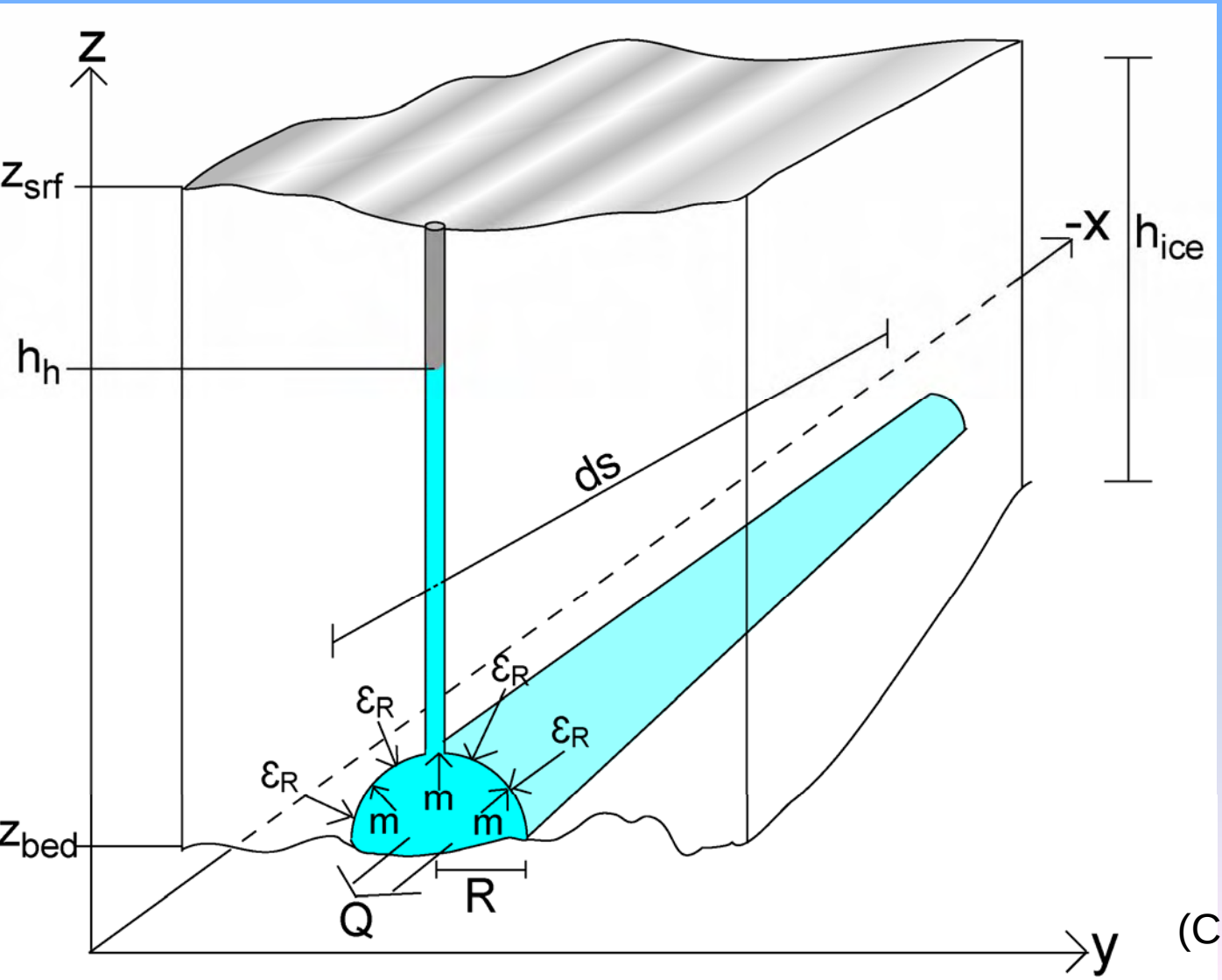
B) Rates of change in the individual destination lakes 1995-2003



- Destination lakes begin filling 2-3 months after release of water from source lake.
- Not enough pressure change to close R-channel.
- Source lake continues draining after destination lakes stop filling.
- Destination lakes loose water April 1998 onward.
- Destination lakes fill / drain simultaneously.

(Carter et al., Submitted)

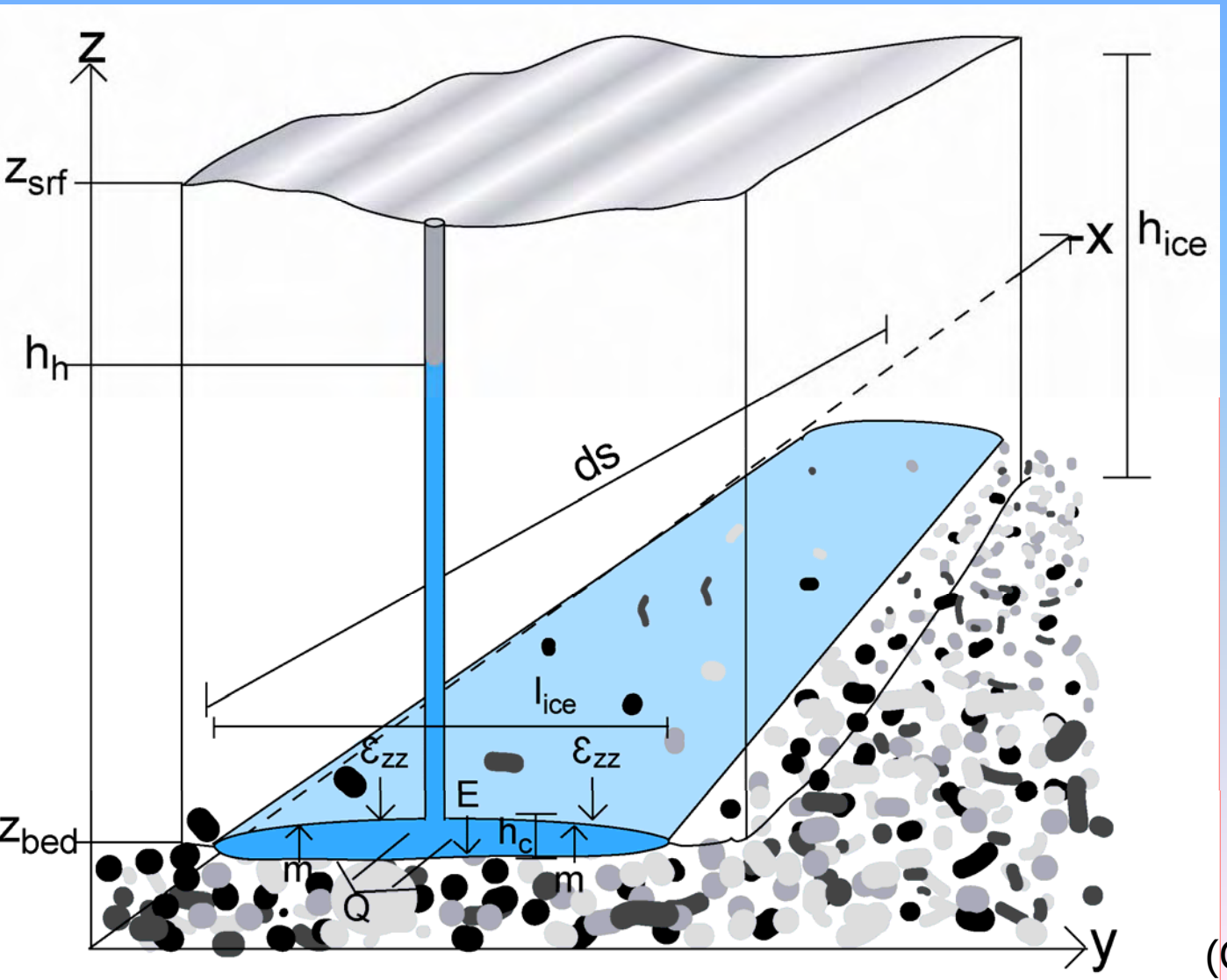
Semicircular Rothlisberger Channel



- Expands by melt
- Contracts through ice deformation
- Travel time ~10 days (Wingham et al., 2006)
- Closure requires change in water presure at “seal” region.
- 3m lake elevation change may not provide sufficient pressure change.
- (Rothlisberger 1972; Nye 1976)

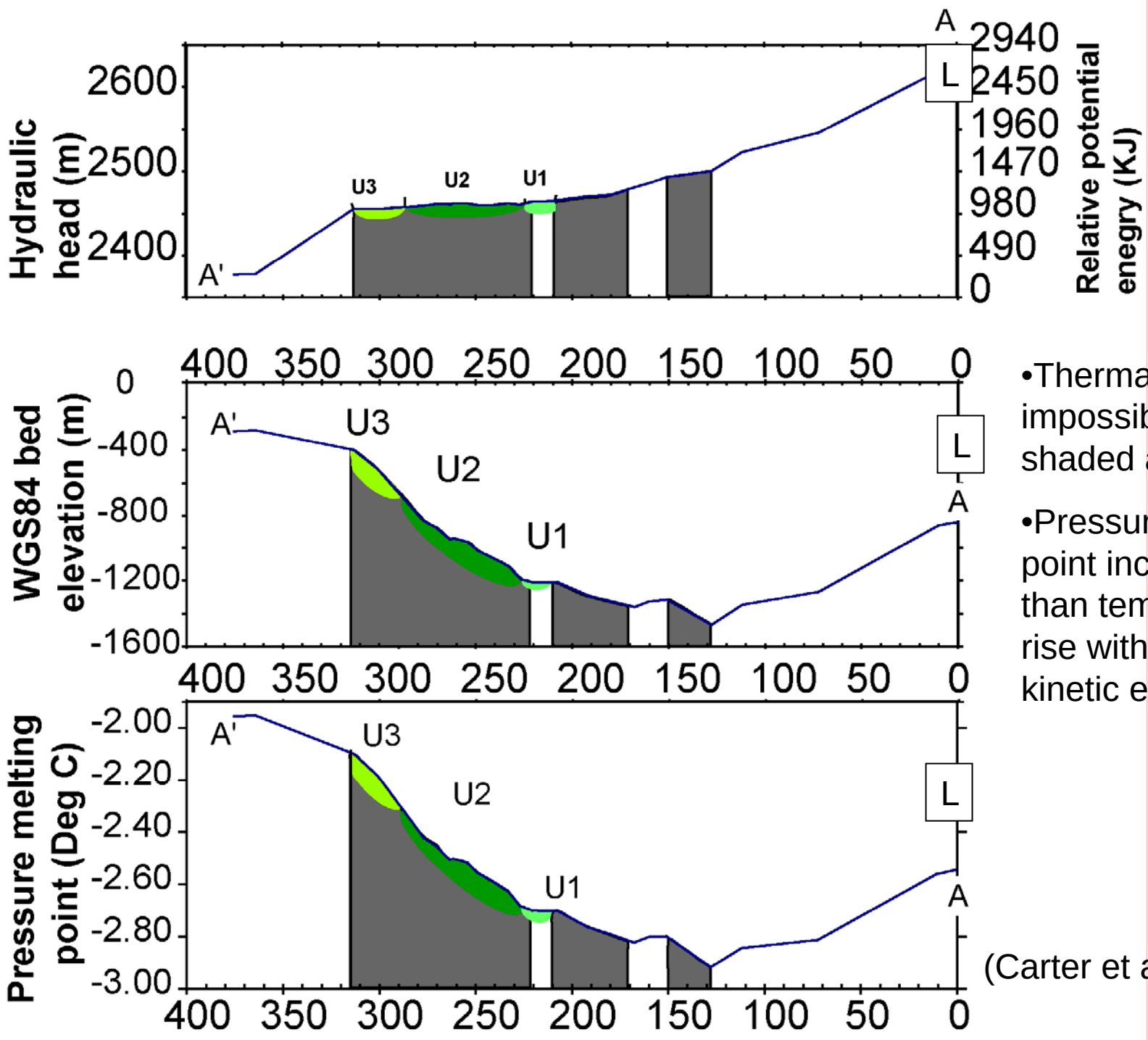
(Carter et al., Submitted)

Sediment-floored, broad, shallow distributed canal



- Floored with deformable sediment
- Water pressures high enough to nearly support overburden.
- Travel time 2-3 months.
- Require deformable sediment.
- AT is a sedimentary basin.
- (Hooke et al., 1990; Walder and Fowler 1994; Fowler and Ng; 1996; Ng 1999)

(Carter et al., Submitted)



- Thermal erosion is impossible in gray shaded areas.
- Pressure melting point increases faster than temperature can rise with available kinetic energy.

(Carter et al., Submitted)

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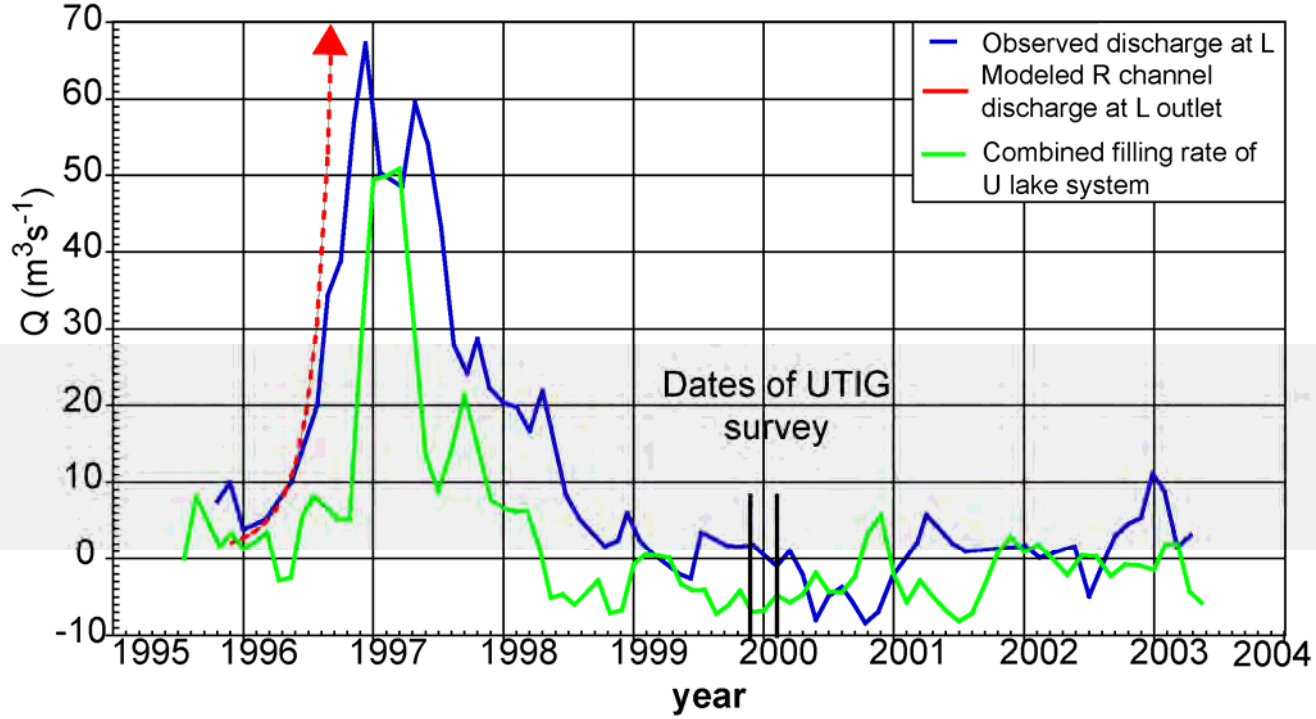

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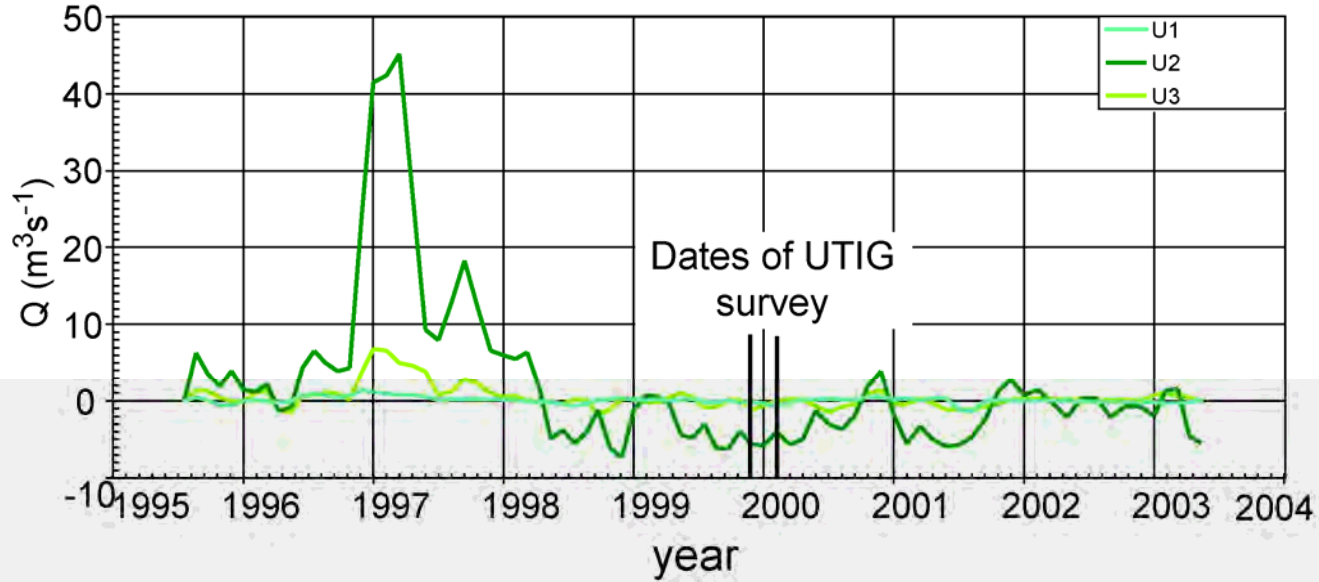

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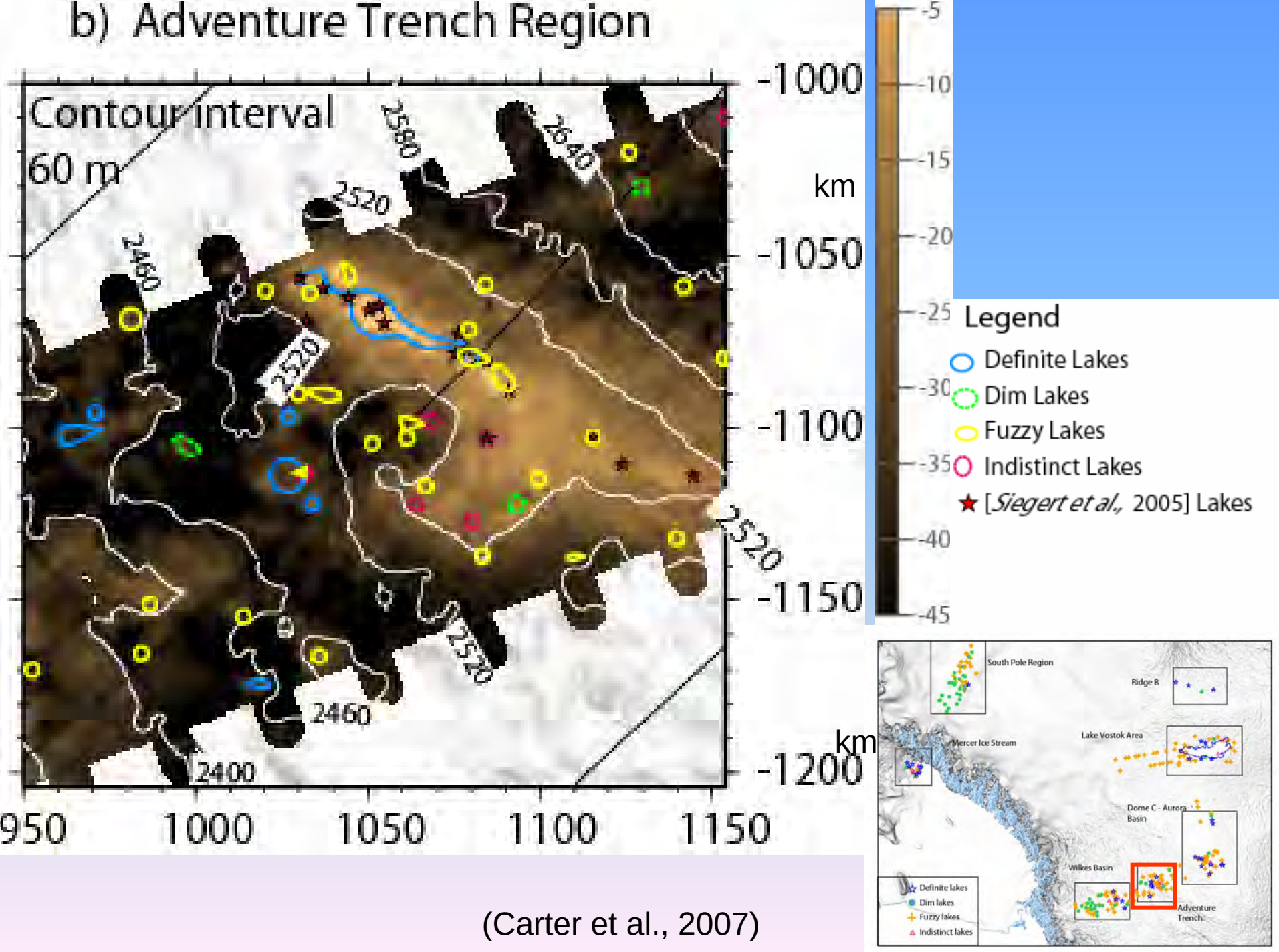


(Carter et al., 2007)

Conclusions

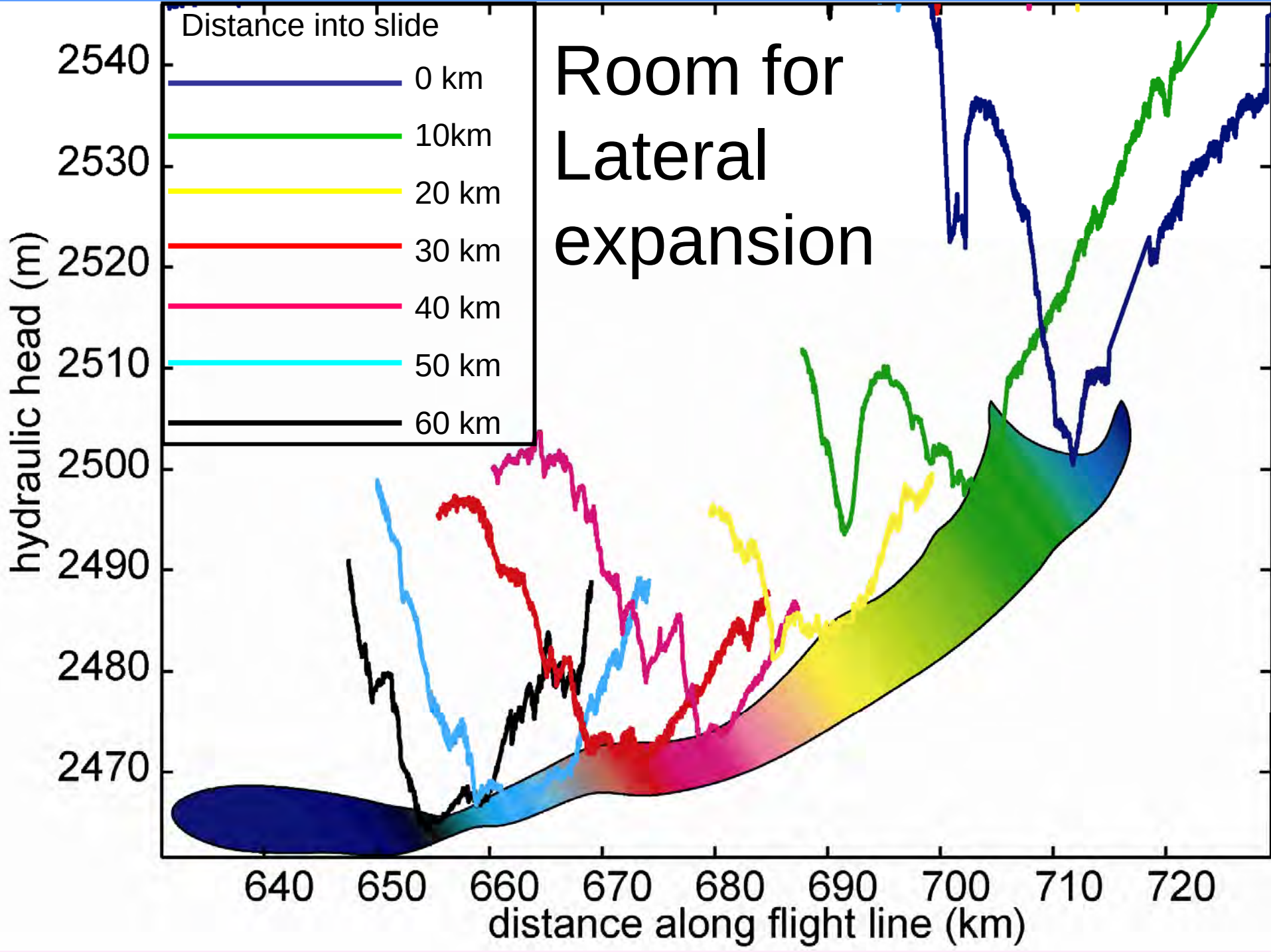
- Discharge from the source lake advanced beyond the initial destination lakes
- U lakes overflowed in mid – 1997. Discharge continued to unknown points downstream.
- Closure rates both for “L” and “U3” outlets consistent with rates estimated for an ice cavity in which width greatly exceeds height.
- Fuzzy lakes and other bright reflections upstream of U lakes are likely relics of this drainage system.

Implications

- L may have opened by channel propagation (Fowler, 1999), but U lakes simply overflowed
- Supercooling at the lake outlet eventually closed this pathway after several years.
- Simultaneous filling of all three destination lakes may implies propagation of a pressure wave through fractured / porous aquifer material
- Distributed systems, unlike narrow conduits CAN influence basal sliding.
- Check out this tracking of ice motion:

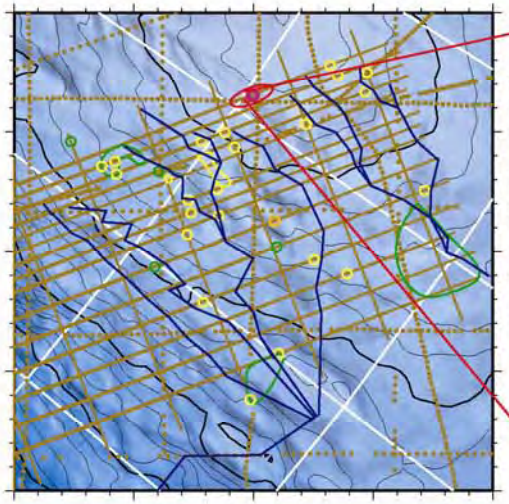
What about Glimmer?

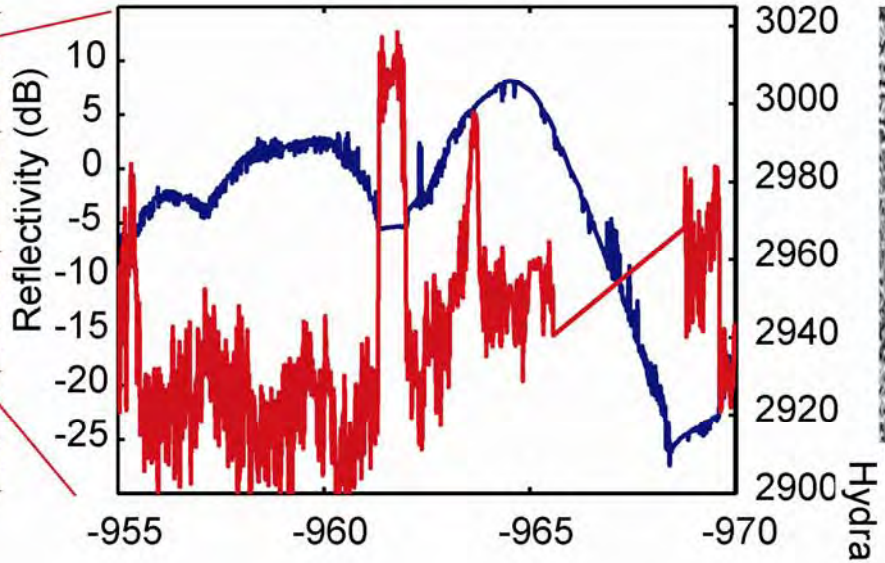
- High resolution vector data is part of the solution.
- Effects of intermittent flow on basal sliding?
- Effects of periodic discharge on sediment transport?
- Habitats-chemical evolution?

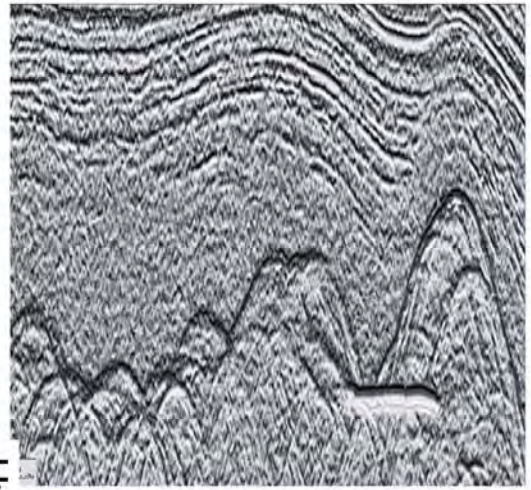

Room for Lateral expansion
Distance into slide
0 km
10km
20 km
30 km
40 km
50 km
60 km
hydraulic head (m)
2540
2530
2520
2510
2500
2490
2480
2470
640
650
660
670
680
690
700
710
720
distance along flight line (km)

Hot spots and Fractures

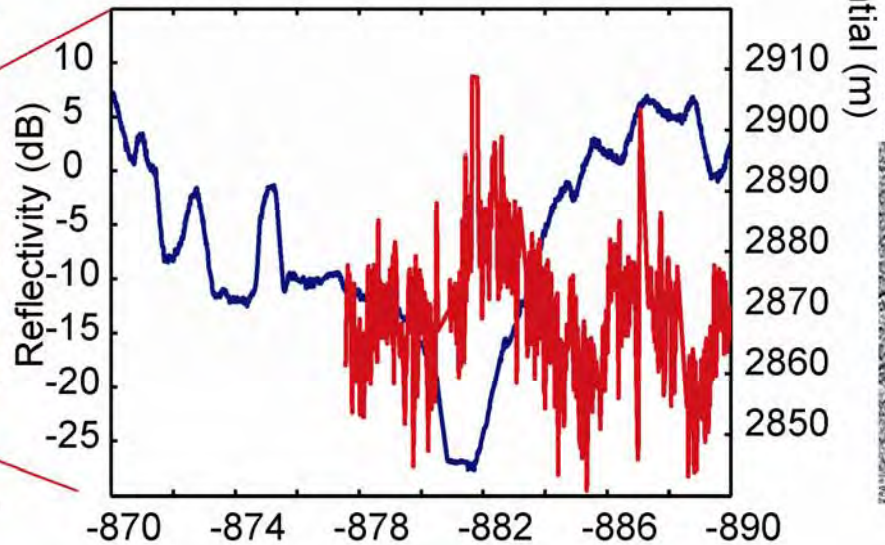
a)

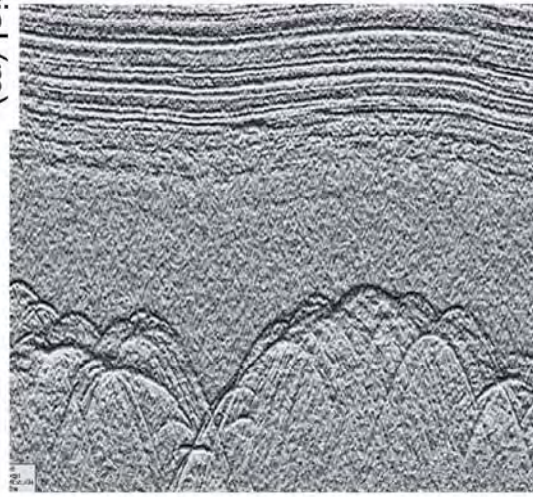




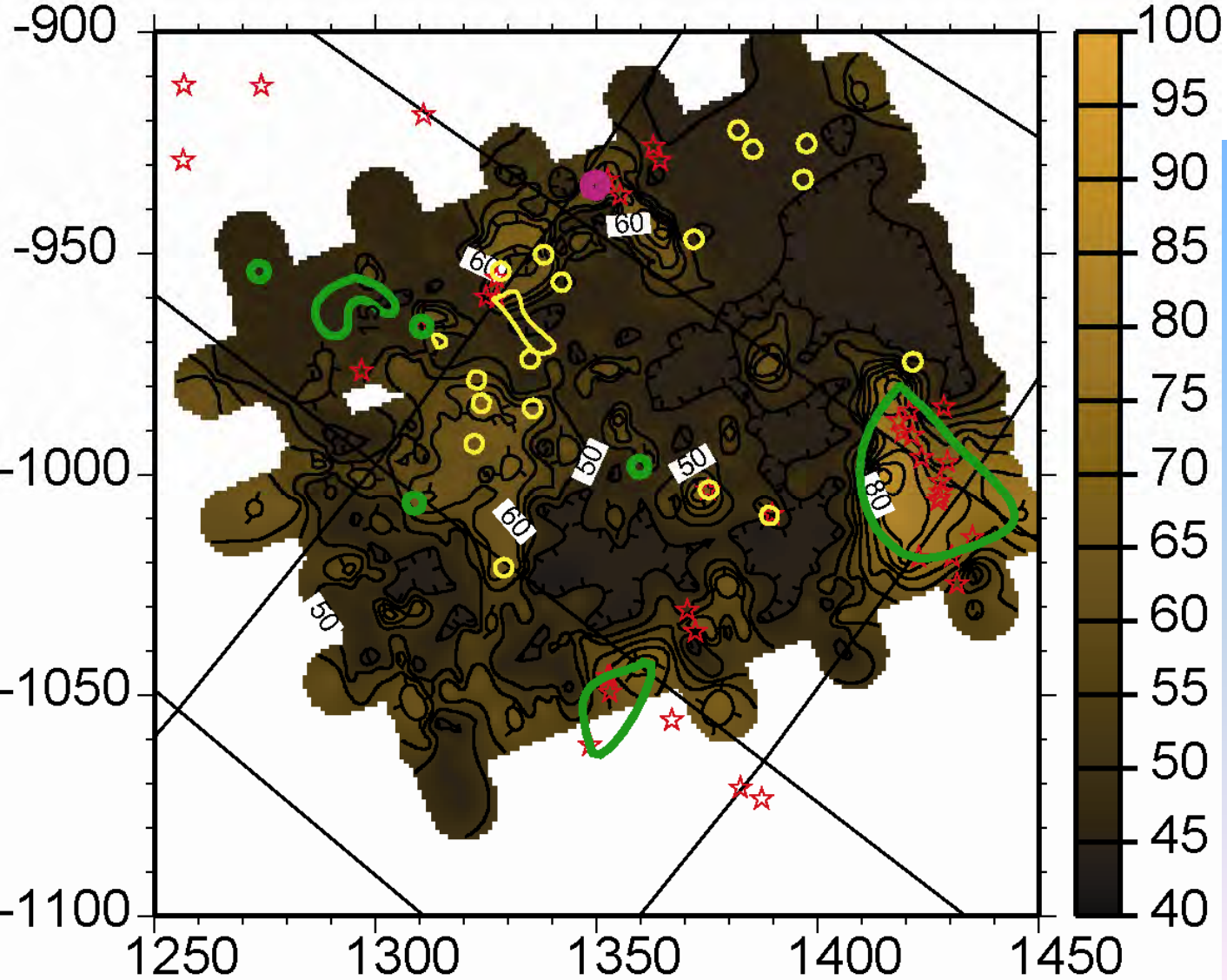


b)



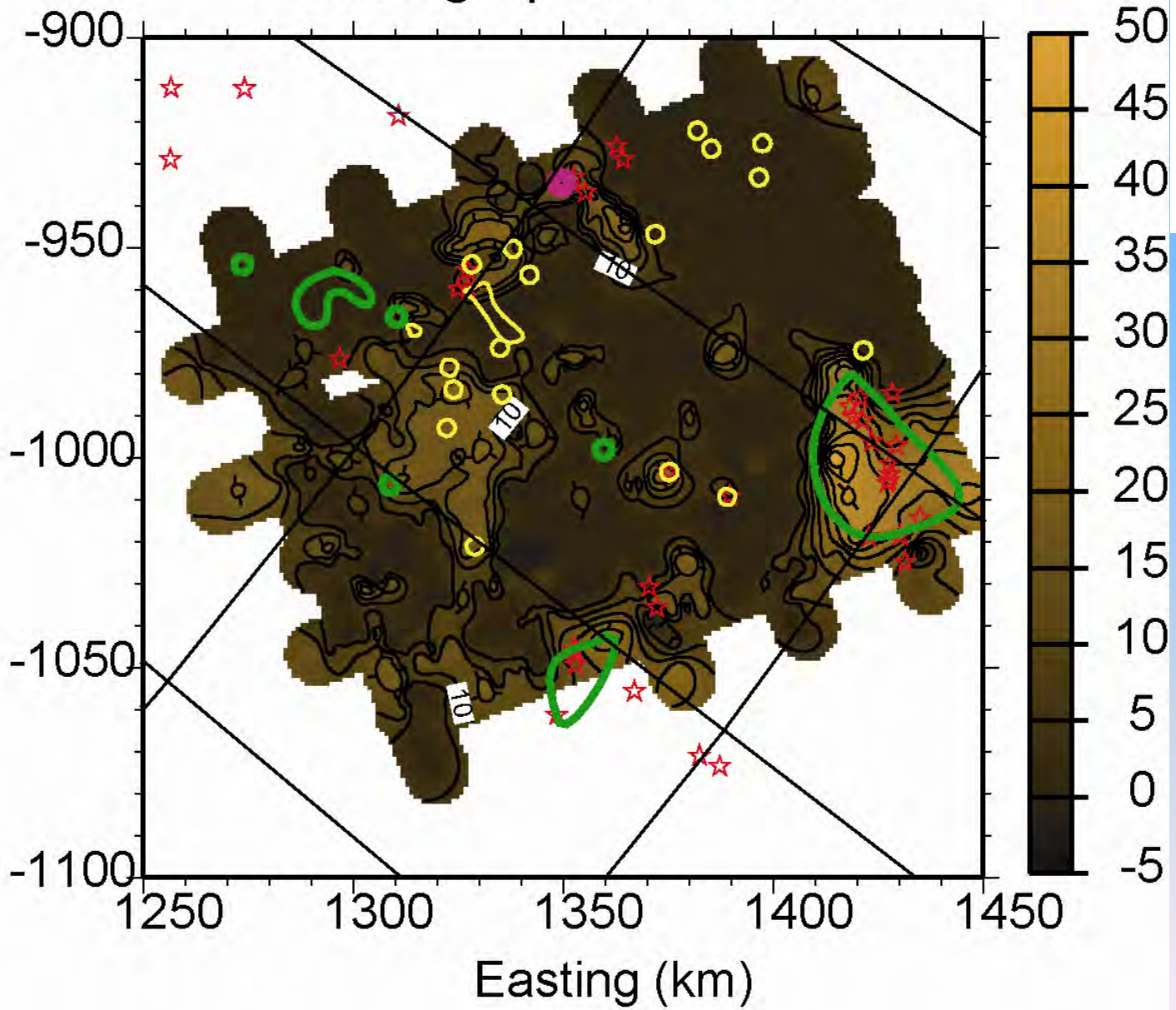


Total geothermal flux



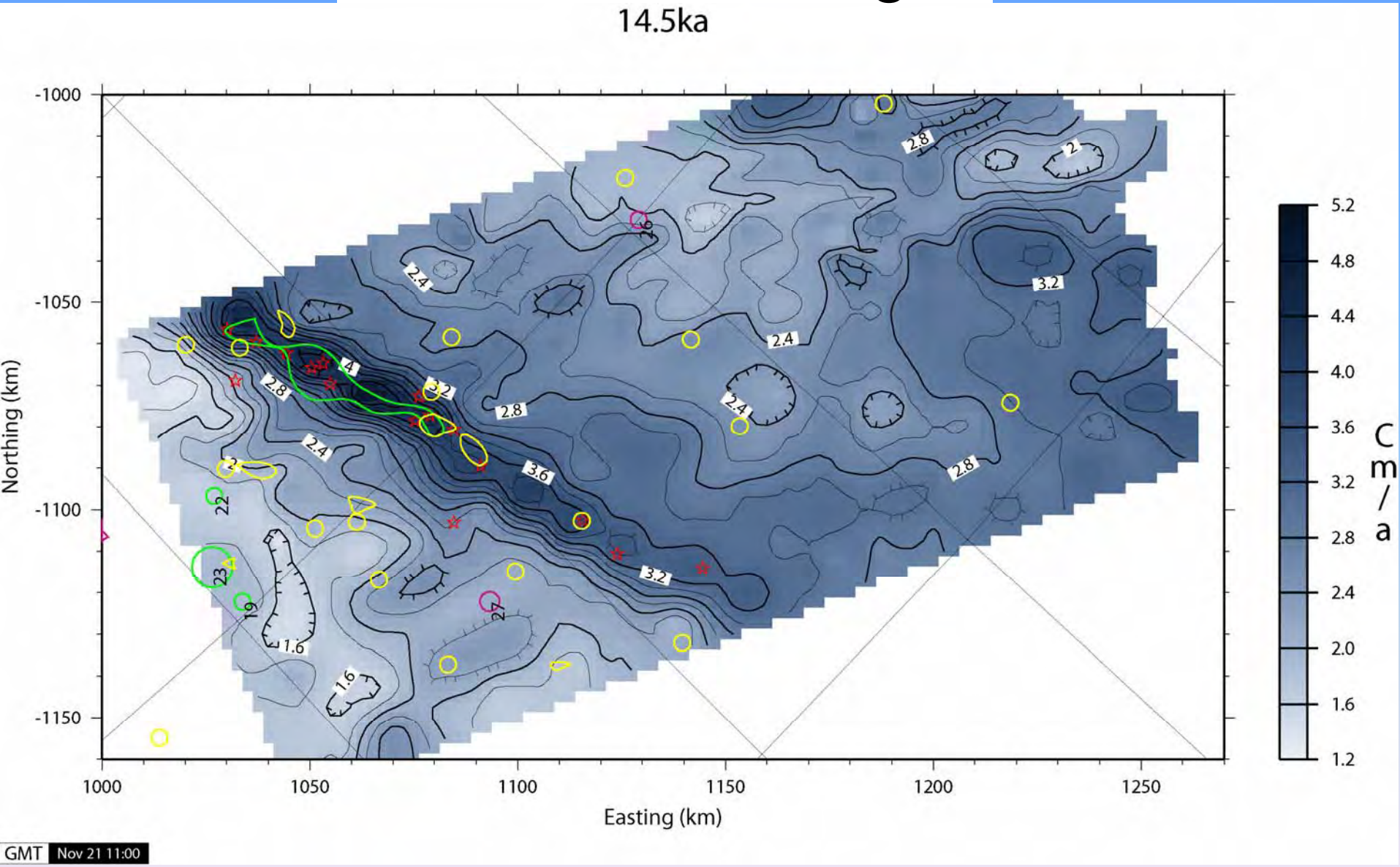
- Definite Lakes
- Dim Lakes
- Fuzzy Lakes
- Indistinct Lakes
- (Siegert,Carter et al., 2005) Lakes
- Hydraulic pathway

Layer / temperature methods versus tomographic inference

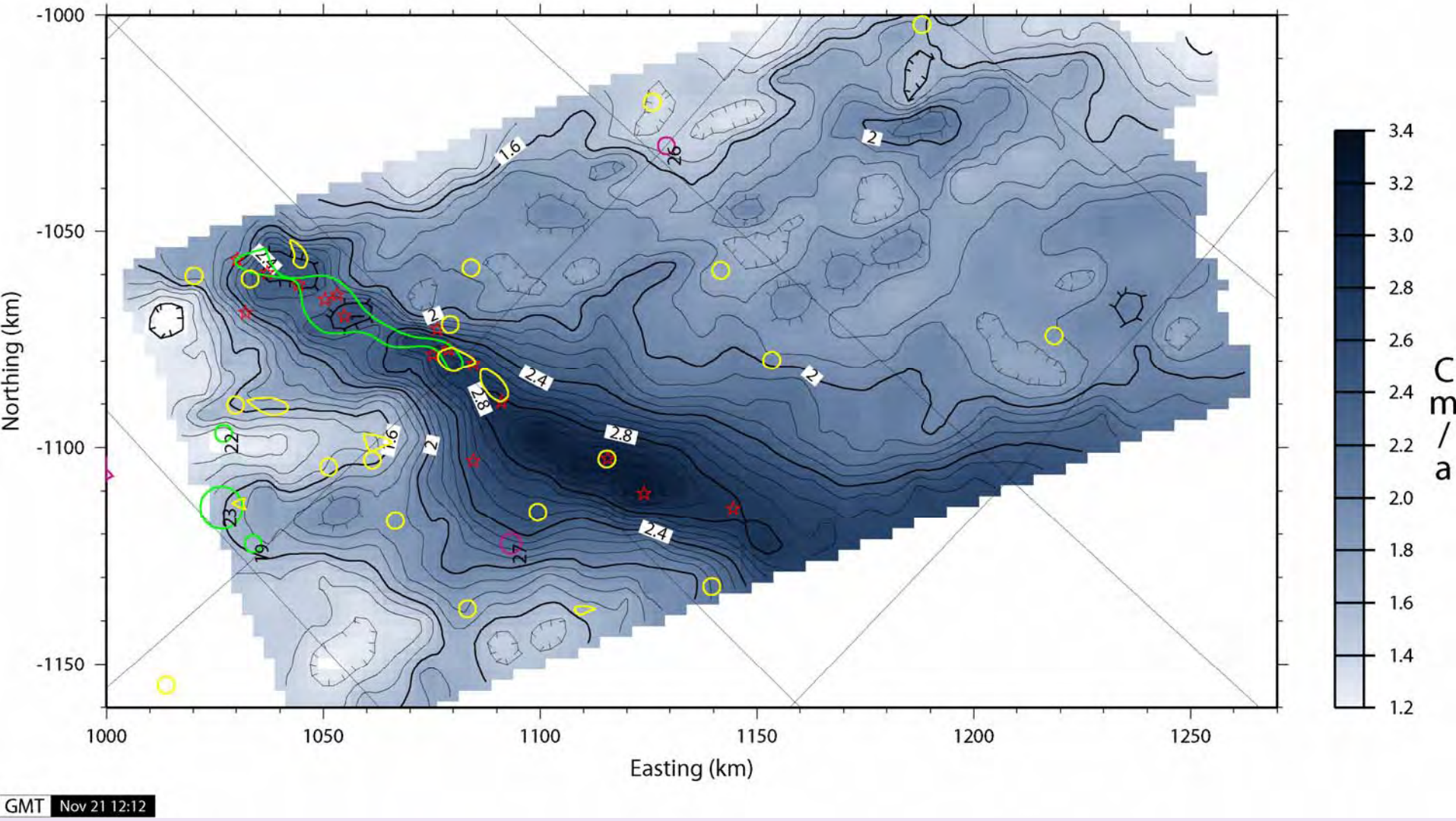


Definite Lakes
Dim Lakes
Fuzzy Lakes
Indistinct Lakes
(Siegert,Carter et al., 2005) Lakes
Hydraulic pathway

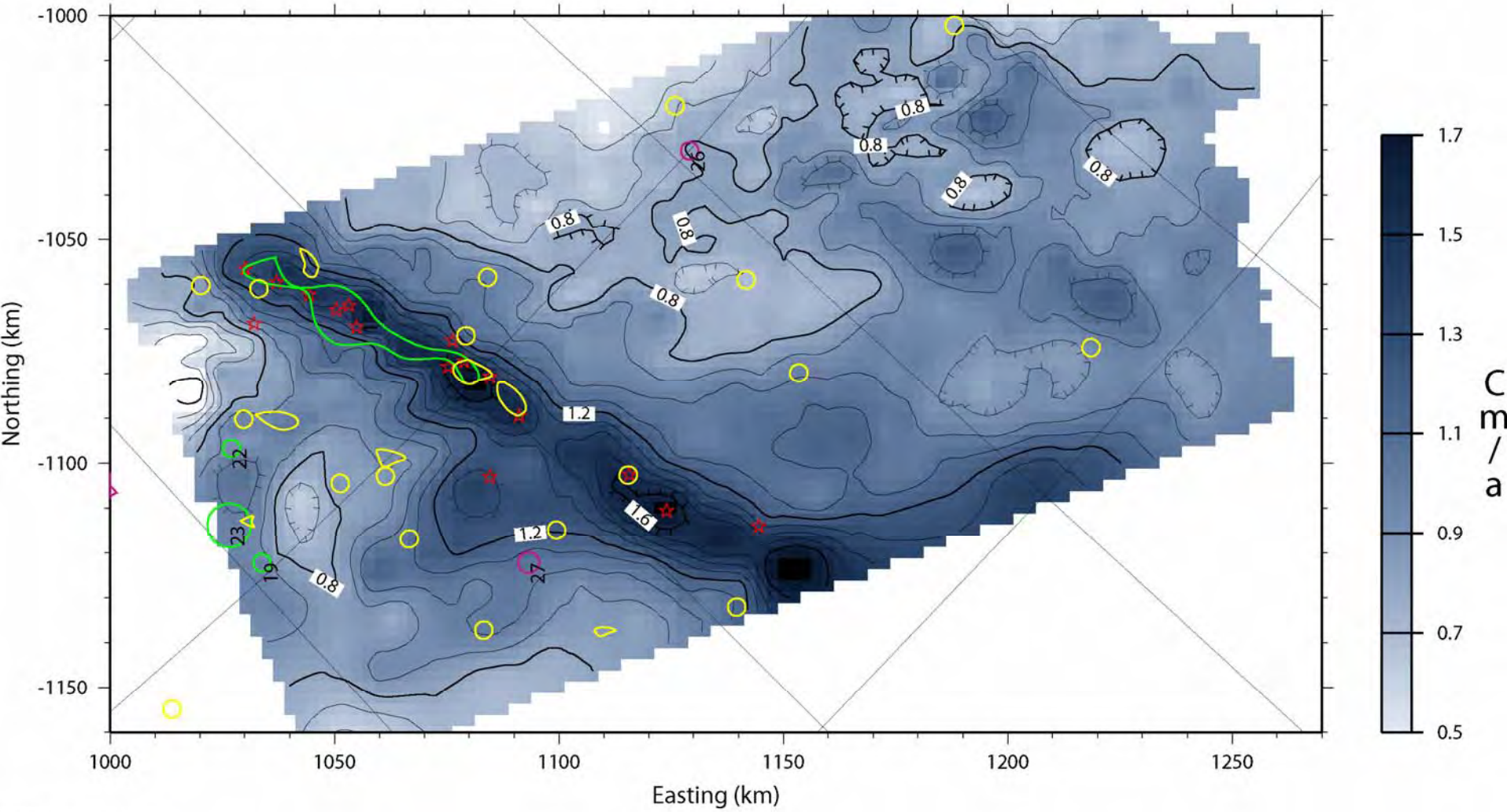
Enhanced sliding?



40ka


-1000
-1050
-1100
-1150
Northing (km)
1000
1050
1100
1150
1200
1250
Easting (km)
1.6
2
2.4
2.8
26
22
23
19
27
3.4
3.2
3.0
2.8
2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
cm/a
GMT
Nov 21 12:12

80ka



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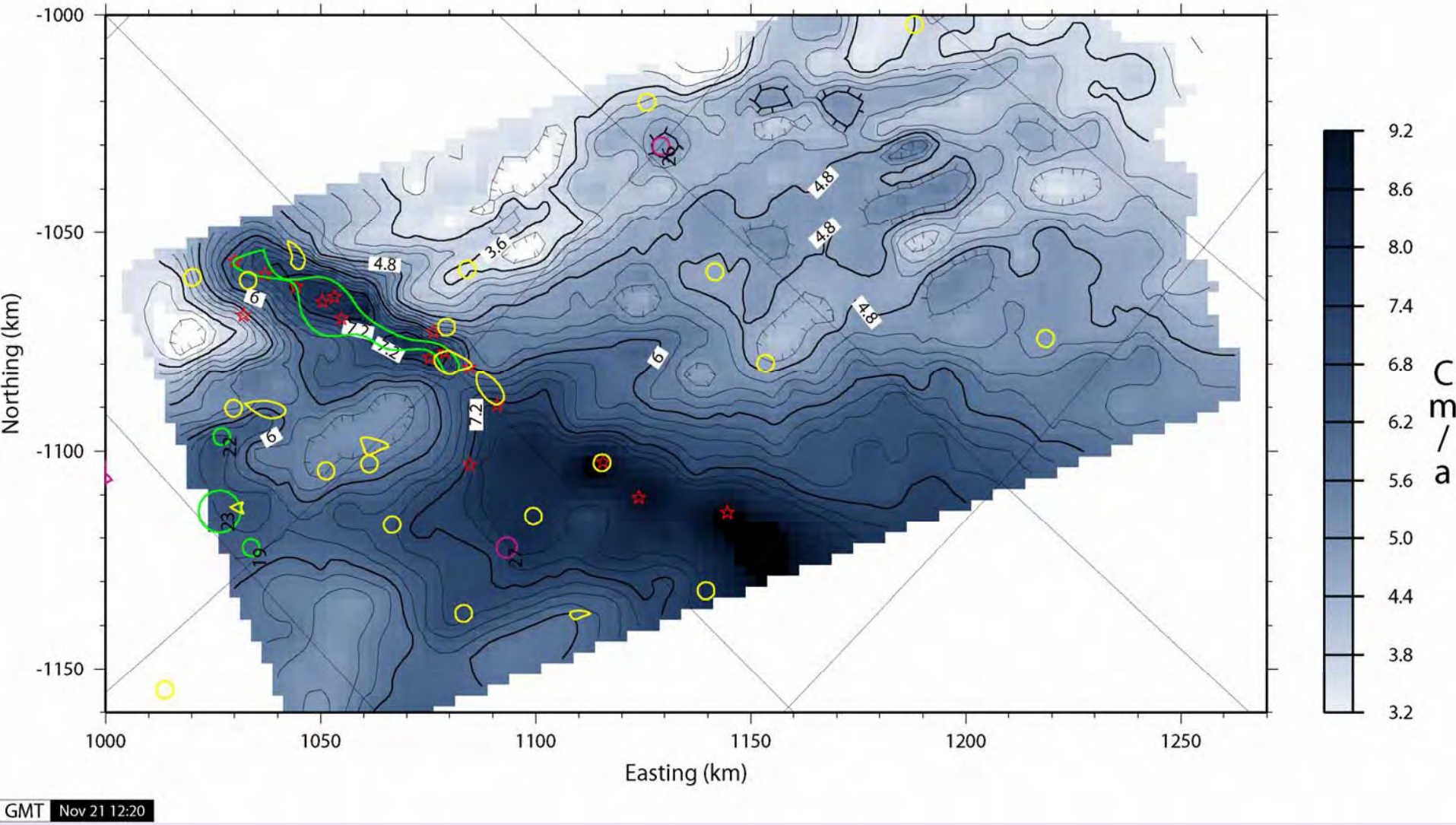
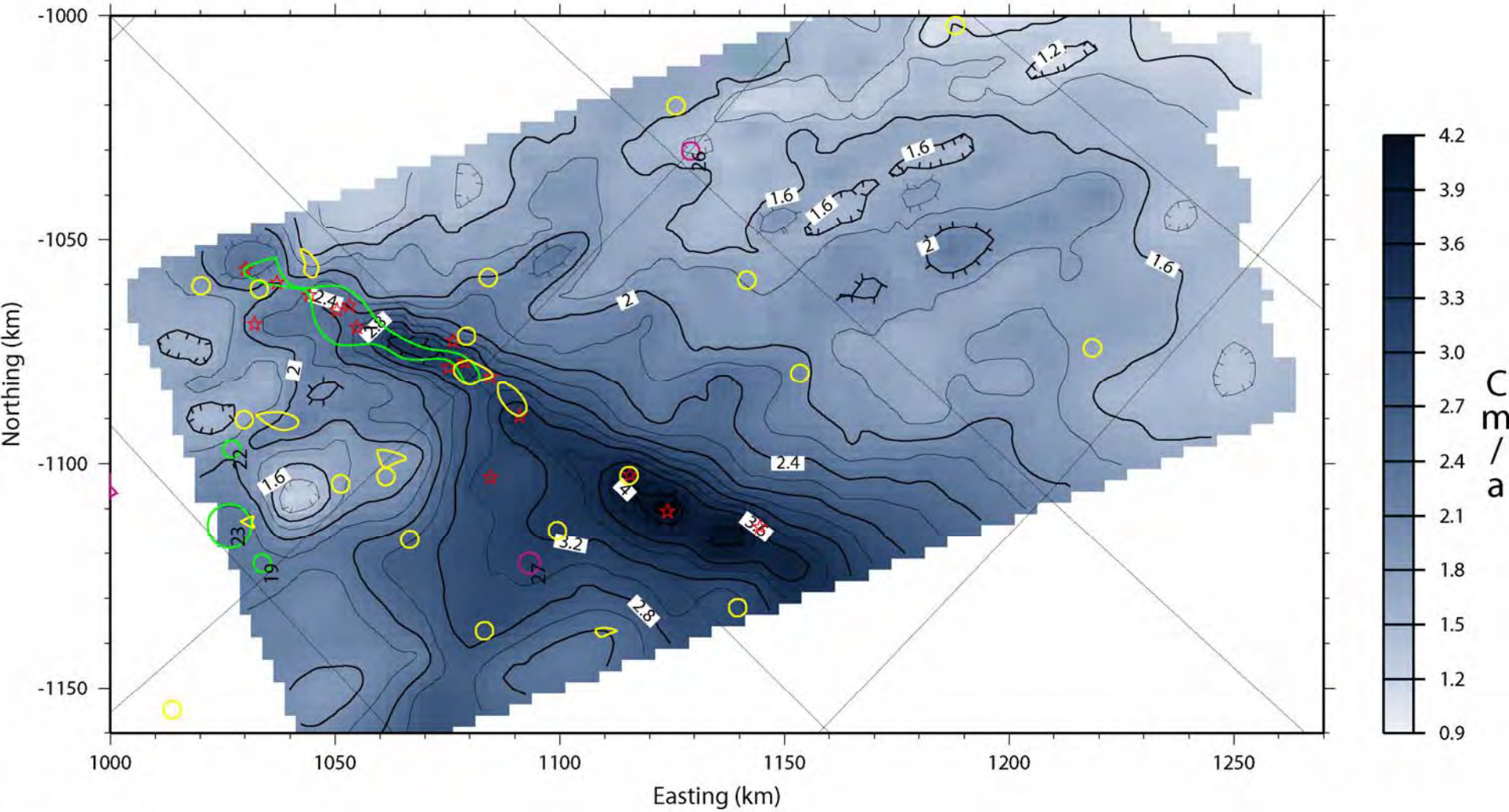
92ka


-1000
-1050
-1100
-1150
Northing (km)
1000
1050
1100
1150
1200
1250
Easting (km)
4.8
3.6
6
7.2
9.2
8.6
8.0
7.4
6.8
6.2
5.6
5.0
4.4
3.8
3.2
cm/a
GMT
Nov 21 12:20

130ka



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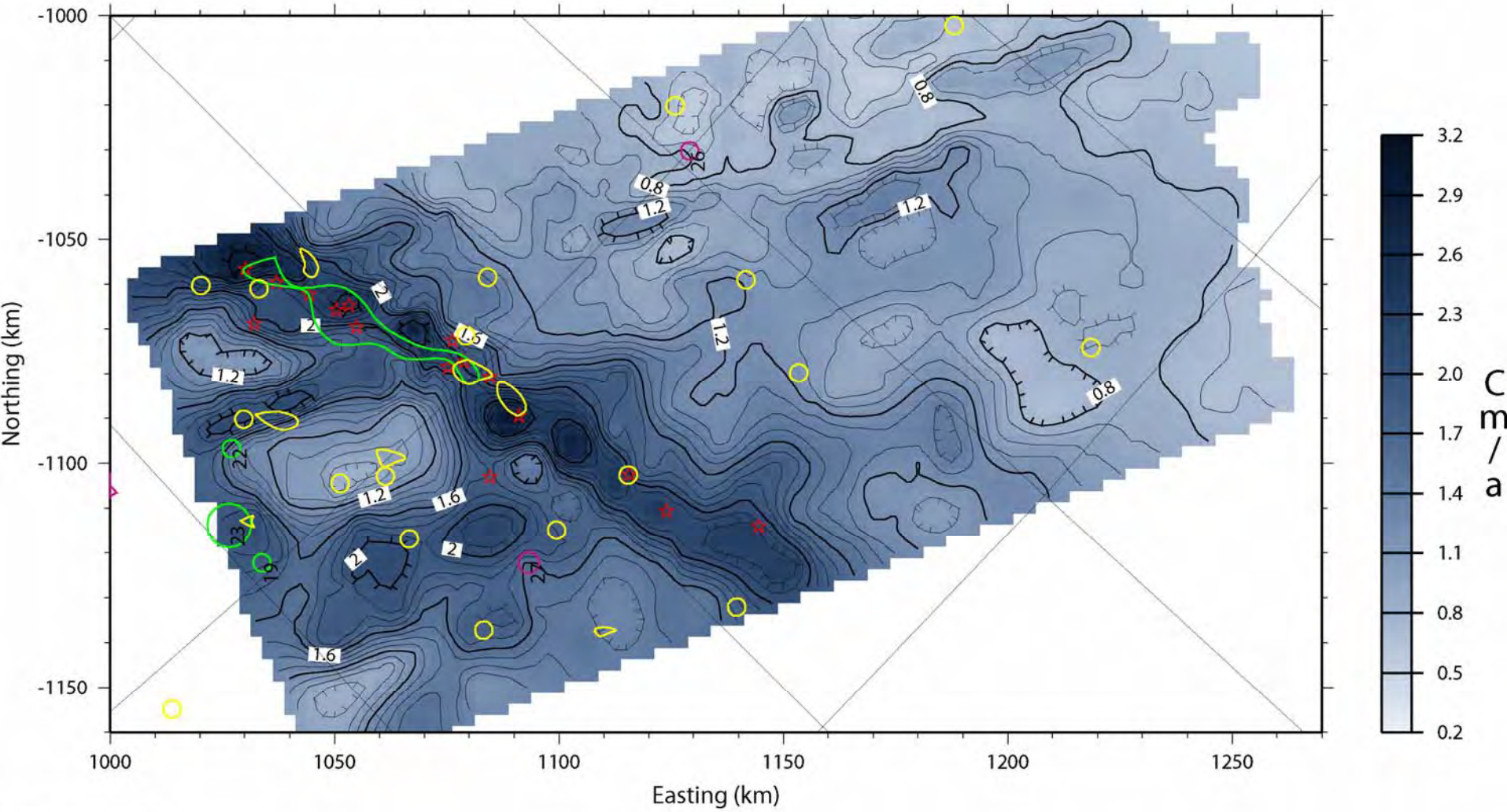
155ka



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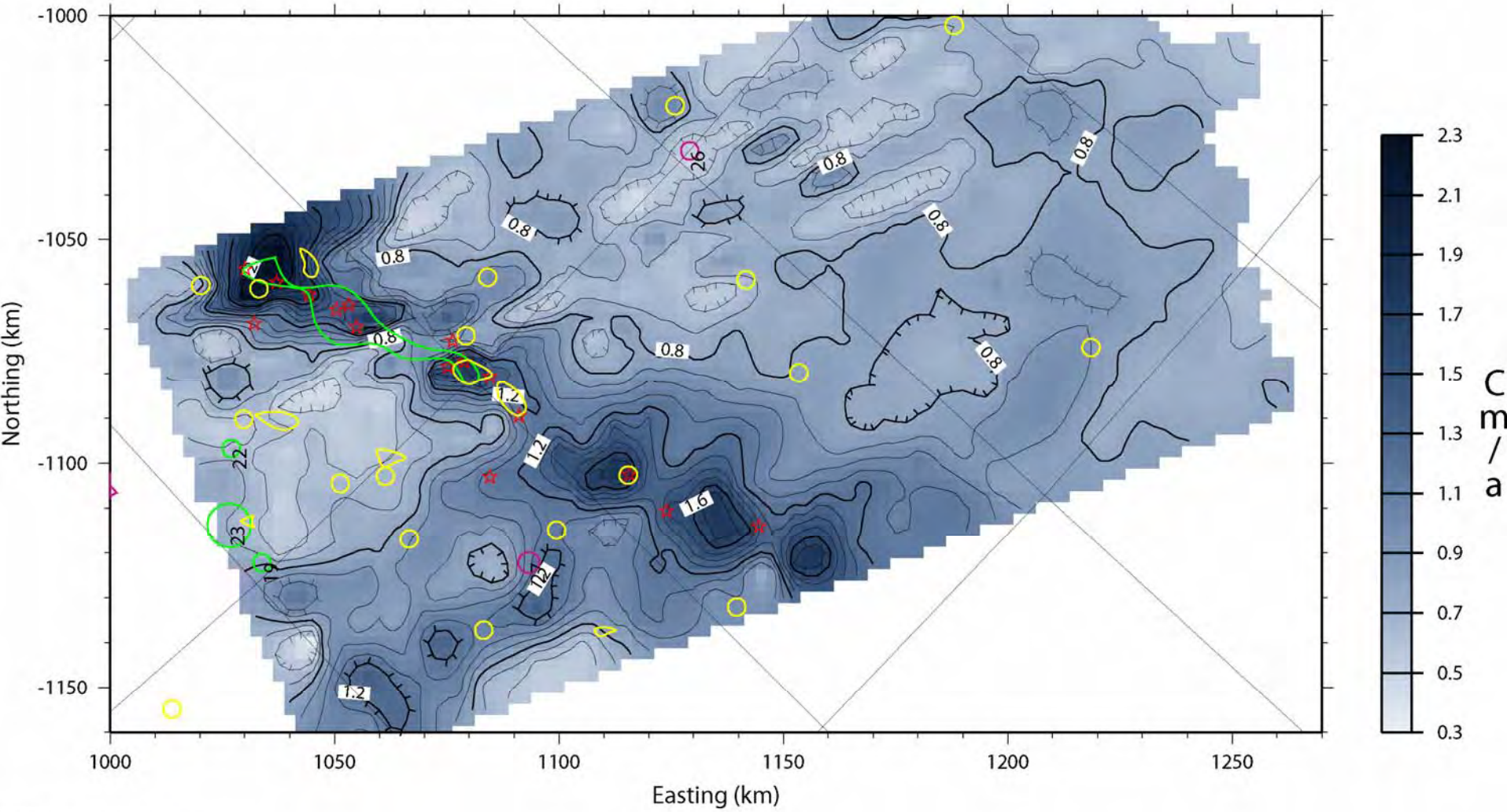
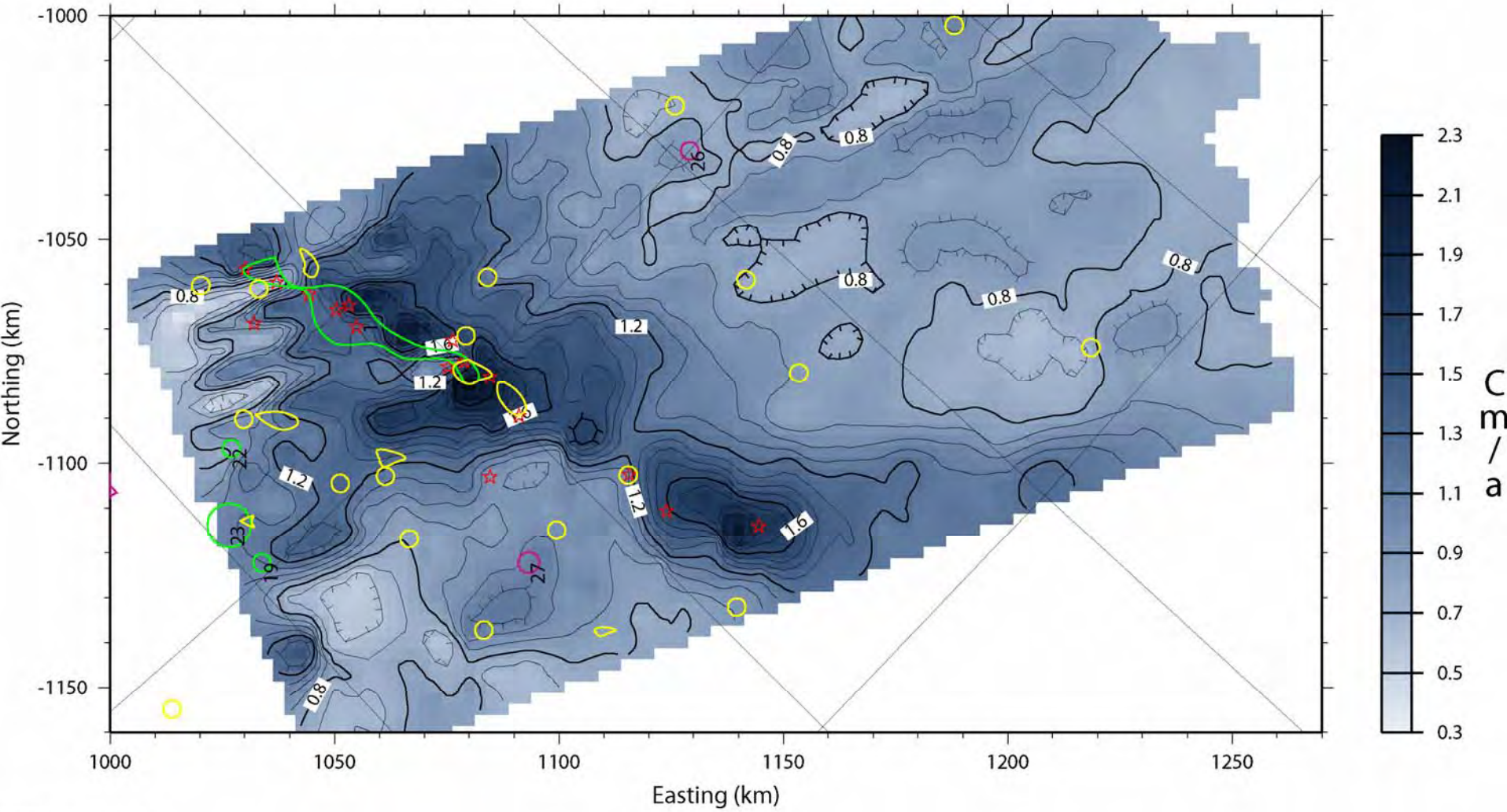
190ka



GMT Nov 21 12:32

256ka



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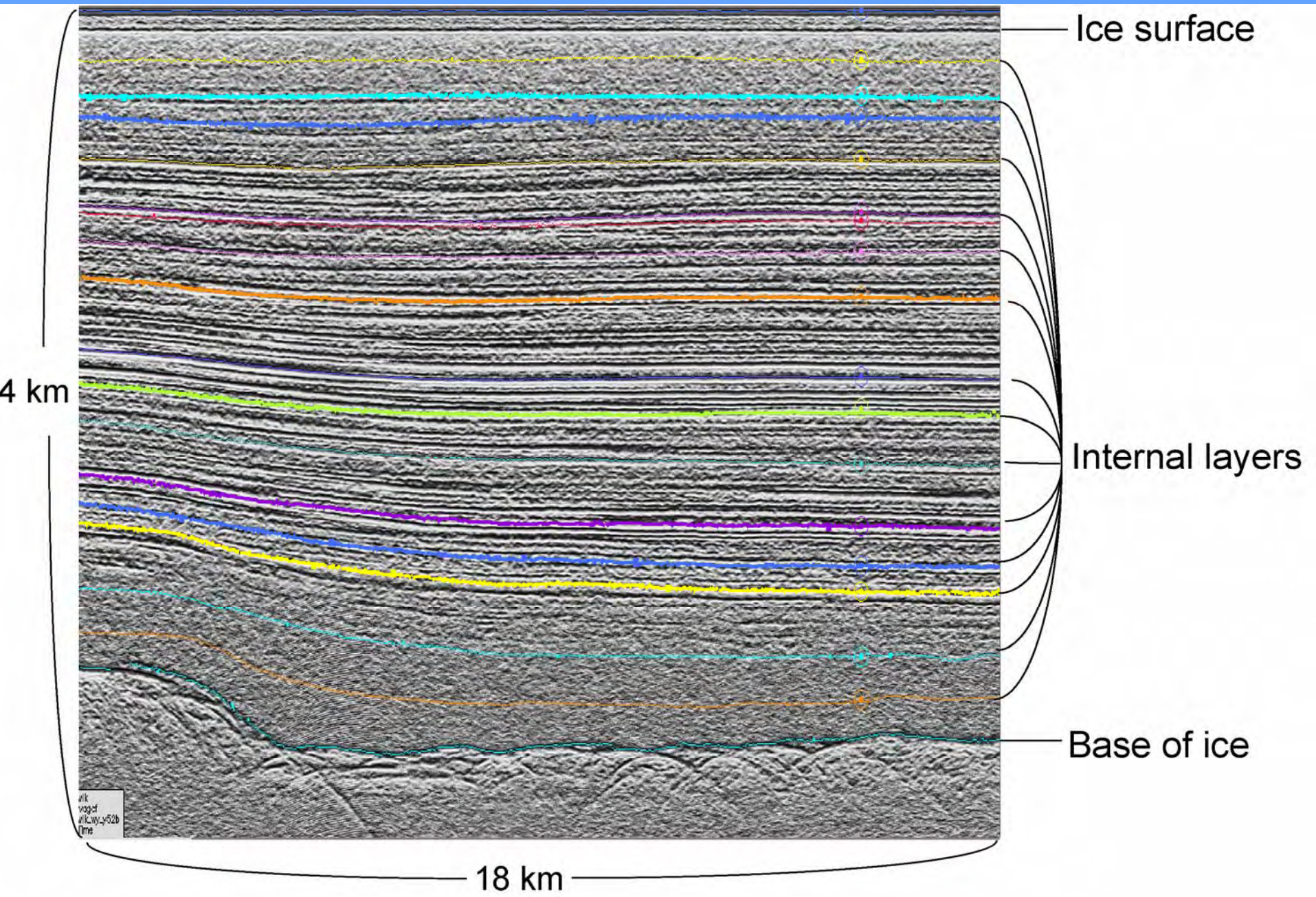
Ice surface
Internal layers
Base of ice
4 km
18 km

Future work

- Extend hydraulic flow path analysis from ice divide to coastline
- Improve models for channel evolution such that they can be applied to the given data
- Propagation of pressure waves in porous media.

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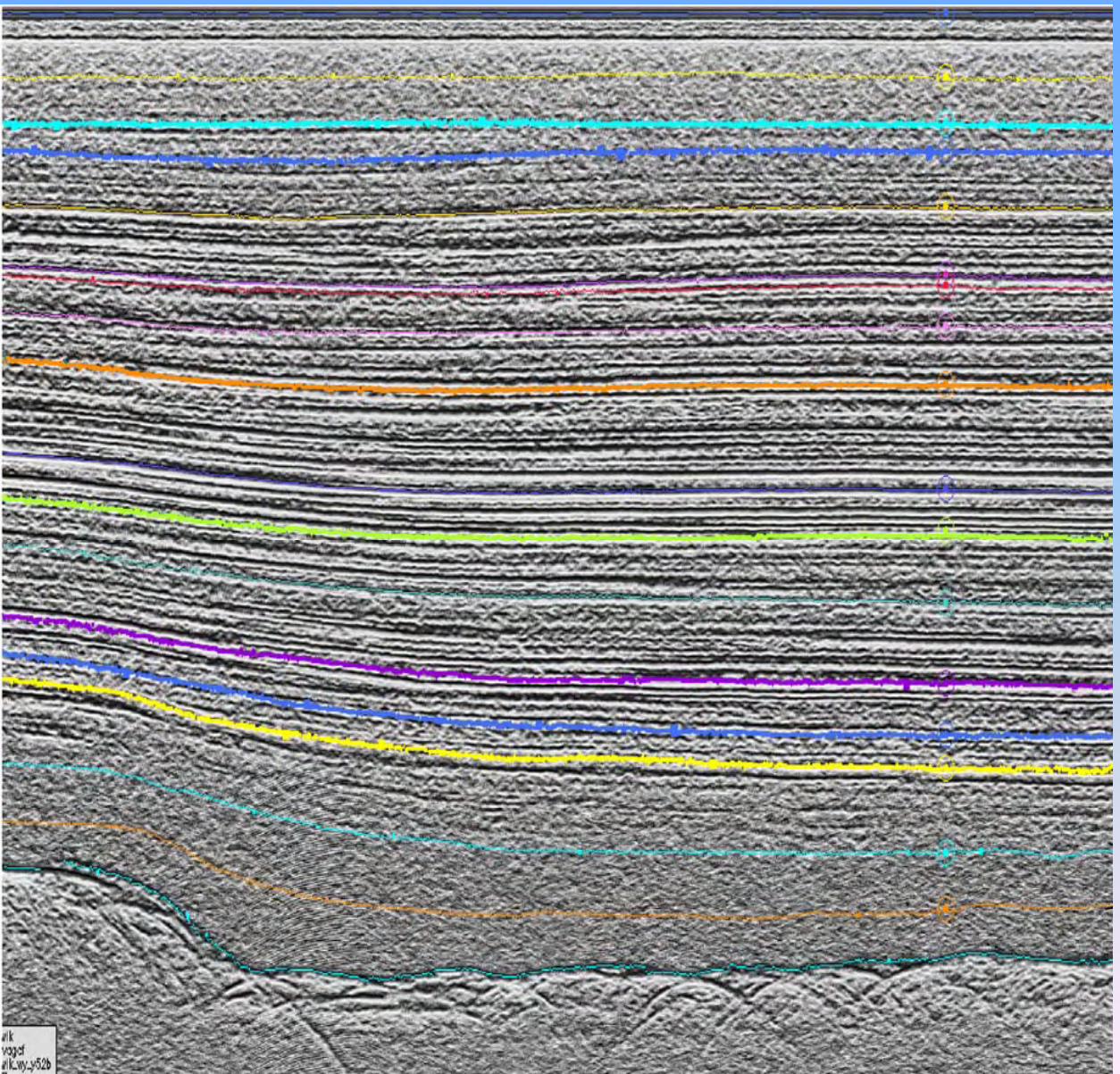
- National Science foundation Office of Polar Programs
- The John A. and Katherine G. Jackson School of Geosciences Geology foundation
- The Vetlesen foundation
- The University of Bristol

Special thanks



Ginny Catania

Charles Jackson

Jamin Greenbaum

Theresa Diehl

Hunter Danque

Erik Leuro

Amy Beth Cabrita

My Family

My neighborhood