Interaction of Eustasy, Ice Sheet Dynamics and Glacial Regime Controlling…

Ross Powell - Northern Illinois University

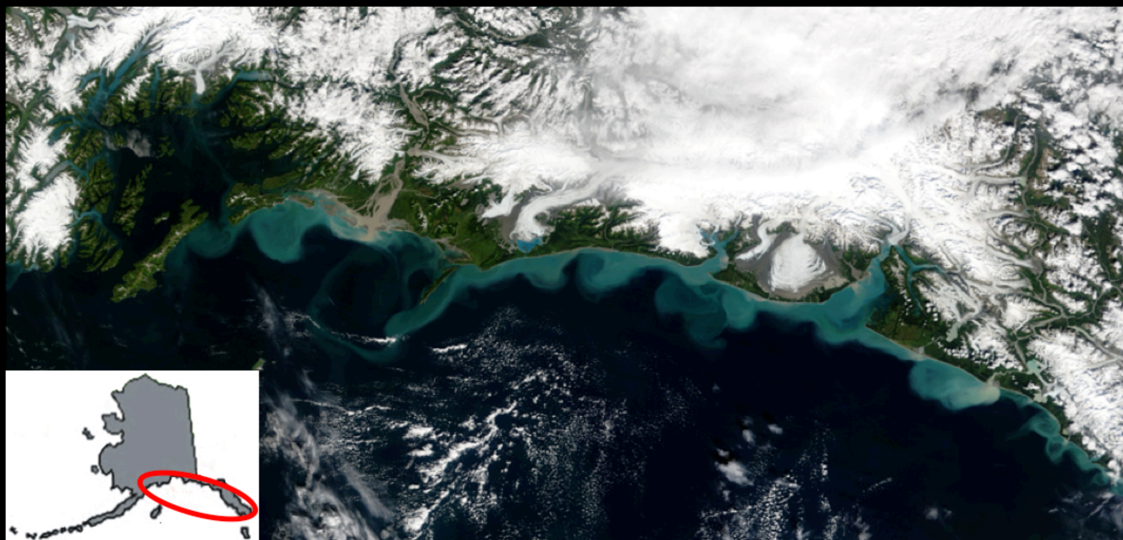
…Sediment Yields, Glacial Sequences and High Latitude Continental Margin Architecture

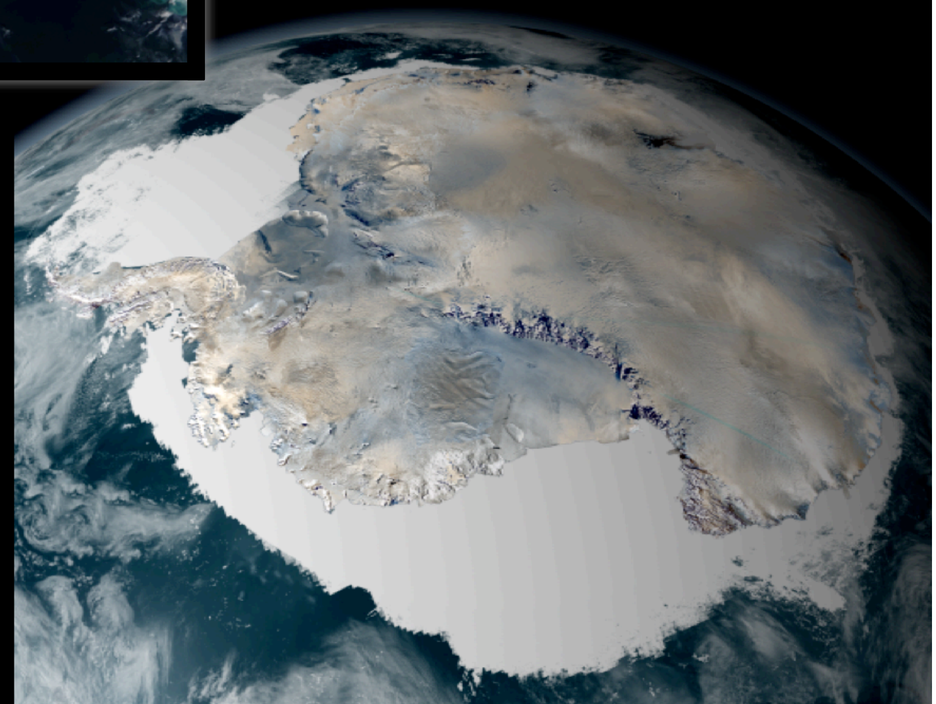
Why Bother?

- Climate-tectonic interactions and mass transfer
- Large proportion of Cenozoic continental margins were glaciated
- IPCC sea level predictions
  - Predictions for dynamics of glaciers and ice sheets are poor
  - Ignored for contributions to future eustasy and rates of sea-level rise
  - Sediment flux important factor for ice stability; a factor in:
    - oceanic melting rates
    - ice flow velocity ⟶ ice dynamics

We need constraints to address these

Glaciated continental margins differ

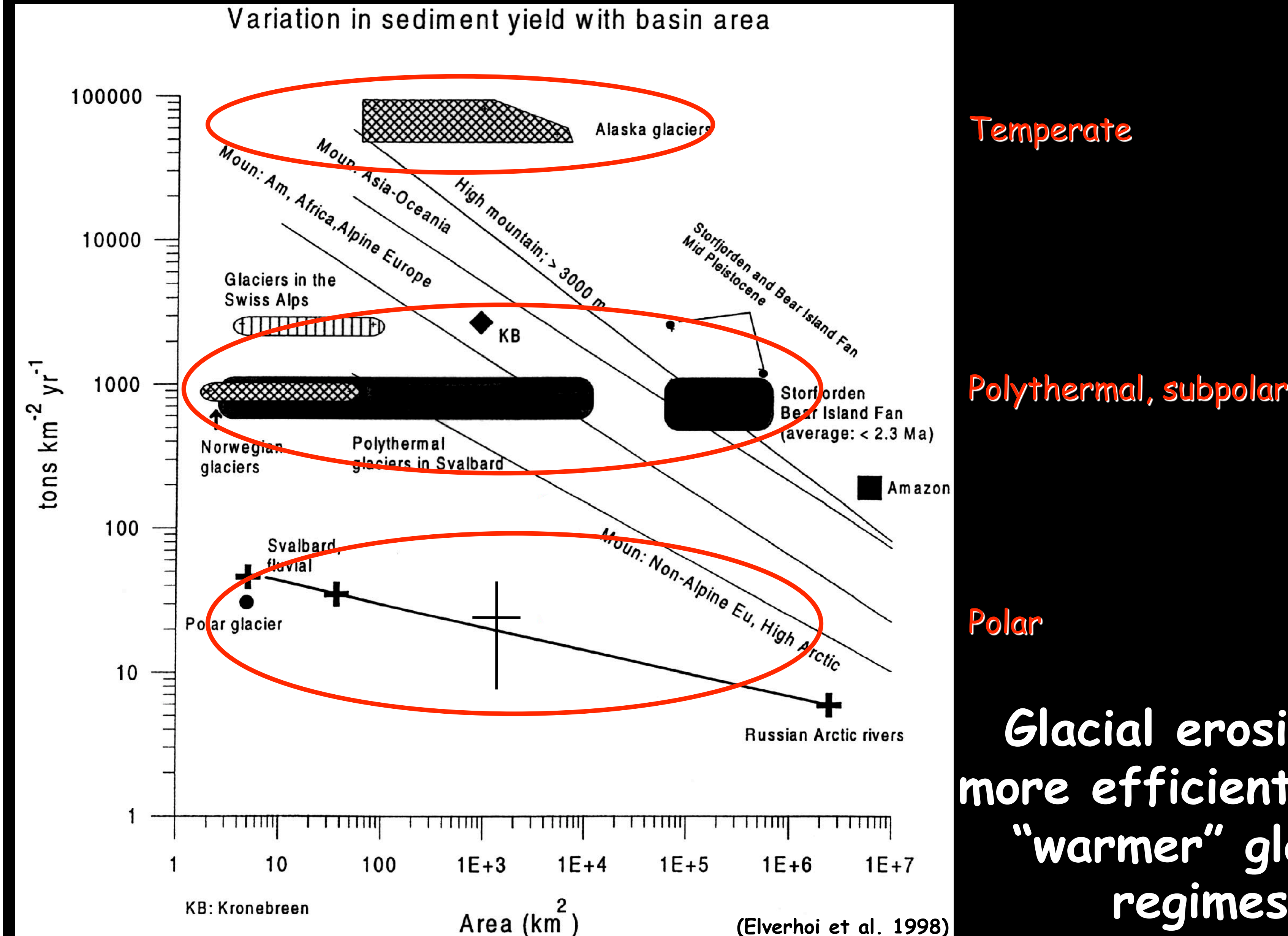




- Glacio-isostasy
- Base-level is grounding-line
  (may also be sea level)
- Grounding-line movement and sea level maybe asynchronous
- Different deposystems

Powell 2004

Sediment volume (erosion) mainly controlled by glacial regime



Glacial erosion is more efficient under "warmer" glacial regimes

Base level varies with grounding-line, which need not vary with shoreline

Accommodation space on glaciated shelves

Complex interaction of:

- glacial advance and retreat
- type of glacial terminus in controlling sediment
- rates and styles of sediment delivery to the sea
- marine dispersal and re-depositional processes
- continental shelf morphology
- eustasy
- glacial and sediment isostatic loading
- local tectonic movements

Largest problems:

- paleo-depth indicators are commonly few
- changes in facies driven by glacial proximity versus relative sea-level changes are often debatable

Powell & Copper, 2001

Look at sedimentation and sediment accumulation rates on different time-scales:

today - suspended sediment traps

- differential bathymetry

short term (1-10s y)

- sediment cores

longer term (10-1000s y)

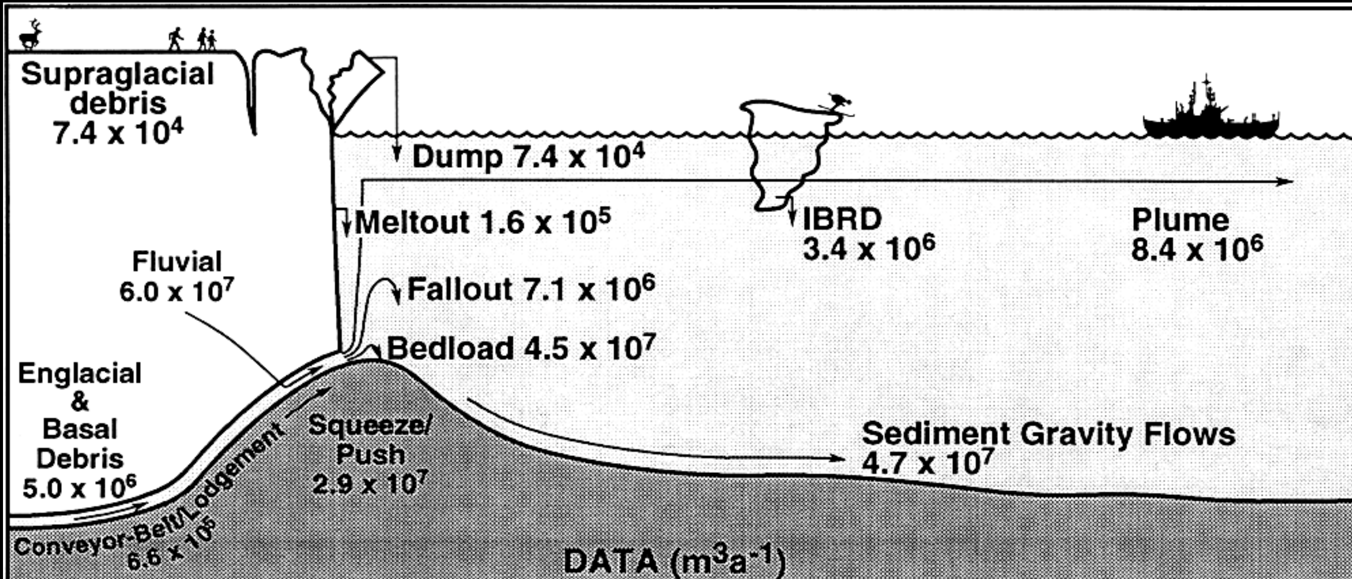
- seismics

Cover different time spans on different time scales:

from modern process to glacial-interglacial cycle

All agree on volumes (within errors, at least the temperate system)

Not only need fluxes to the grounding line,
but also net sediment budget at the grounding line
- sediment dispersal processes in the sea
- sediment stability criterion on slopes



INPUT		RECYCLING	RESIDUAL	LOST	BY-PASS
Supraglacial	7.4×10^4		Dump 7.4×10^4		
Englacial & Basal	5.0×10^6		Meltout 1.6×10^5		IBRD 3.4×10^6
Subglacial	→	Conveyor 6.6×10^5			
		Squeeze/Push 2.9×10^7			
Fluvial	6.0×10^7		Fall 7.1×10^6		Plume 8.4×10^6
			Bedload 4.5×10^7		
				Sediment Flows 4.7×10^7	
TOTALS	6.5×10^7	2.9×10^7	5.2×10^7	4.7×10^7	1.2×10^7

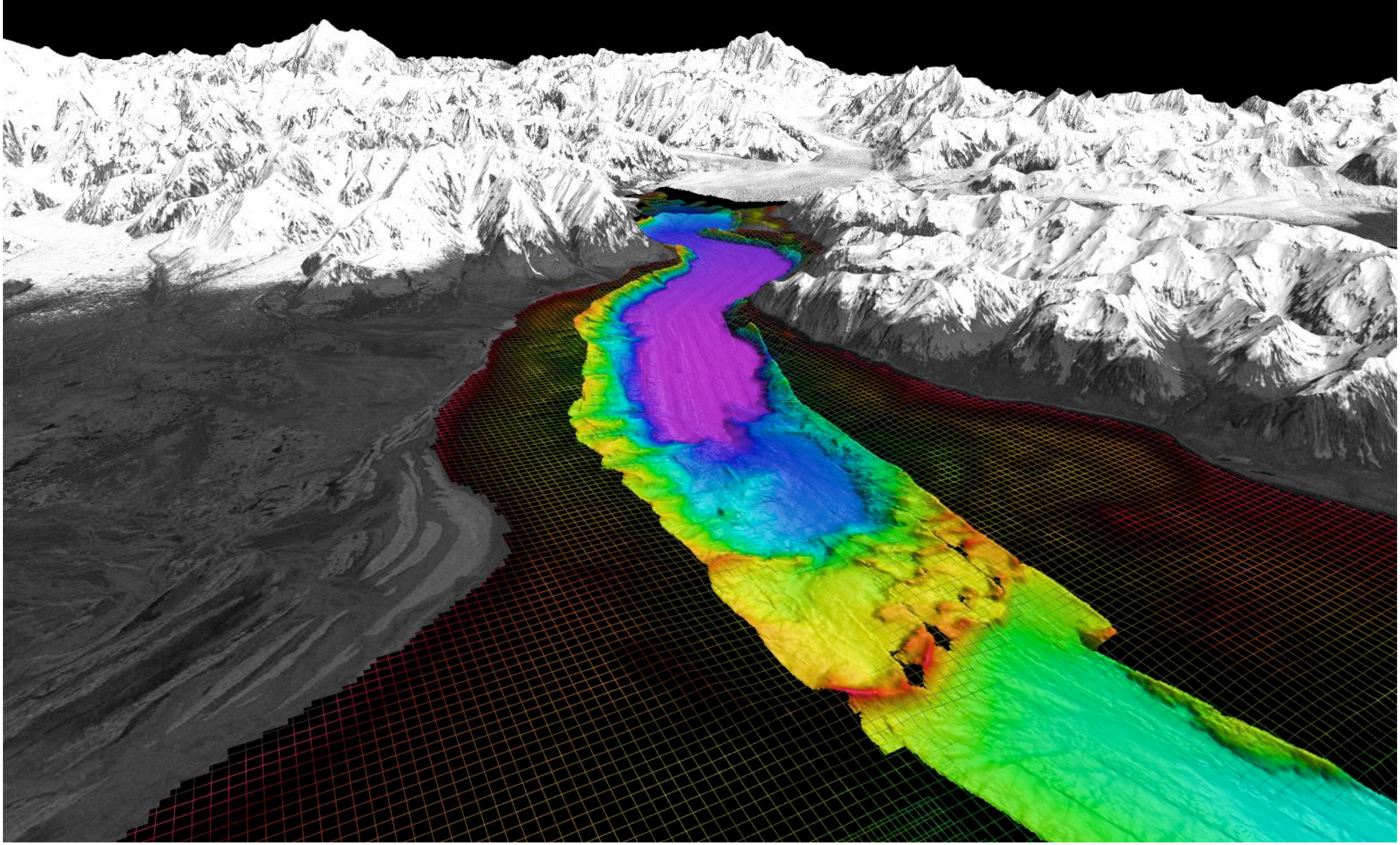
TOTAL VOLUME CHANGE $= (2.9 \times 10^7) + (5.2 \times 10^7) - (4.7 \times 10^7)$
$= 3.4 \times 10^7$

Hunter et al. 1996

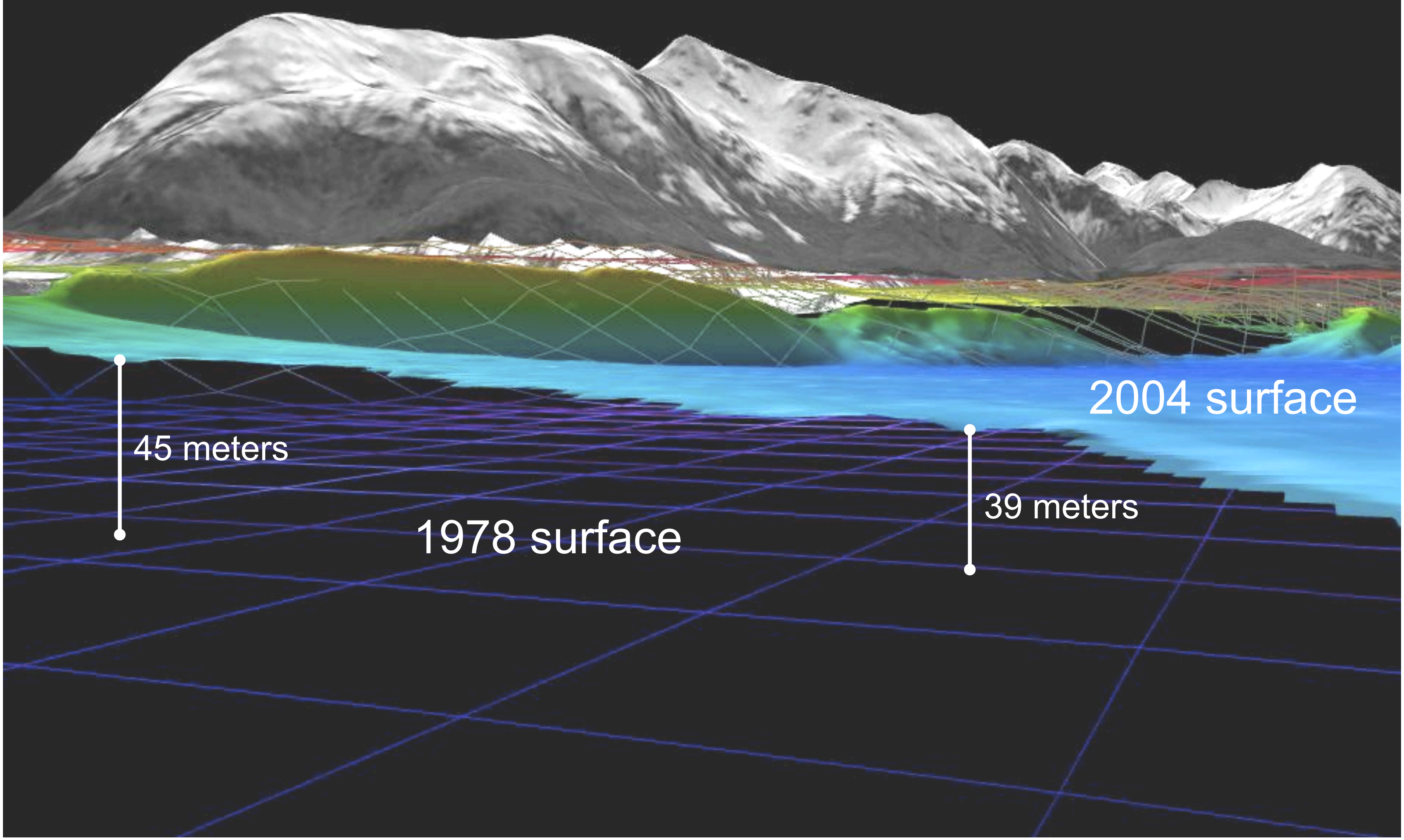
Hubbard Glacier, Yakutat Bay, AK

net advance 1978-2008

differential bathymetry checked by seismic reflection



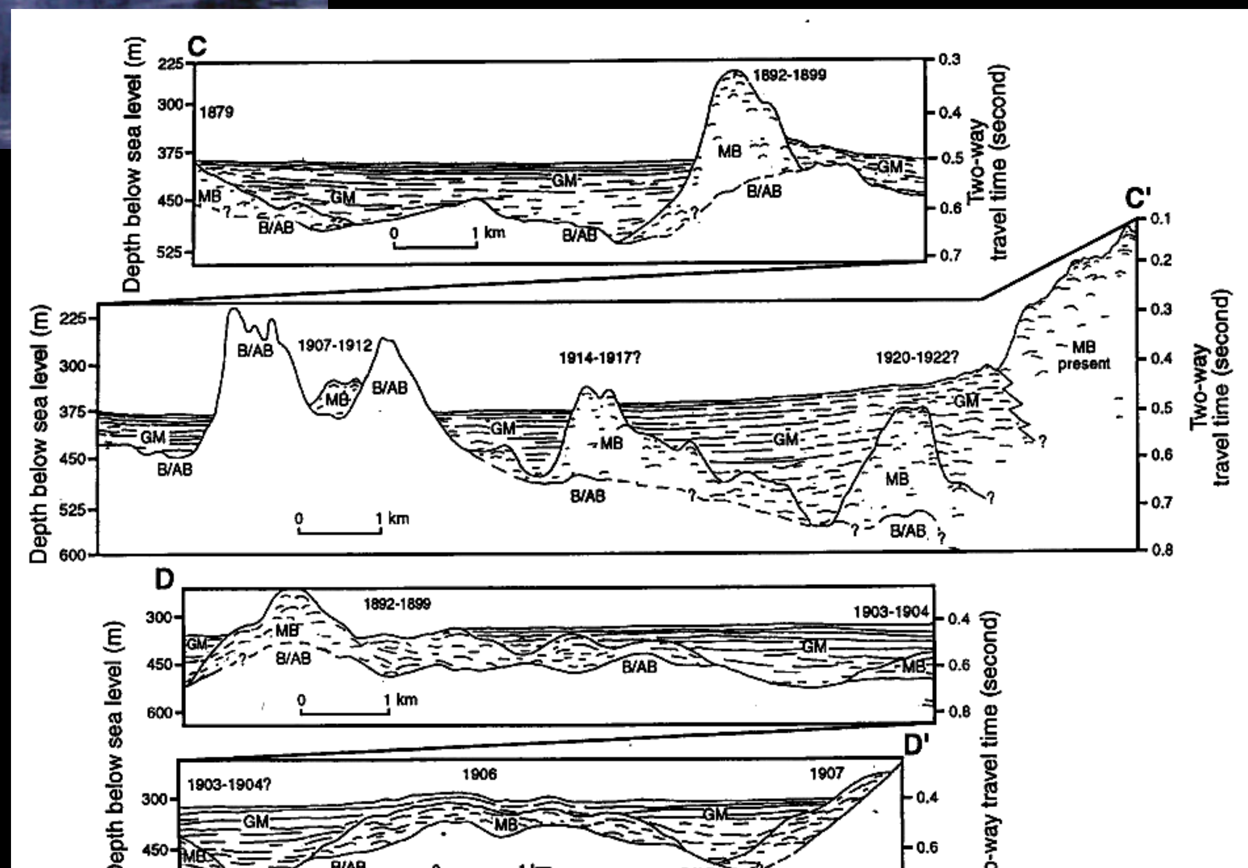
Sediment Flux Measurements



Sediment accumulation rates:

longer-term from seismic reflection data

Johns Hopkins Glacier and Inlet, Alaska

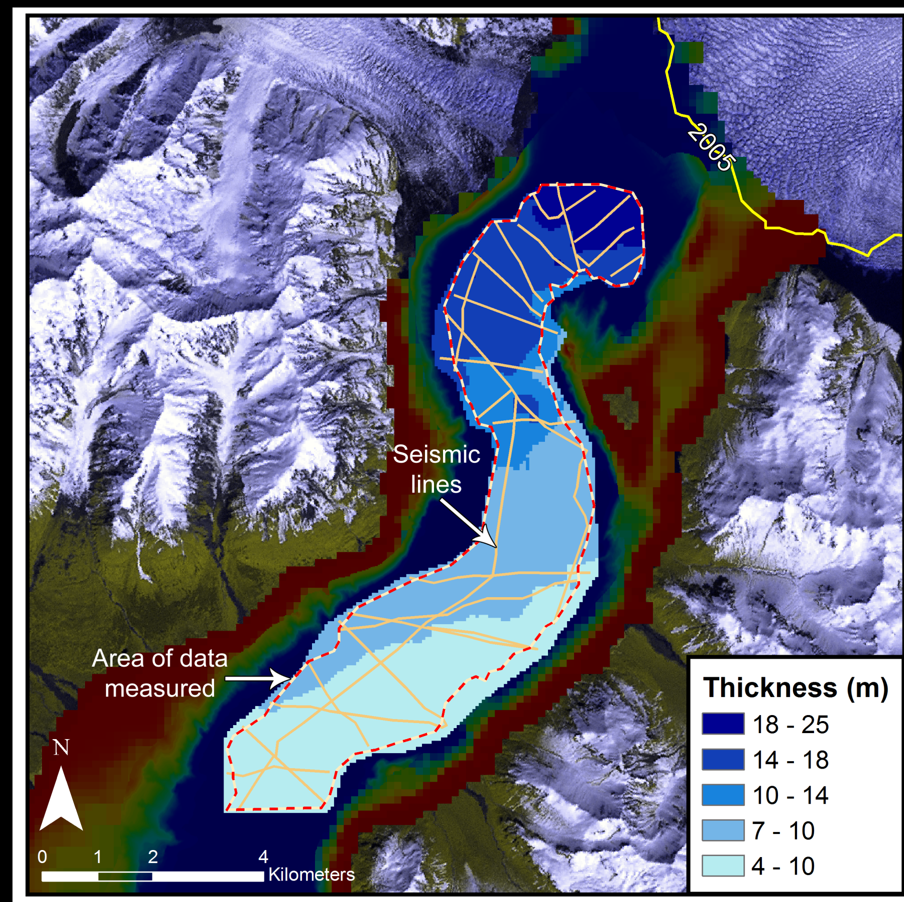


Cai et al. 1997

Methods check: seismic accumulation record

	Seismic Data	Bathymetric Data
Volume Measured (m^3)	$2.69x10^8$	$4.66x10^8$

17% difference – error in methodology

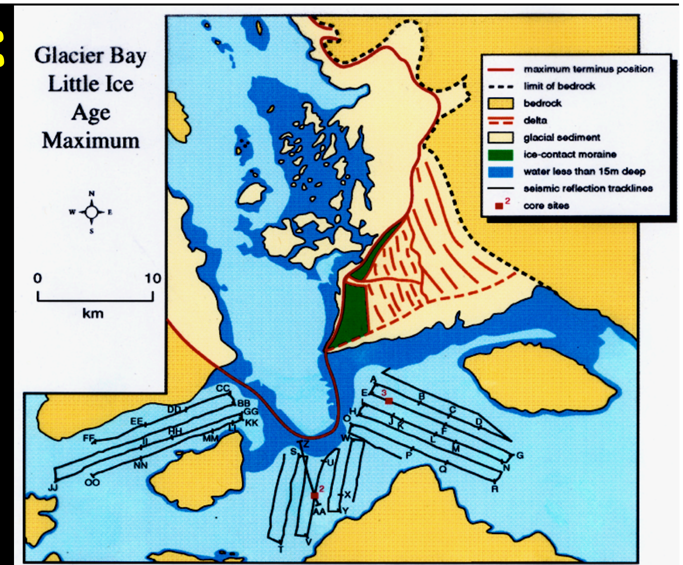


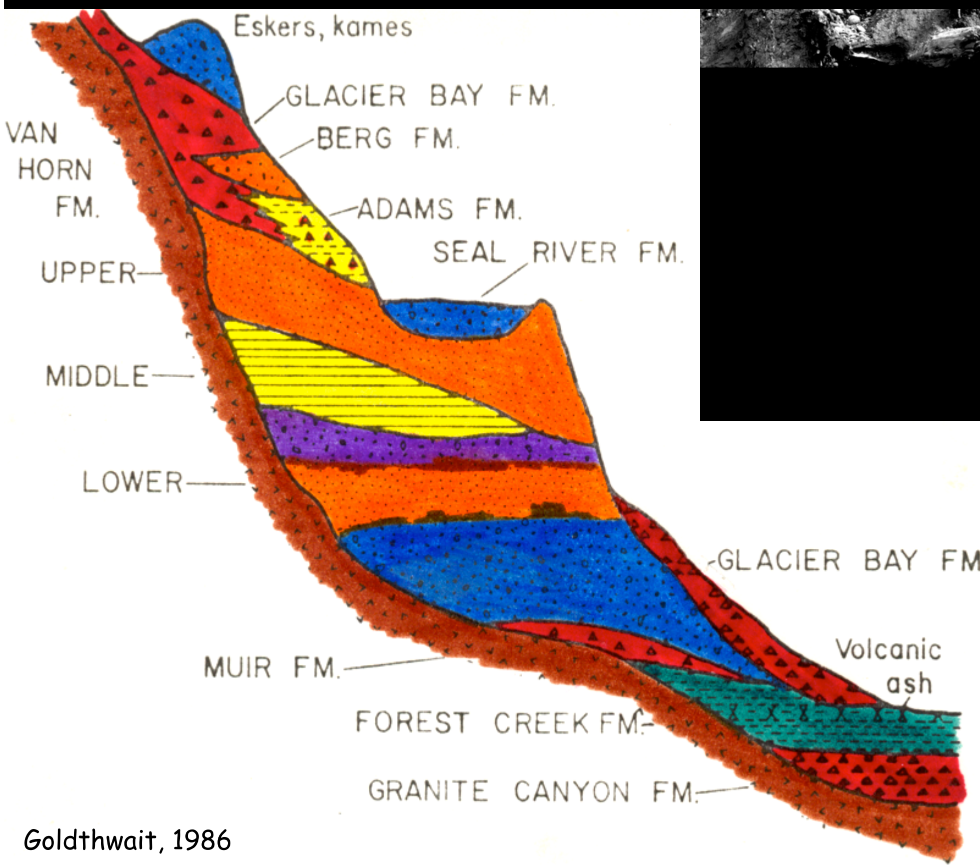
Trusel et al. 2009

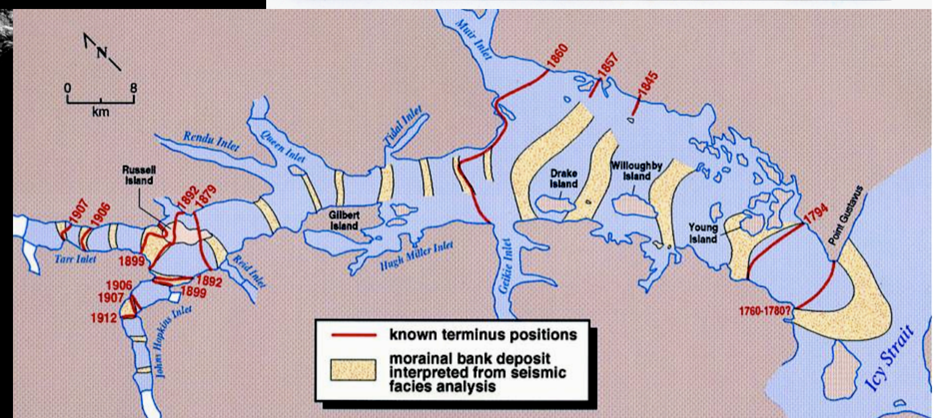
Longer-term from glacial history:

Glacier Bay "Little Ice Age" advance to entrance

Sediment flux from estimated volume removed ~ Seismic reflection estimate of what was deposited at entrance



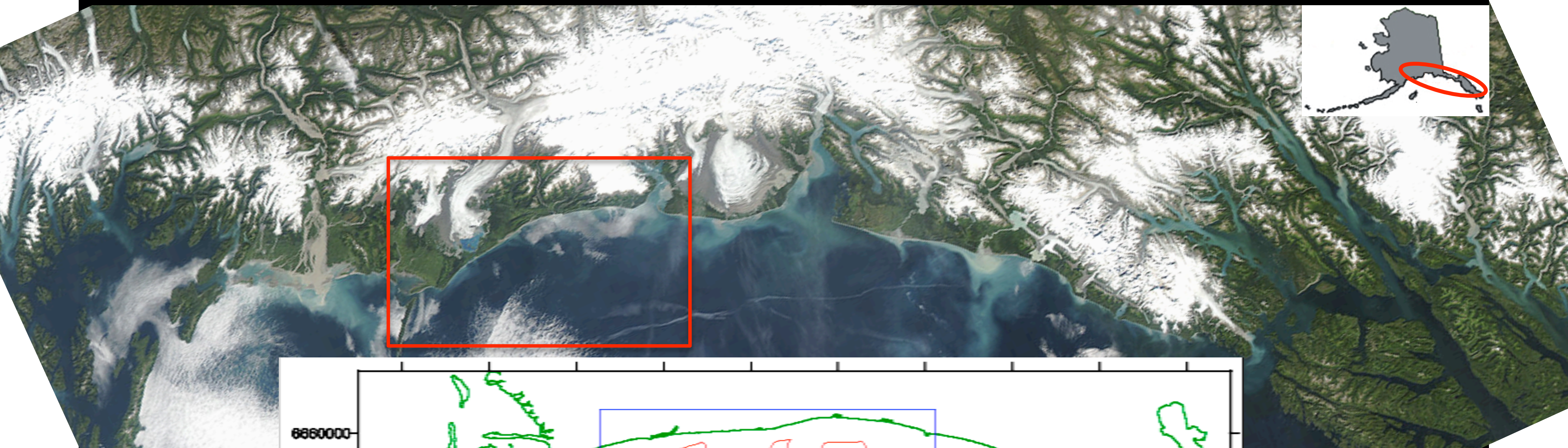


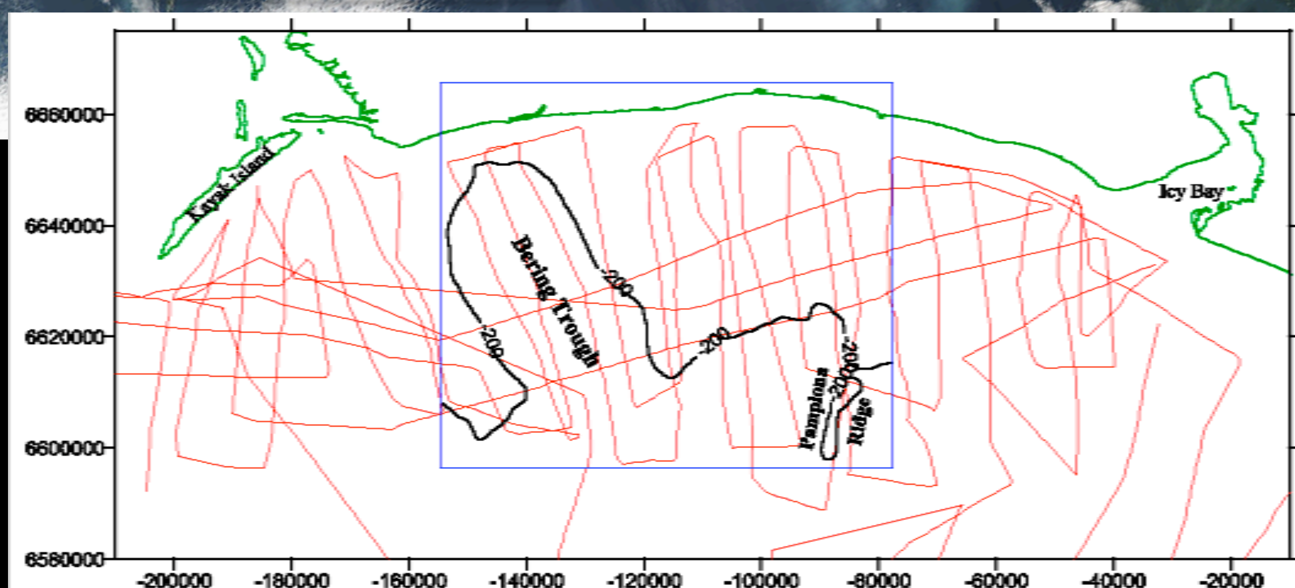


Goldthwait, 1986

Sediment accumulation rates from seismic reflection records over a glacial cycle

Bering Glacier, southern Alaskan continental shelf

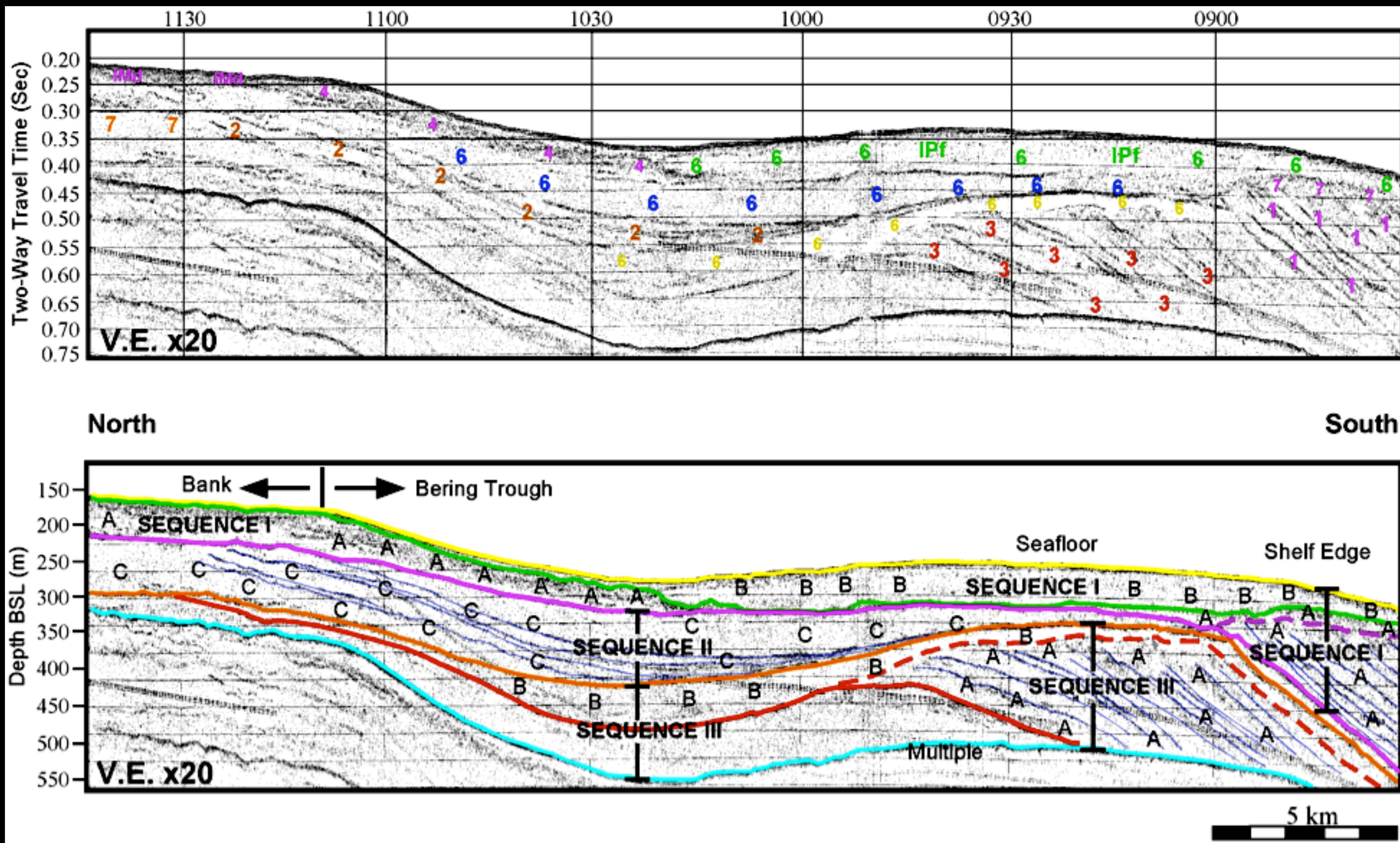




Source: NASA MODIS
Aug. 9, 2003

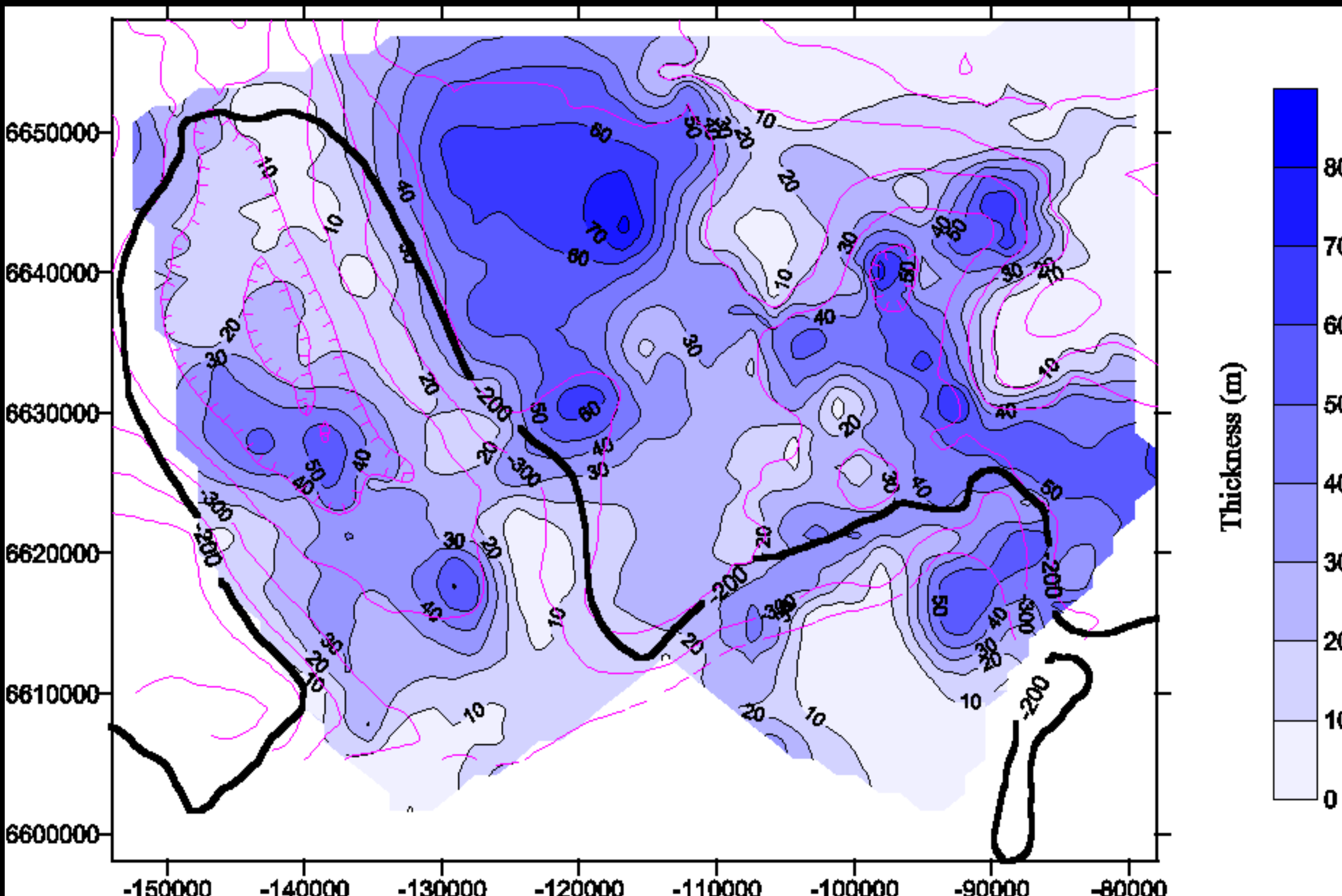
ALASKAN SHELF - BERING TROUGH

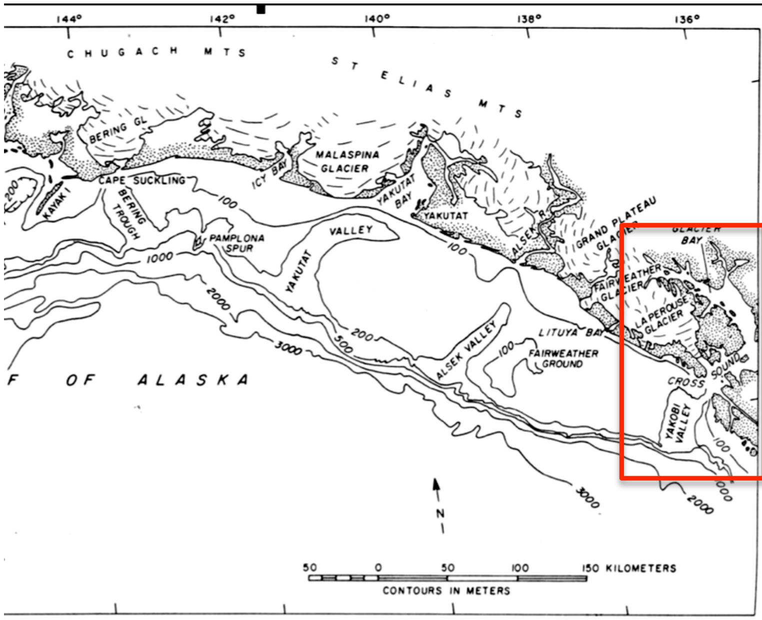
LINE 19 – Bank to Bering Trough (dip line)

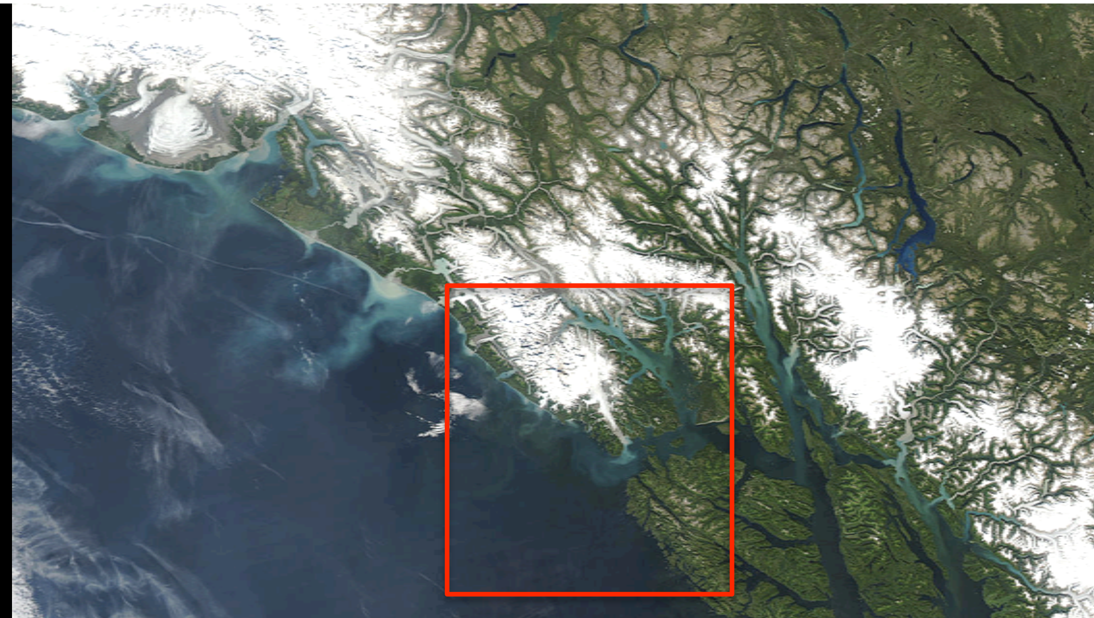


Powell & Cooper 2001

Isopach of ice contact and ice marginal retreat assemblage set on the basal erosion surface of Glacimarine Sequence I

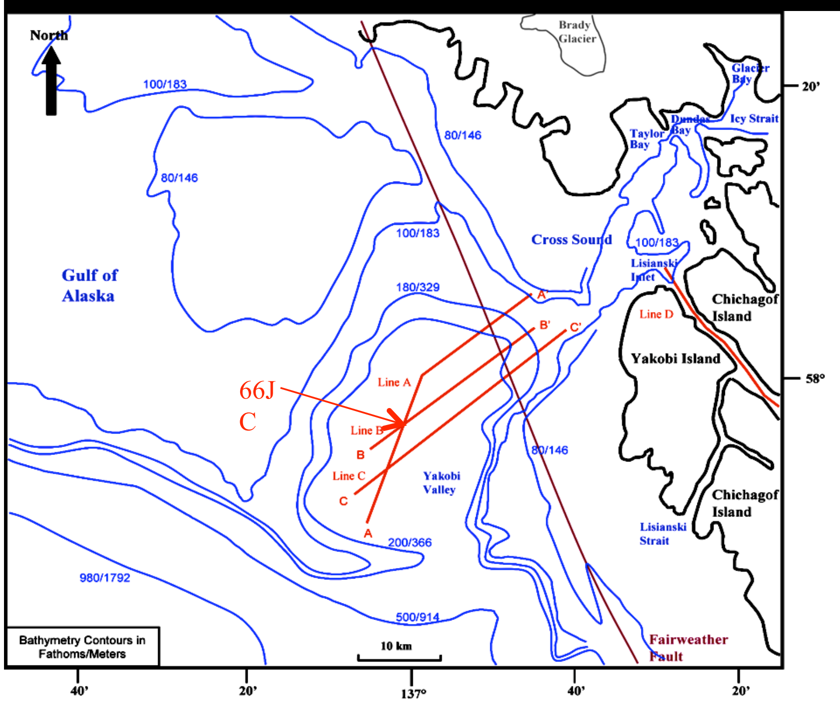






Carlson et al. 1979

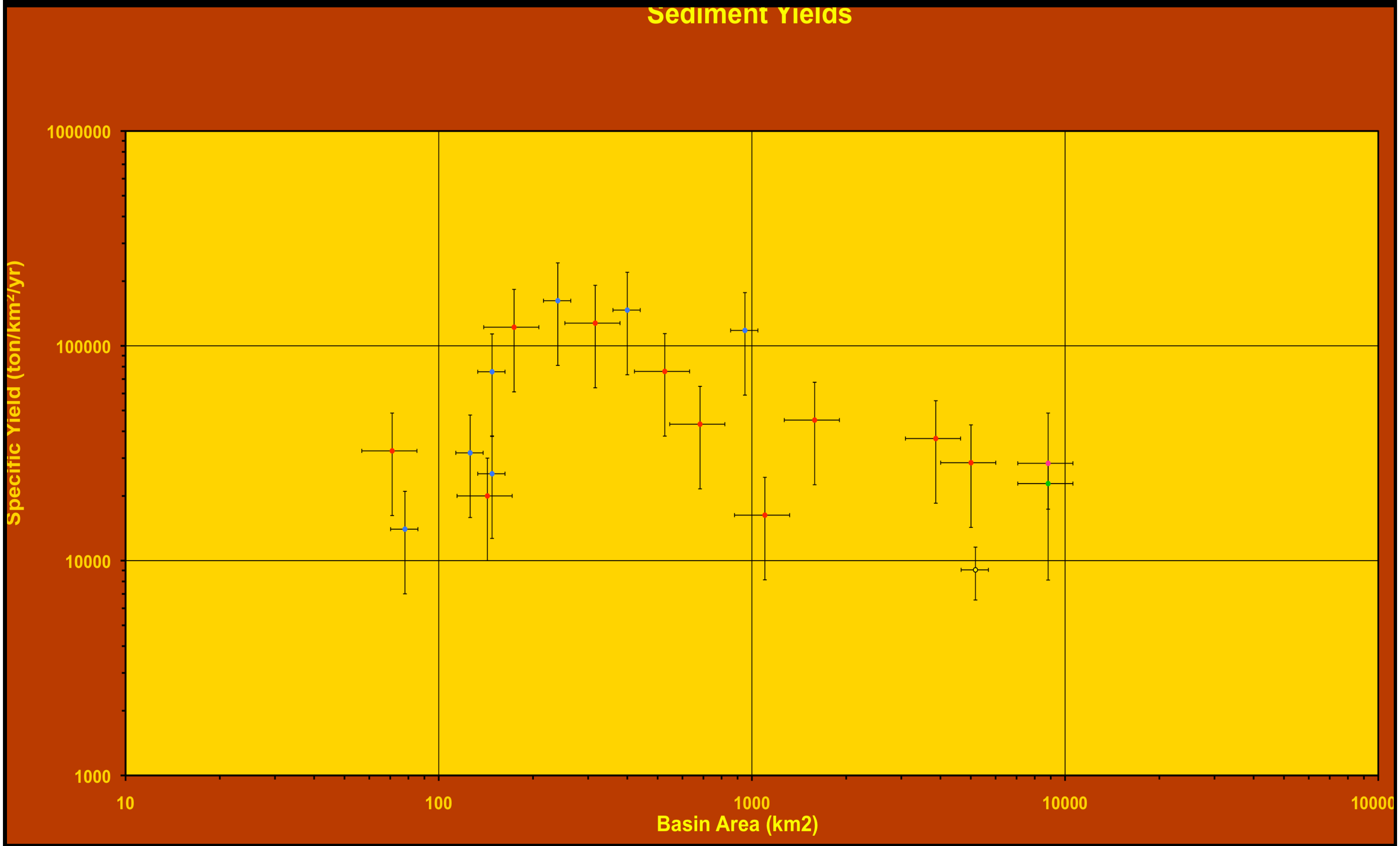
Yakobi Sea Valley at Cross Sound



All Yakobi Sea Valley sediment deposited by Cordilleran Ice Sheet took about 1ky

~ time between retreat from outer shelf and retreat from sea valley is also about 1ky

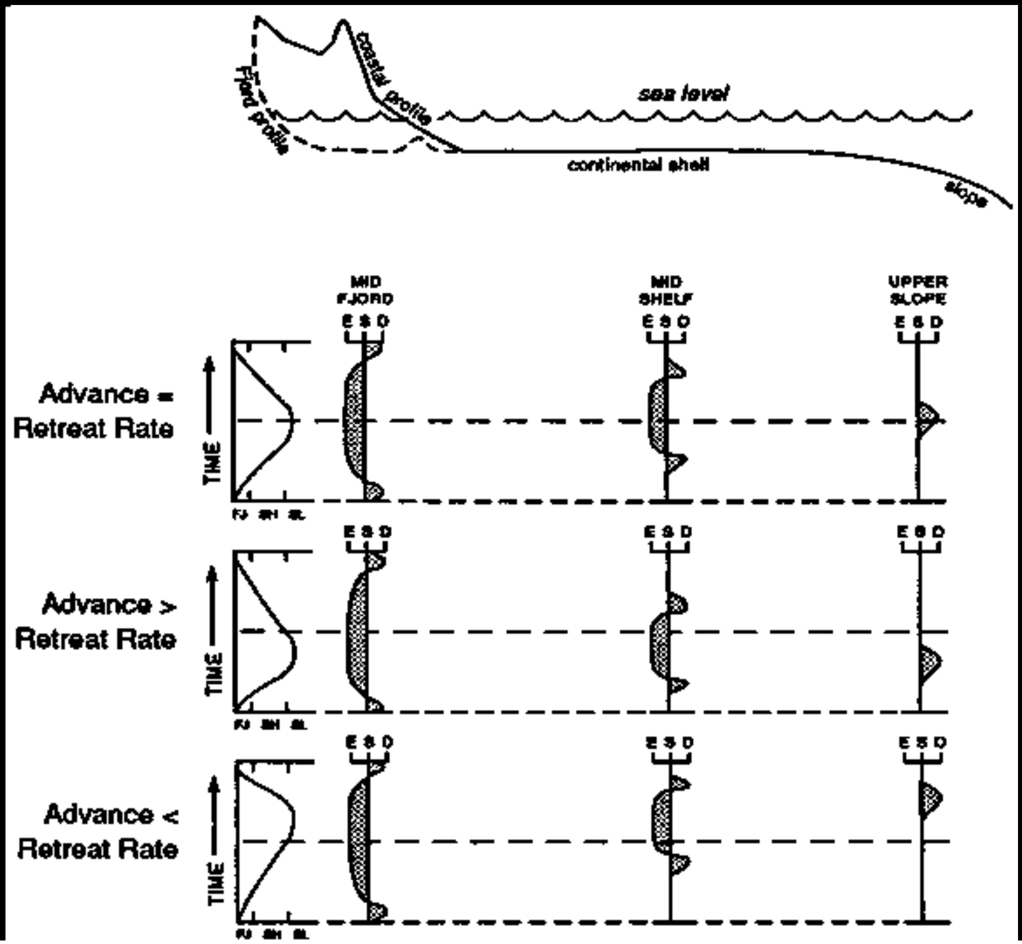
Ewing research cruise 2004



Sediment Yields
1000000
100000
10000
1000
Specific Yield (ton/km²/yr)
10
100
1000
10000
Basin Area (km2)

Erosions & Sediment depocenters move through time

Glacial Stage	Locus of Erosion	Bed Material Eroded	Depocenter
minimum	mountains	bedrock	land, fjord
early advance	fjords	sediment – bedrock	fjord, shelf
late advance	shelf	sediment	outer shelf, slope
maximum	shelf	sediment	slope, rise
early retreat	shelf	sediment	outer shelf, slope
late retreat	fjords	bedrock	shelf, fjord
minimum	mountains	bedrock	fjord, land



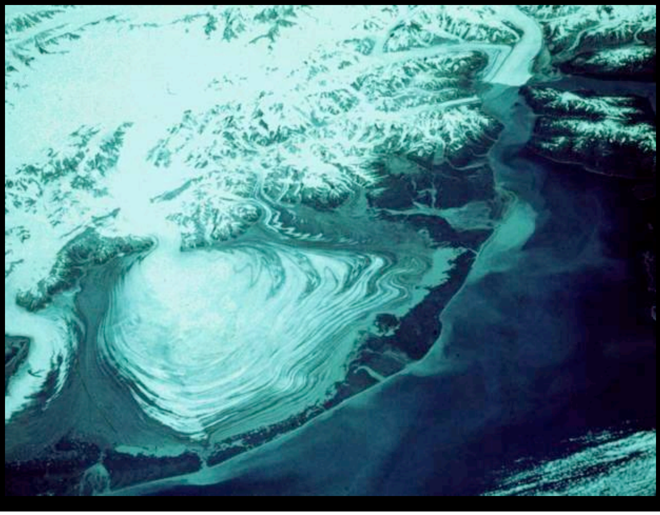
Powell, 1991

Temperate Glacier Sediment Yields and Erosion Rates

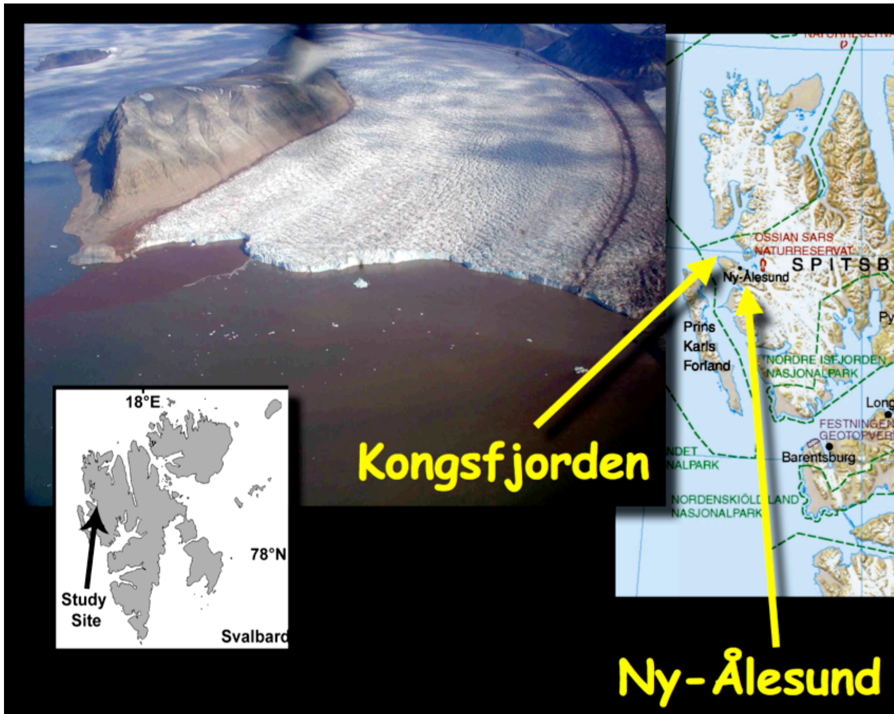
Erosion rates are:
- similar on different time-scales (days to millennia)
- similar whether advancing or retreating

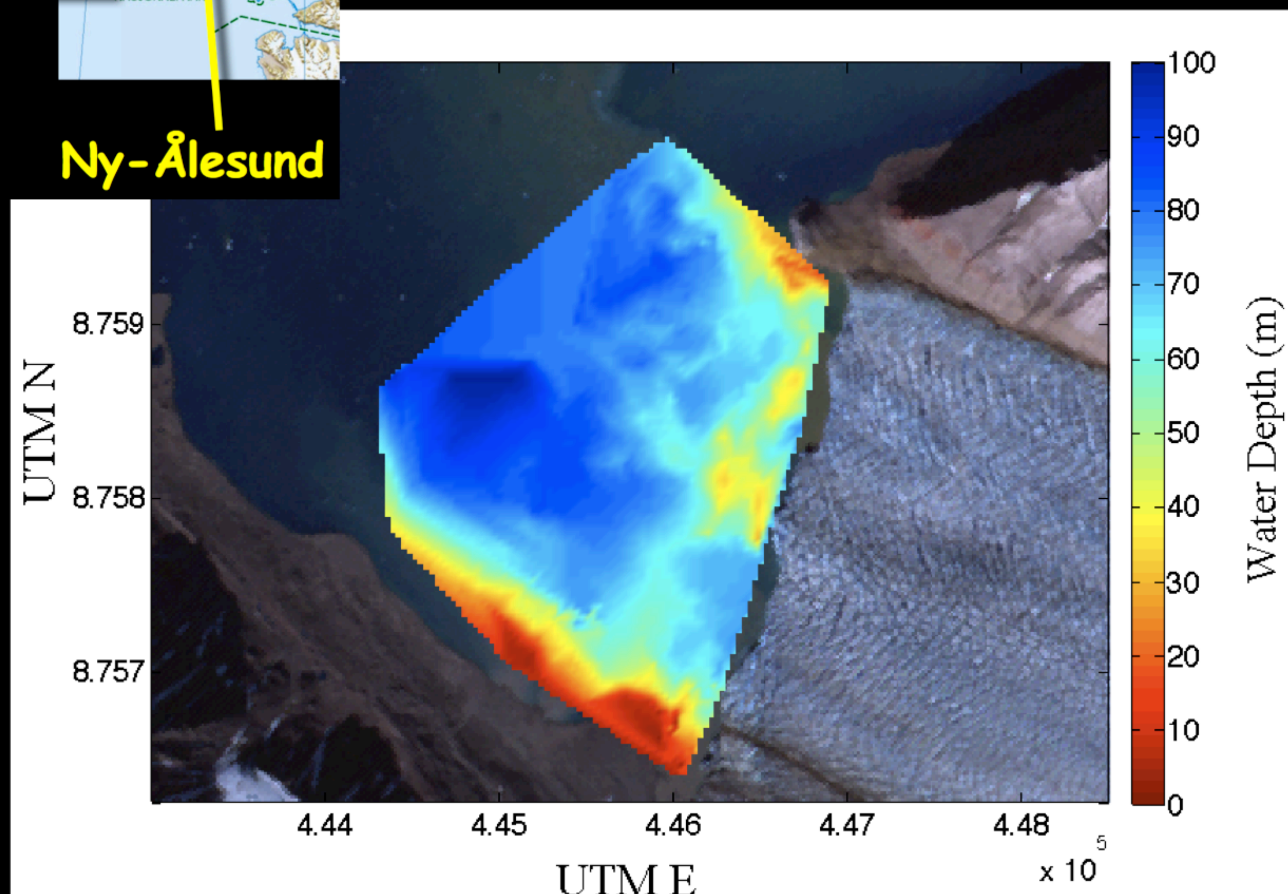
Loci of erosion and deposition move through time

Need to be careful to remember:
- subglacial erosion can involve sediment recycling rather than solely "new" bedrock erosion

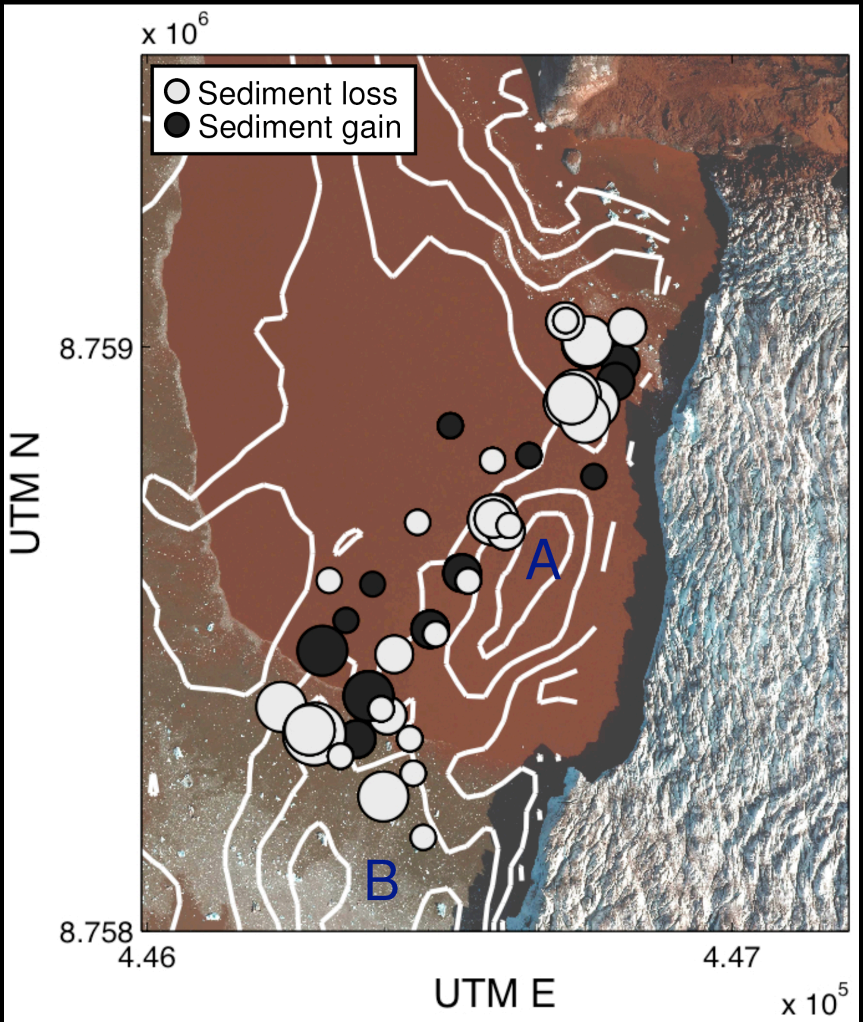


Intermediate polythermal (subpolar) system of Svalbard





Kehrl et al. submitted

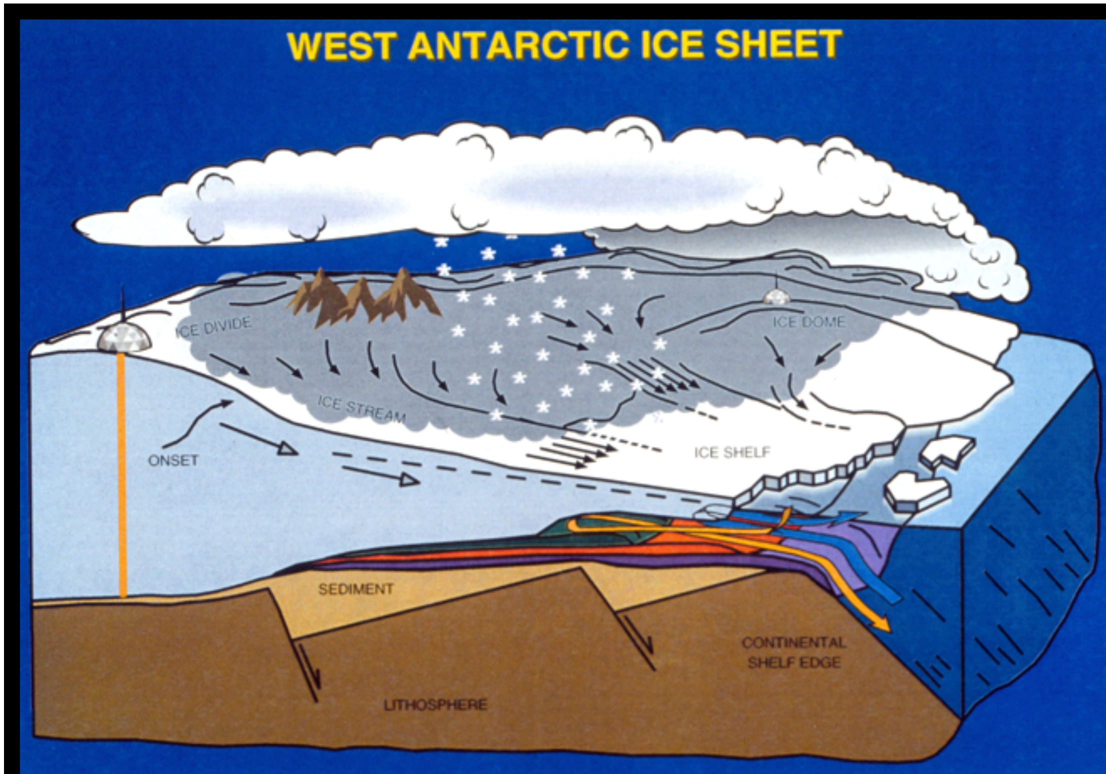


Minimum grounding-line fan sediment:
6.7×10^3 $g \cdot m^{-2} \cdot d^{-1}$ (>300 $mm \cdot a^{-1}$)

Avg sediment flux to ice-contact basin:
2.6×10^3 $g \cdot m^{-2} \cdot d^{-1}$ or
1.6×10^5 $g \cdot m^{-2} \cdot a^{-1}$

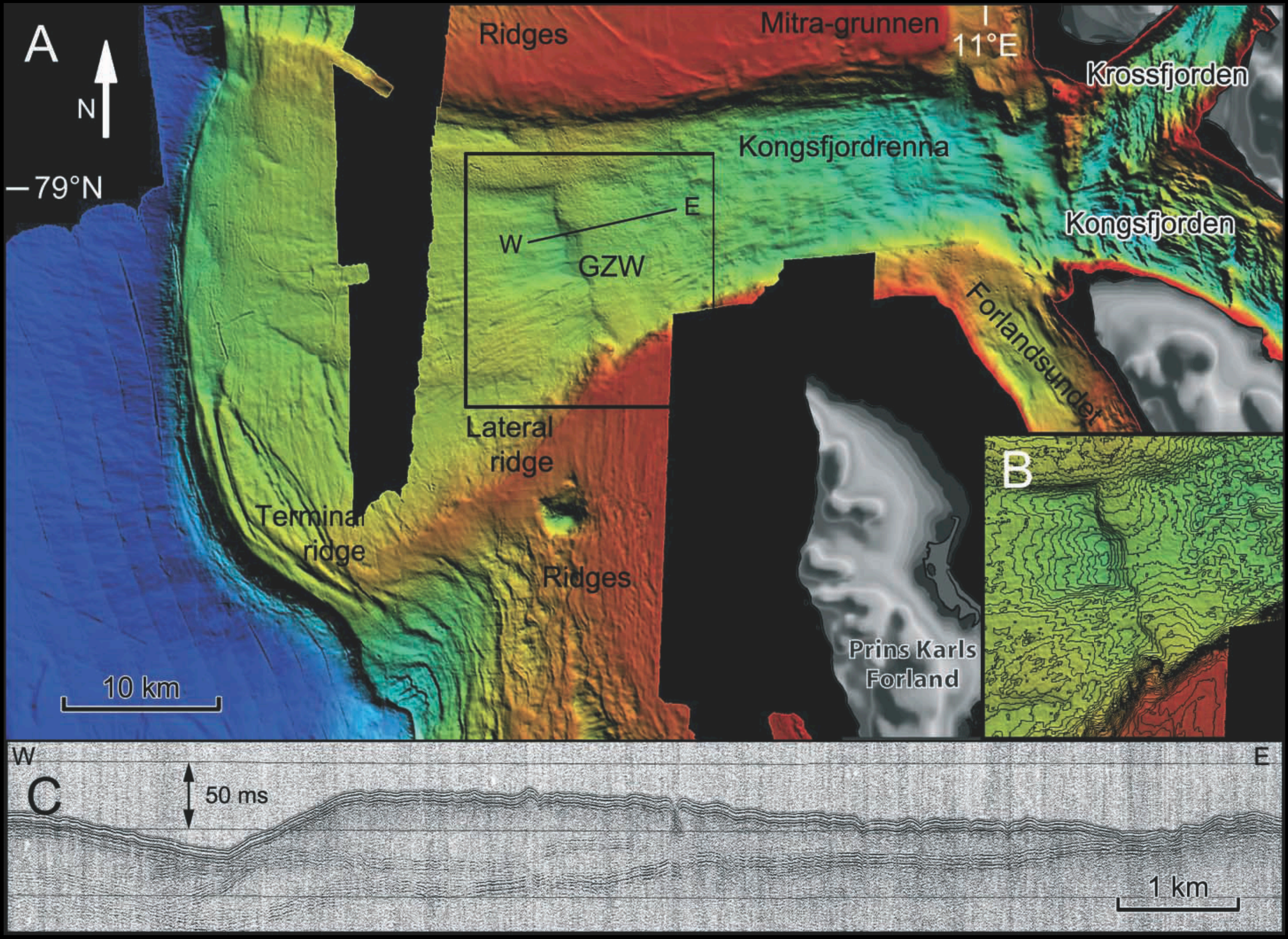
Avg ice-contact sediment yield:
1.2×10^4 $t \cdot km^{-2} \cdot a^{-1}$

Trusel et al. 2010
Kerhl et al. submitted



Polar Ice Sheets and Ice Shelves

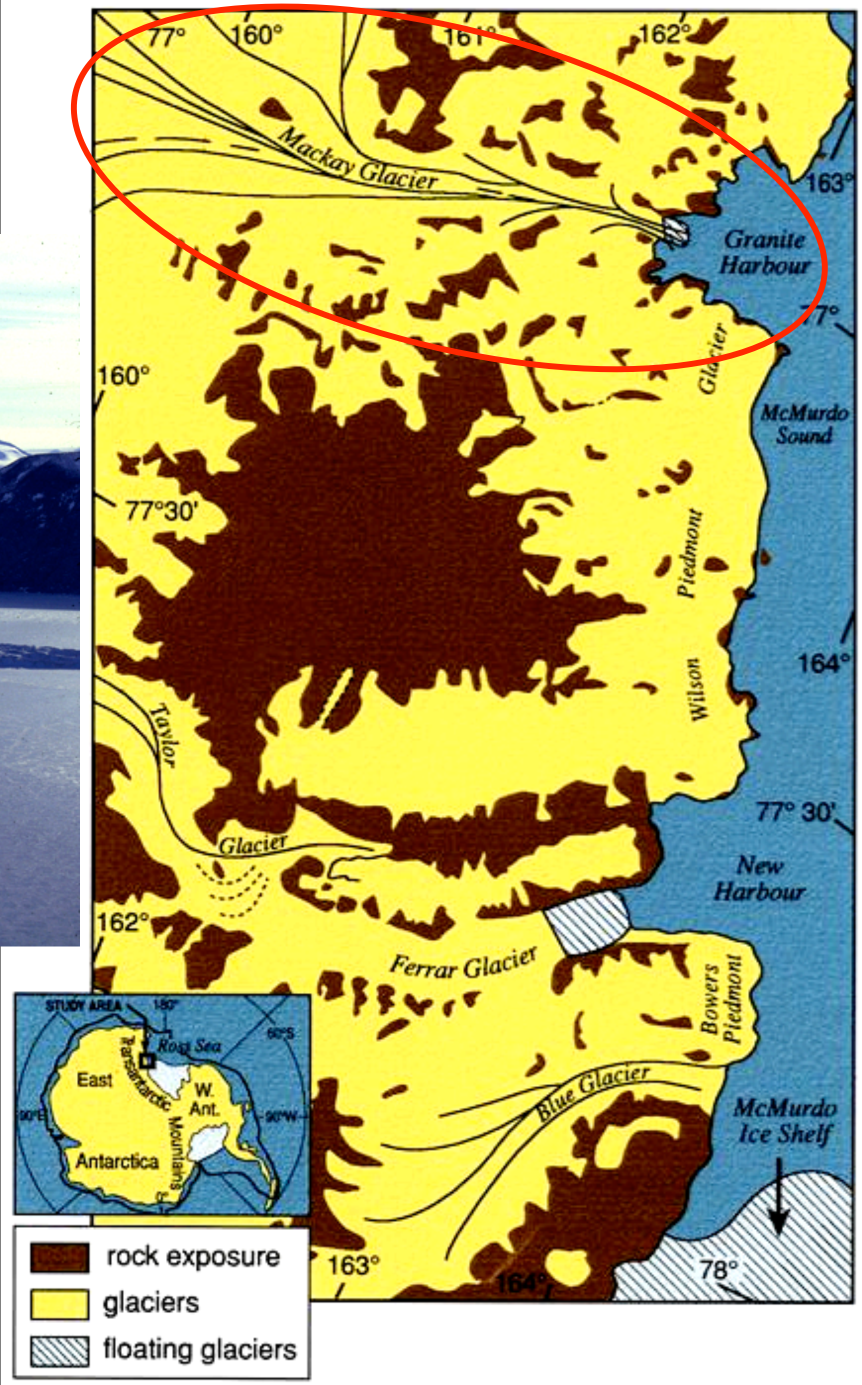
Grounding-zone wedge, Svalbard



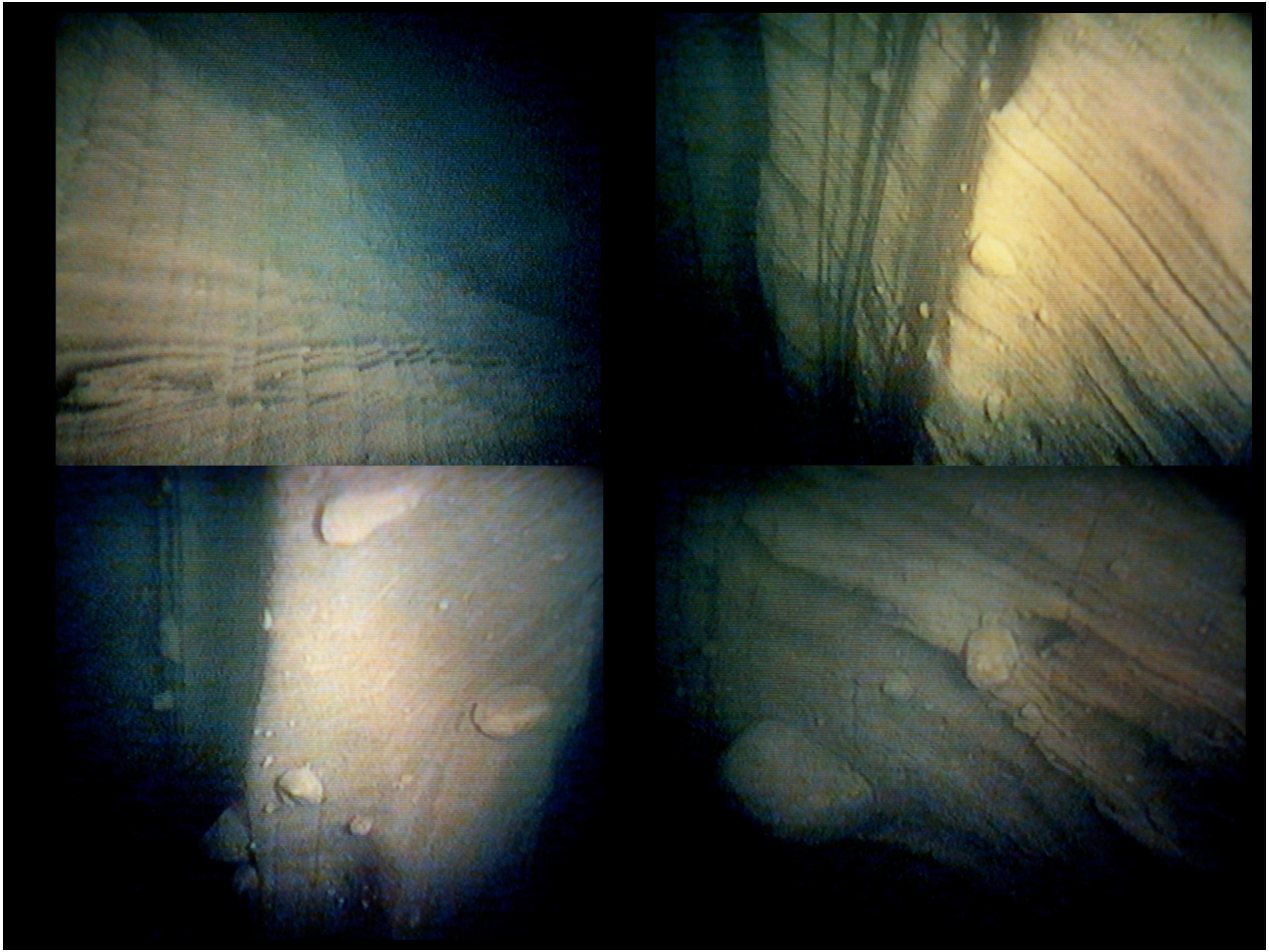
Otteson et al., 2006

Sediment yields are poorly constrained

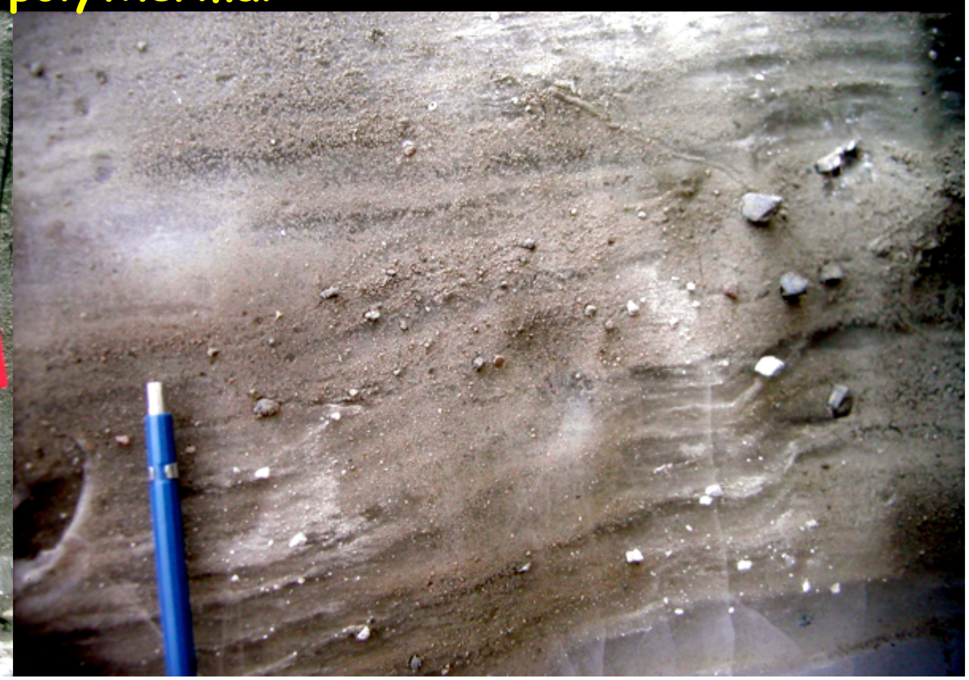
Mackay Glacier
SW Ross Sea, Antarctica



Powell et al., 1996; Powell 2006

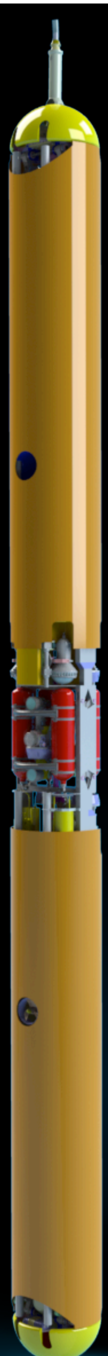


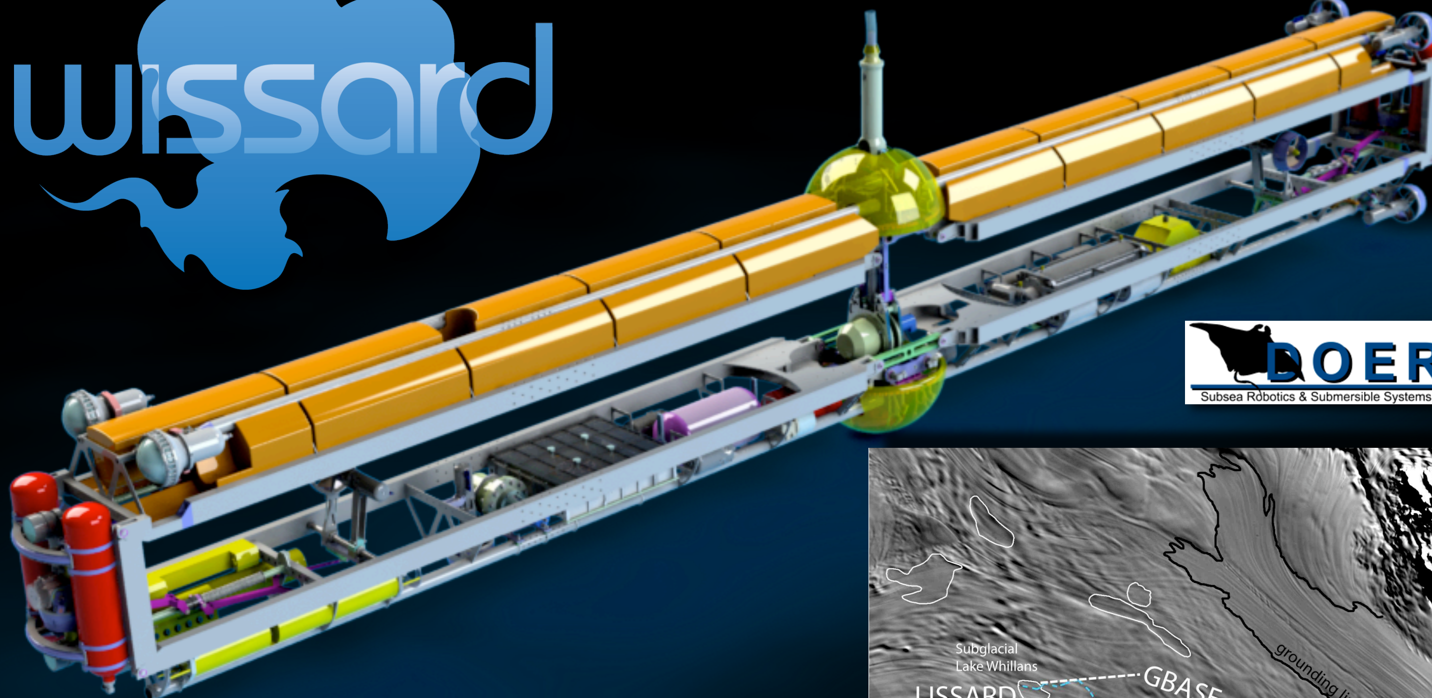

Sediment yield and erosion rates 1 to 2 orders of magnitude less than polythermal

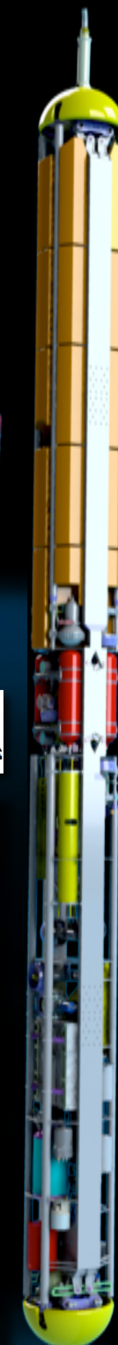



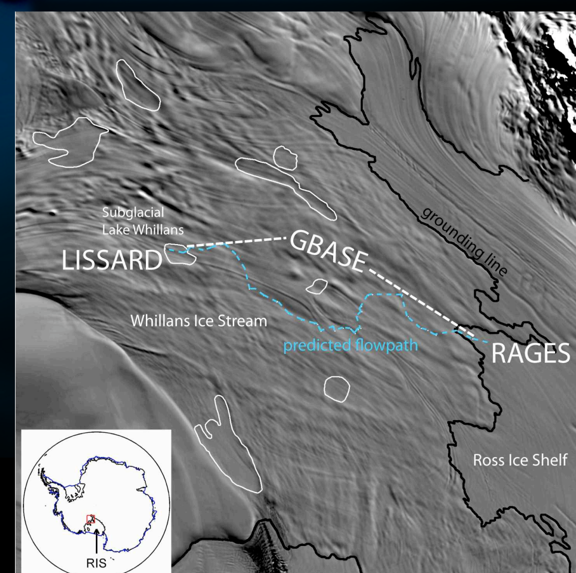
SIR, the Sub-Ice ROVer
Remotely Operated Vehicle

a robotically operated submarine

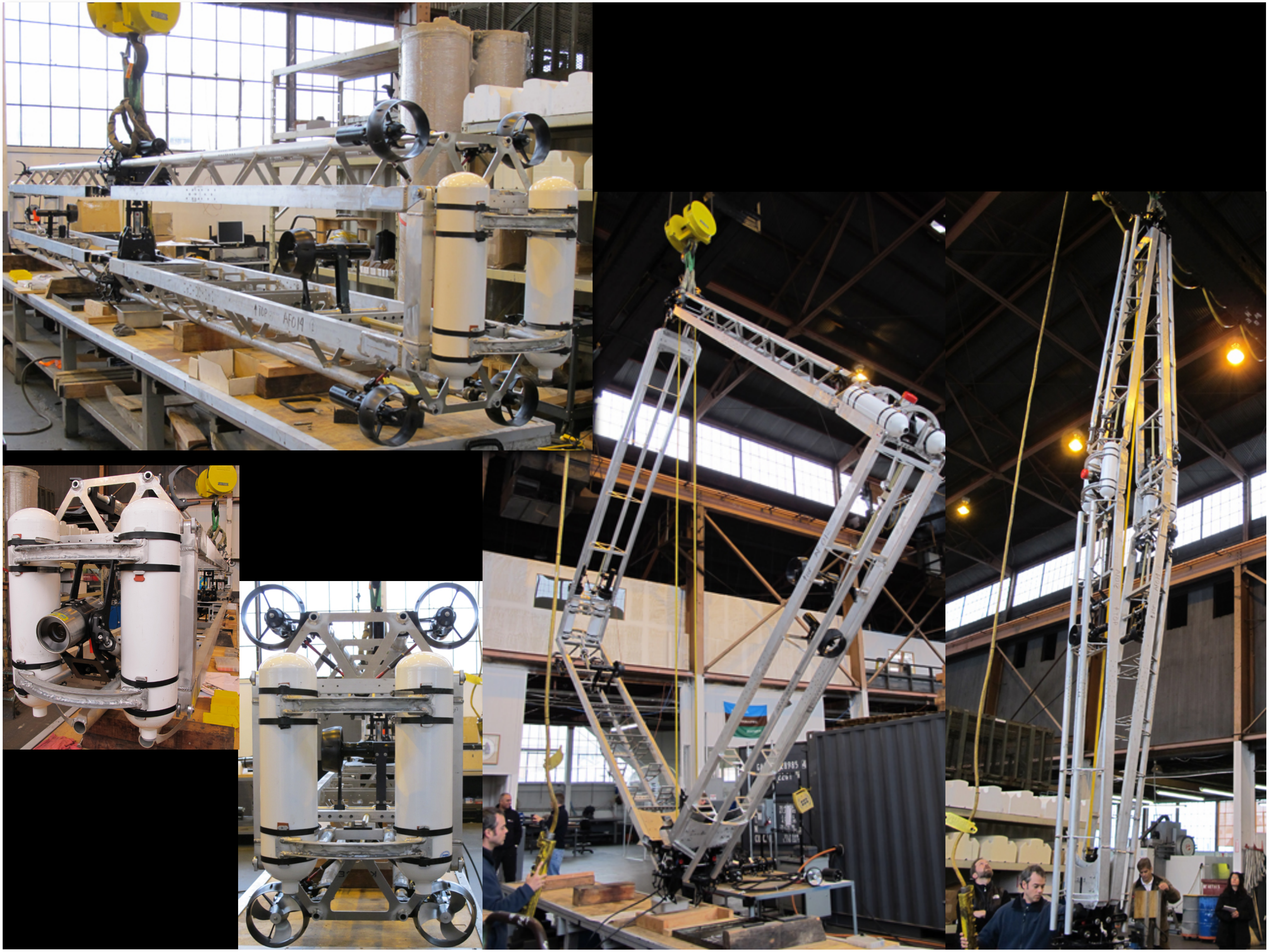








Subsea Robotics & Submersible Systems



Deeper time -
Help from modern analogs to link to paleoclimatic change

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Ross Powell, Tim Naish, David Harwood, Fabio Florindo,
Rich Levy and the MIS and SMS Projects' Science Teams

Antarctica New Zealand

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PROGRAMMA NAZIONALE DI RICERCHE IN ANTARTIDE

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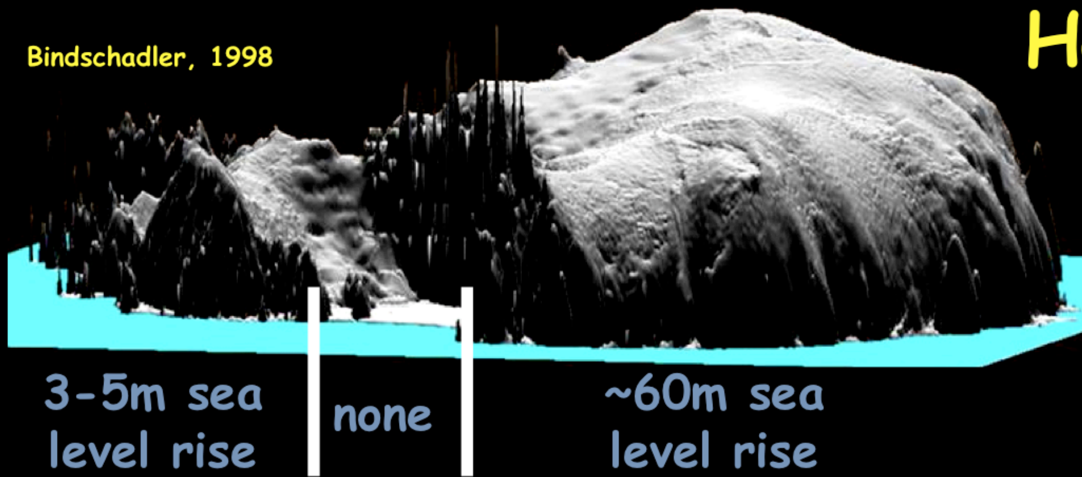
UNITED STATES ANTARCTIC PROGRAM

NATIONAL SCIENCE FOUNDATION

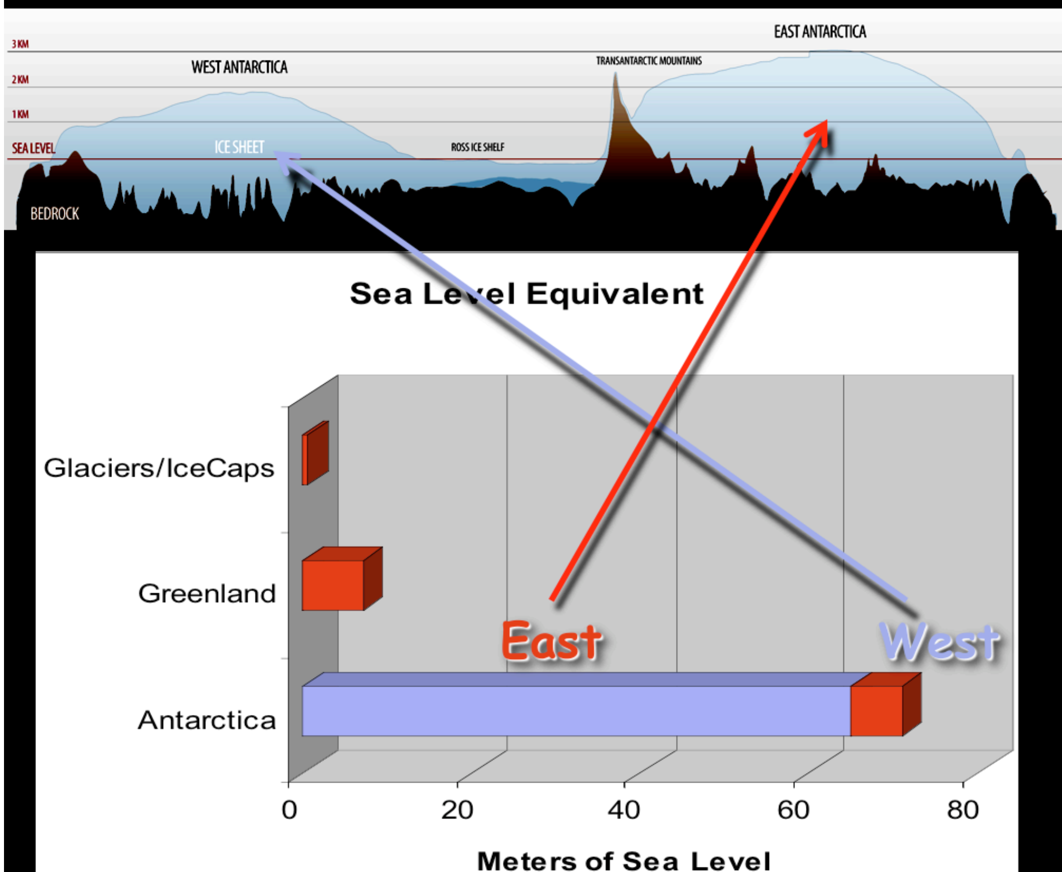
INTERNATIONAL POLAR YEAR 2007-2008

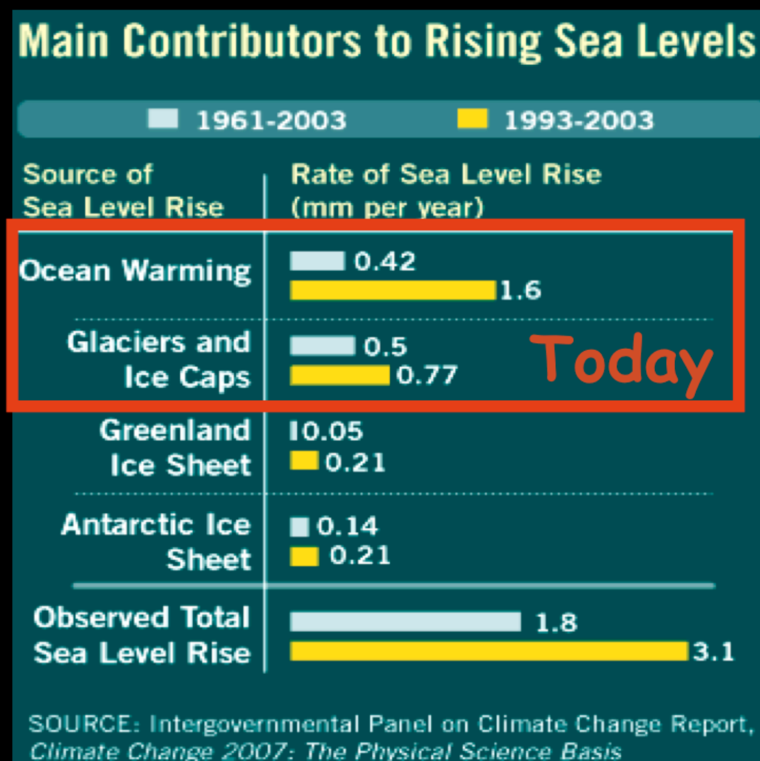
How much water is in ice sheets?

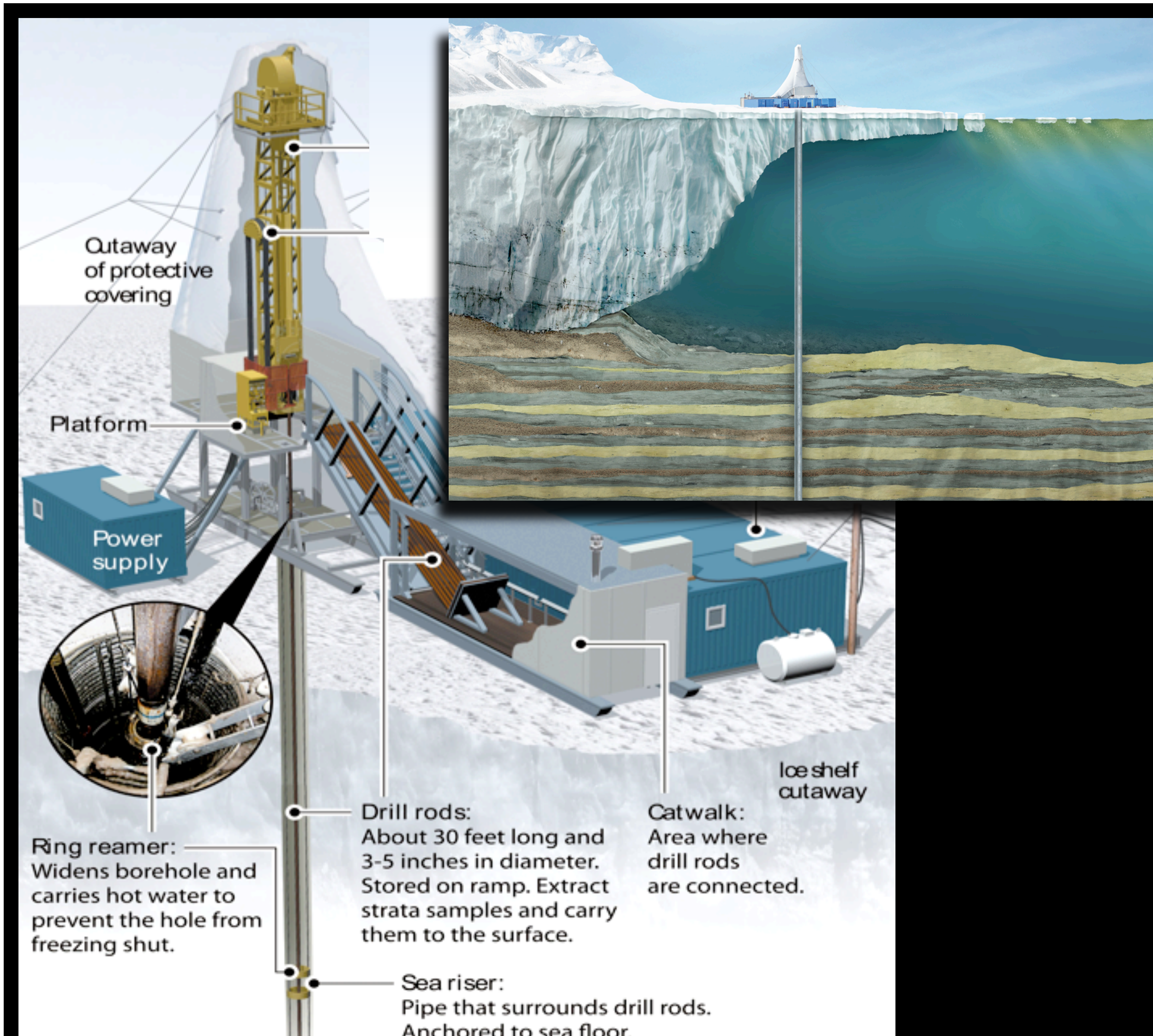


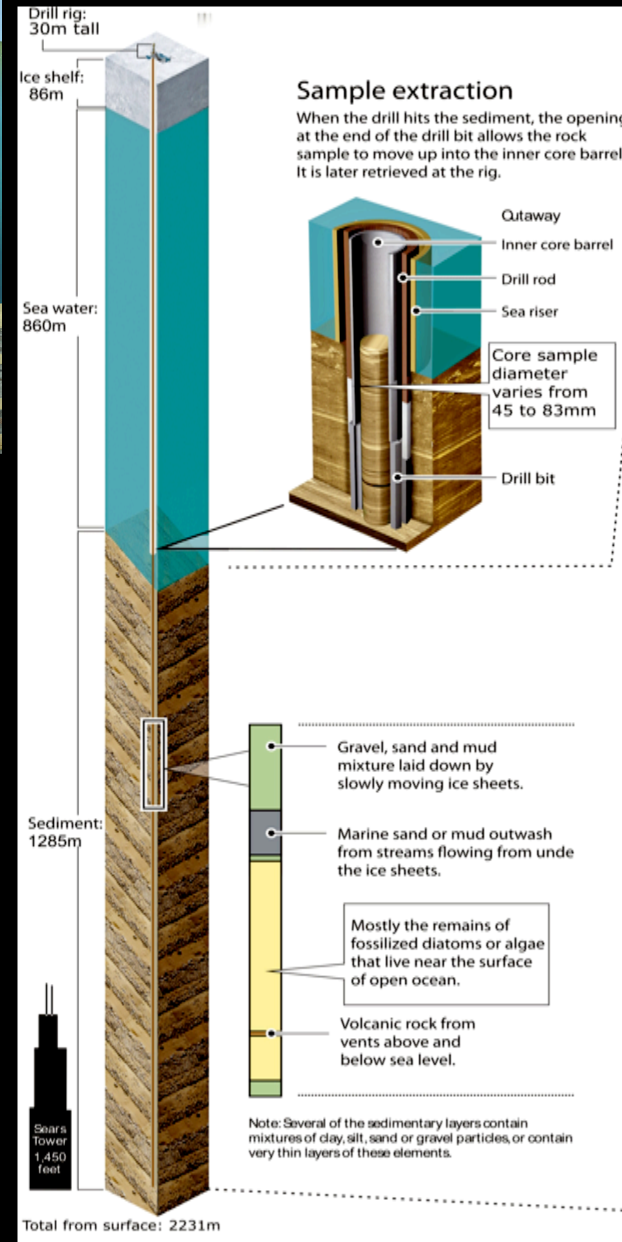
2-6% of all water on Earth

70-80% of all fresh water on Earth









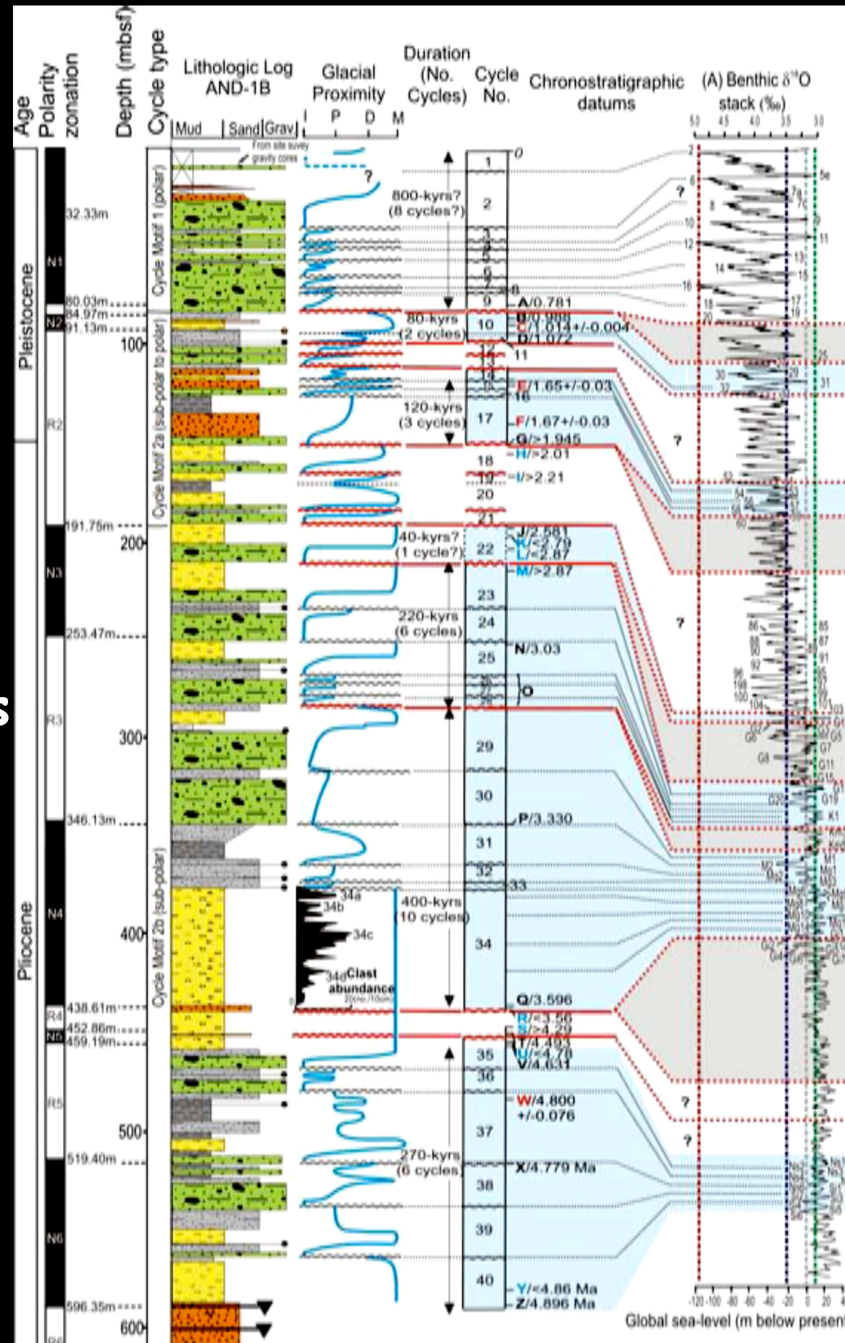
Chicago Tribune

Drilling for ice sheet history on a nearshore marine shelf to:

- **reveal the pace and magnitude of changes,**
- **test climate sensitivity through data and numerical modeling integration**

Summary AND-1B

Link Antarctic Ice Sheet fluctuations to global proxy records of ocean temperature and ice volume



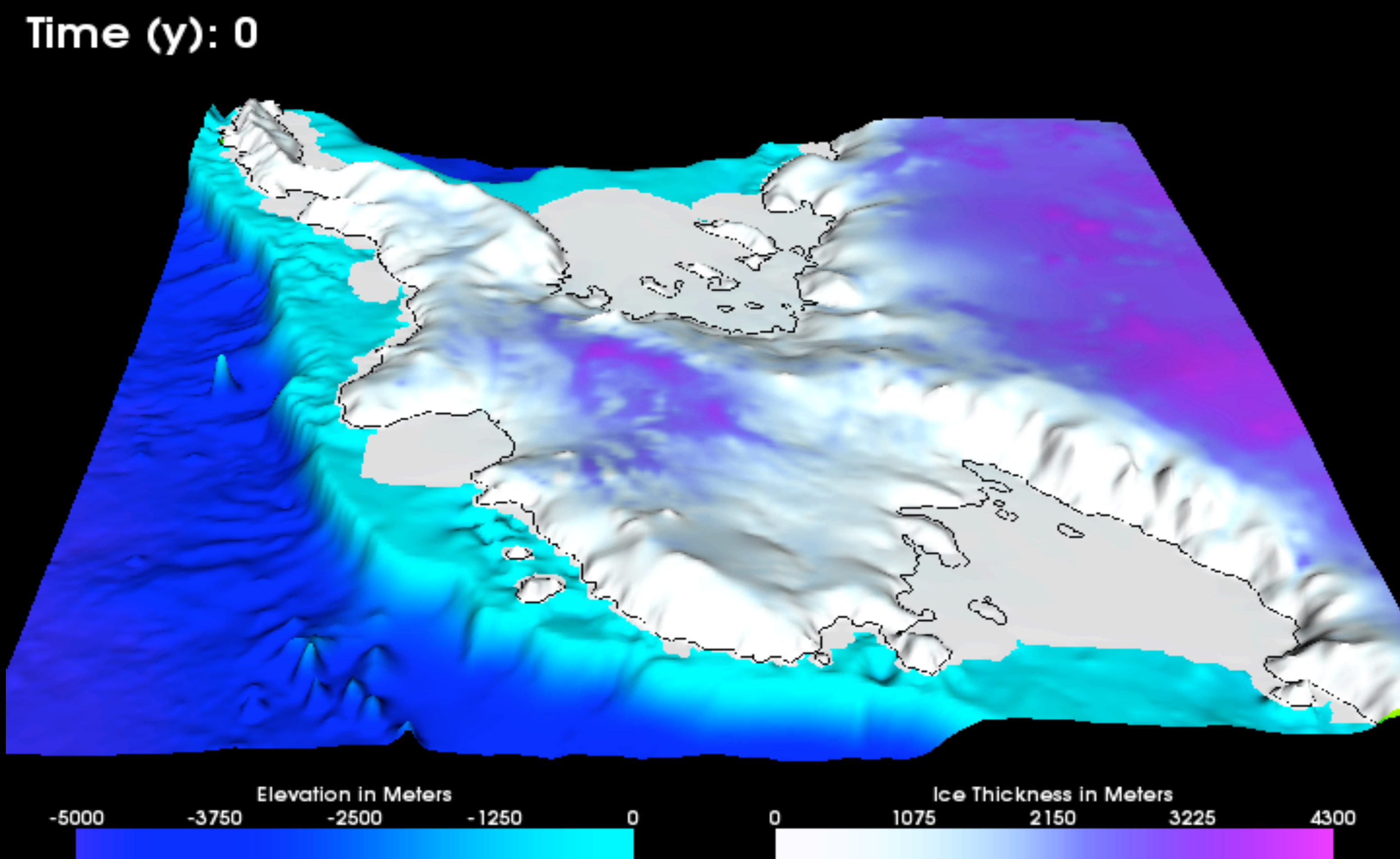
Diatoms absent or rare

Summer sea-ice diatom assemblage

Ice-free oceanic diatom assemblage

Naish et al. 2009

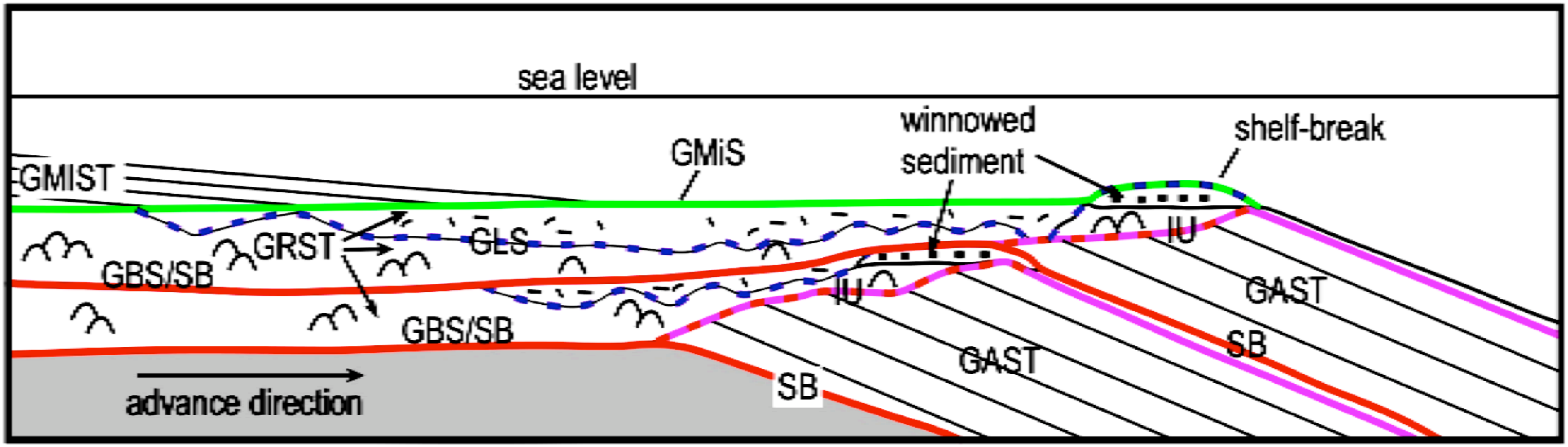
Ice sheet modeling driven by GCM and constrained by geological data



Pollard & DeConto 2009

Now need integrated subglacial sediment flux models

Glacial Sequence Stratigraphy



Temperate regime - offshore

GMiST – glacial minimum ST

GAST – glacial advance ST

GRST – glacial retreat ST

GBS – glacial basal surface

GMiS – glacial minimum surface

GLS – grounding line surface

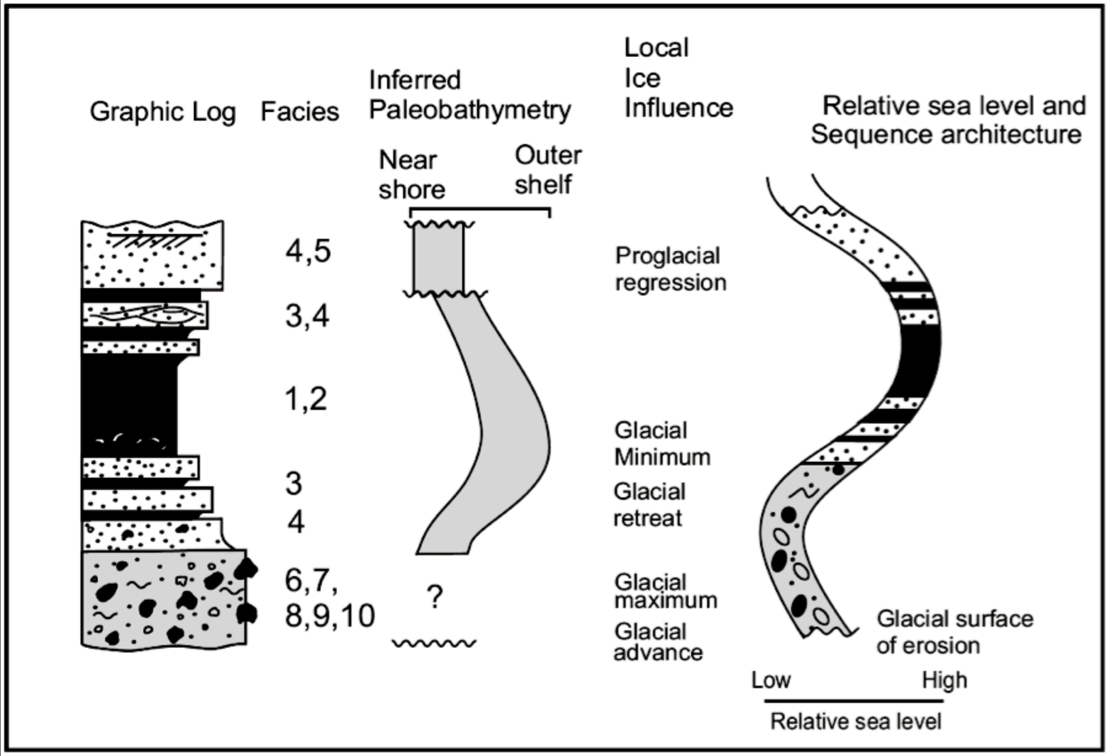
IU – intraformational unconformity

SB – sequence boundary (GBS + CC)

Powell & Cooper 2001; Willems et al. in prep

Glacial Sequence Stratigraphy

Temperate regime
- Coastal



Facies	Lithology	Interpretation
1	Mudstone	-hemipelagic suspension in offshore water depths
2	Interstratified sandstone and mudstone	-range of processes: low to moderate density sediment gravity flow deposition; combined wave & current action
3	Poorly sorted (muddy) v. fine to coarse sandstone	-medium to high density sediment gravity flow deposition
4	Moderately to well sorted, stratified sandstone	- dilute tractional currents (within or about wave base to shoreface)
5	Moderately to well sorted, stratified or massive, fine to coarse sandstone	-marine currents/wave influence
6	Stratified diamictite	-subglacial or ice contact-proglacial marine deposition
7	Massive diamictite	-subglacial or ice contact-proglacial marine deposition
8	Rhythemically interstratifed sandtone and siltstone	-deposition from turbid overflow plumes associated with glacier snout efflux
9	Clast-supported conglomerate	-Deposition from a variety of processes in shallow marine environment
10	Matrix-supported conglomerate	-Deposition from a variety of processes in shallow marine environment

G. Dunbar et al. 2006

- **Need better understanding of erosional and transfer processes (including modeling)**

- **Need better data on transfer rates of different glacial regimes**

- **Need GCM-driven ice sheet models that include sediment transfer modules**

- **Need more long-term records of ice sheet histories**

- **Need more comprehensive proxies to link ice sheet records to global climate records**

- **Need more comprehensive sequence stratigraphic models**