Late Pleistocene Glacial Lake Ahtna, Alaska: Constraints on Lake Extent and Volume, and Relationships to Modern Glaciers

Gregory Leonard and Jeffrey S. Kargel
University of Arizona

State of the Arctic Conference
17 March 2010 – Miami, Florida USA

"Glacial Lake Missoula" by Bryon Pickering

Copper River Basin, South-Central Alaska

MODIS Blue Marble image base

Lake deposits recognized (Schrader 1900)

Lake Ahtna named (Nichols 1965)

Several mapping projects (1950's – 1980's)

Lake extent / volume estimates absent

SUMMARY:

- **Lake Ahtna-(Susitna) volumes comparable to Lake Missoula**
- **Potential to discharge megaflood water volumes (10^2-10^3 km^3)**
- **Potential for future ice damming and flooding**
- **CRB outstanding analog for large-scale deglaciation and postglacial landscape and ecosystem evolution**

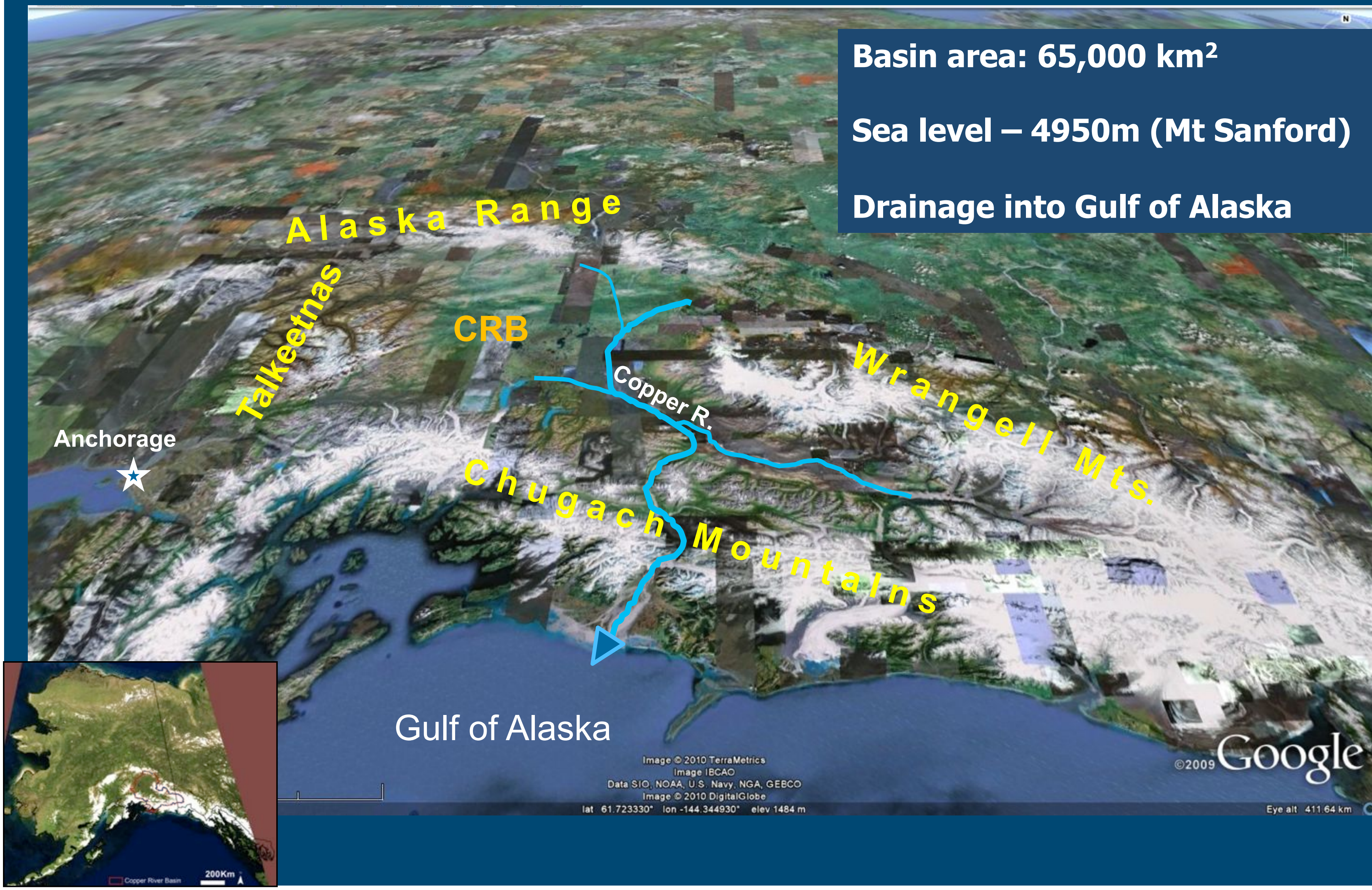
“Glacial Lake Missoula” by Bryon Pickering

Copper River Basin: Geography

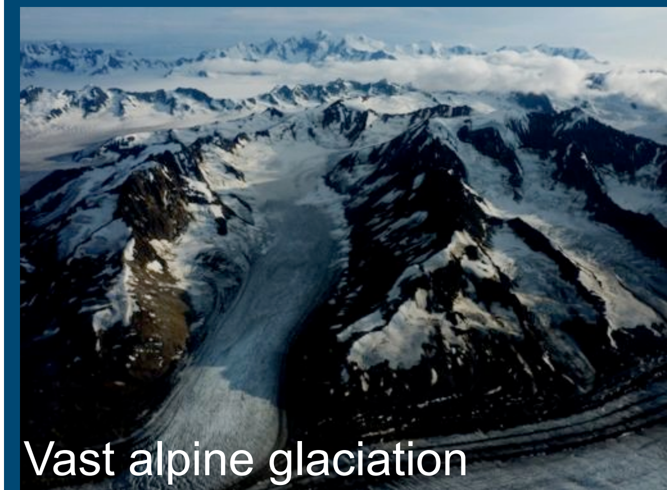
Basin area: 65,000 km^2

Sea level – 4950m (Mt Sanford)

Drainage into Gulf of Alaska



Copper River Basin: Biophysical Diversity



Vast alpine glaciation

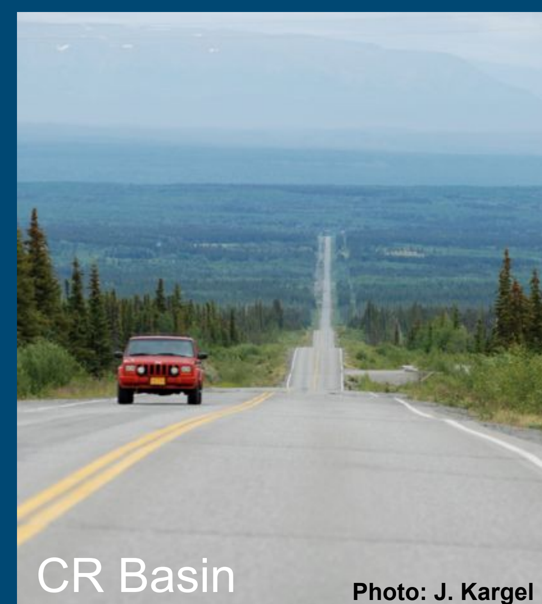
World-class bird migratory path

Commercial fishing

CR Delta Ecologic Zone

Worldclass wildlife

Sub-arctic tundra



CR Basin

Photo: J. Kargel

How to Measure a (vanished) Lake?

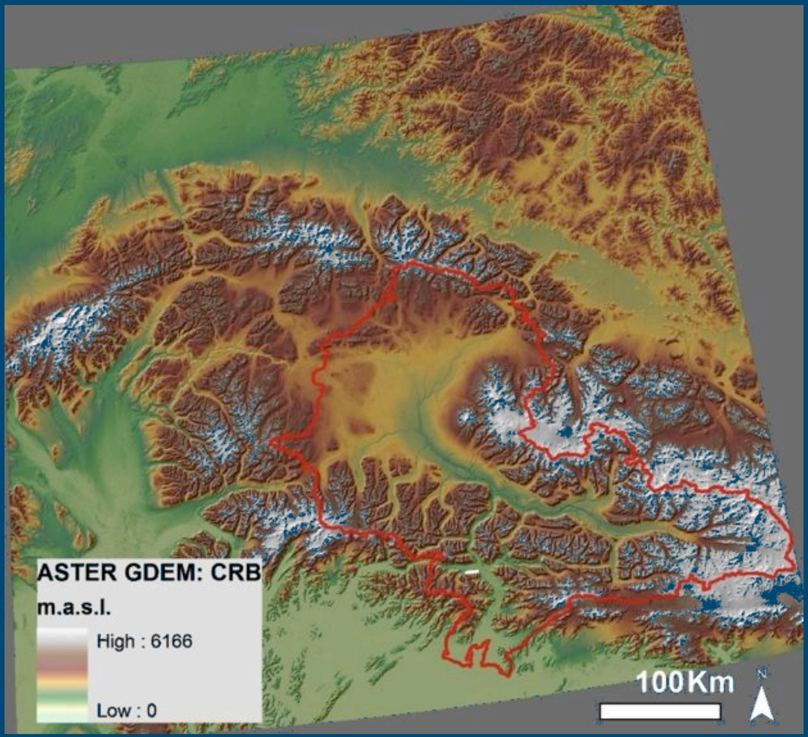
Identify Evidence for its Spatial Extent:

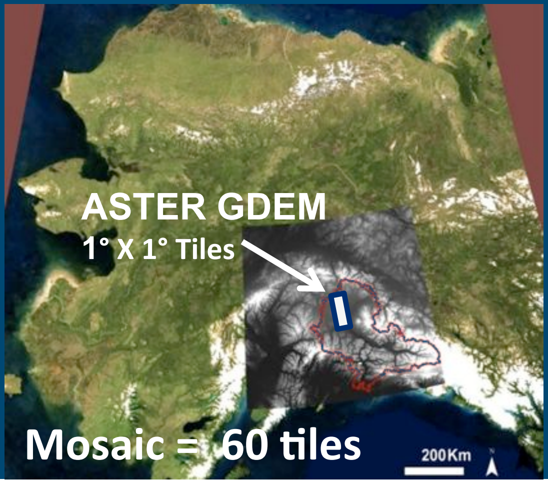
- **Map known / interpreted lake margins**
- **Map known / interpreted lake surface elevations**
- **Use spatial constraints as input for morphometric estimates**

Integrate historic map and fieldwork into GIS project database

Caveat: Lakes are fluctuating through extent, depth, and time.
Uncertainties allow only for calculations of upper boundary lake extents.

ASTER SATELLITE: Global DEM (GDEM)





ASTER GDEM: 2009

- 83˚N to 83˚S coverage
- Automated stereo-correlation products
- 30m data postings (30m / pixel)
- 20m vertical accuracy (95% confidence)
- Anomaly & artifact problems related to cloud cover, no inland water mask and to overlapping image stacks (pits, bumps, mole runs)

Evidence for Glacial Lake Ahtna: Classic Glacio-lacustrine deposits


Silt rhythmites

Valdez roadcut silt


Dropstone in silt


River cutting glacial lake sediments


Glaciofluvial & glaciolacustrine deposits

Photos: Jeff Kargel

Evidence for Glacial Lake Ahtna: Surface Elevation

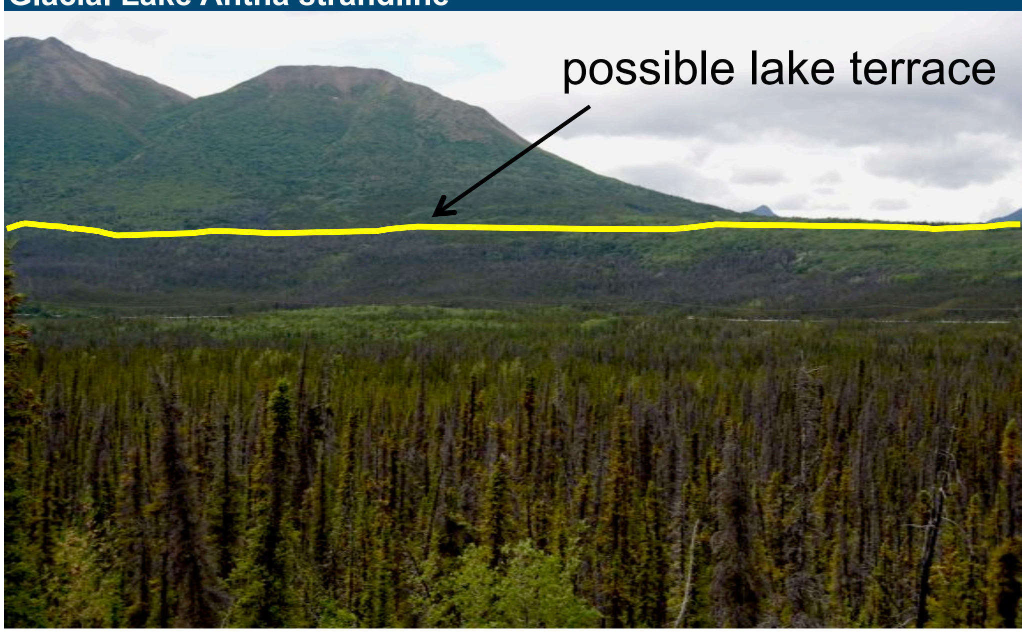
Indicators:

- Minimum and Maximum elevations of lake deposits
- Lacustrine geomorphic features (shorelines, strandlines)

<u>Strandlines difficult to trace around the basin</u>

- different unit erosion susceptibilities
- complexity of lake margin / glacier geomorphic features
- non-isotropic isostatic rebound

Glacial Lake Ahtna strandline

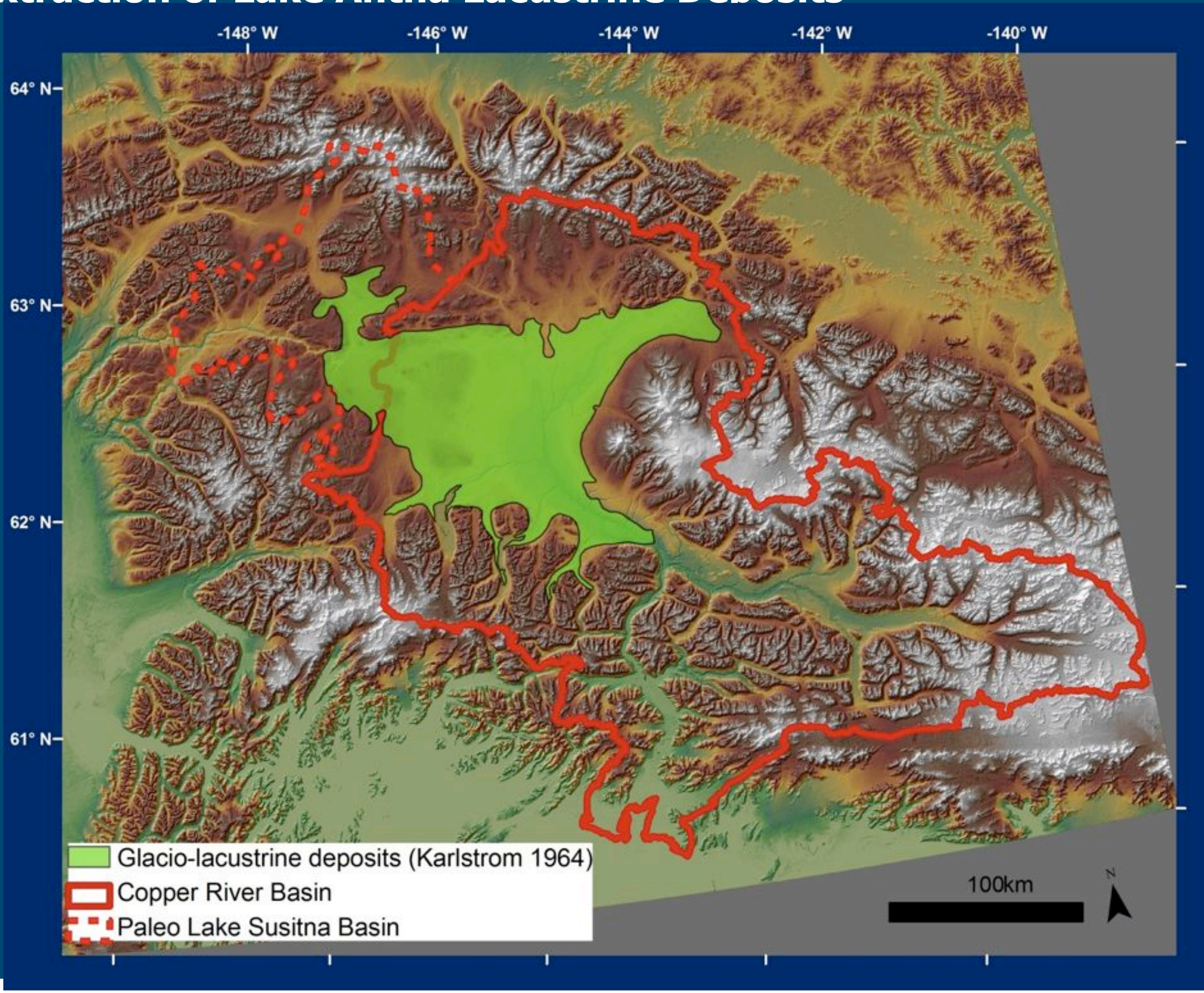


Glacial Lake Missoula strandlines, Montana

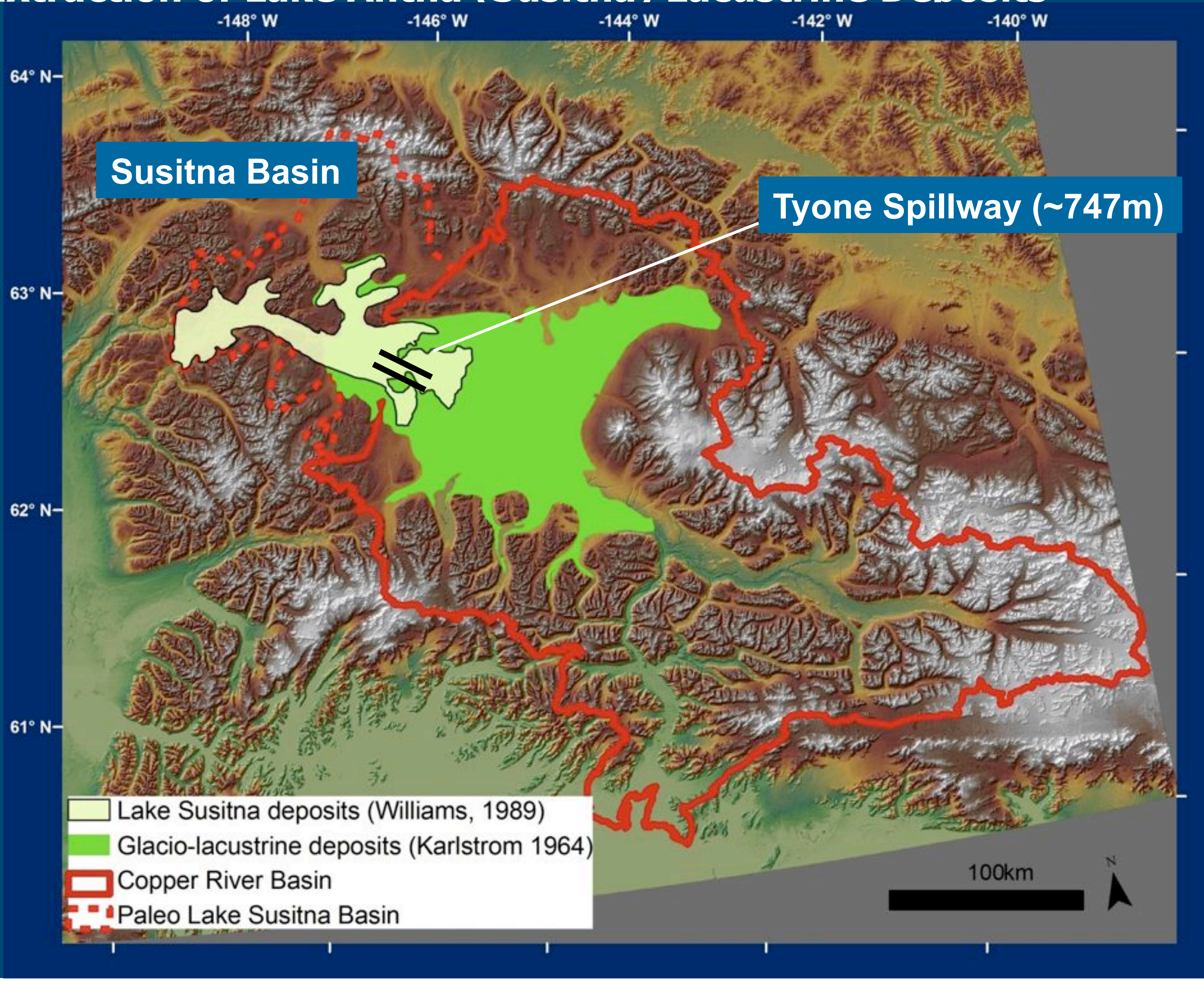
Five Prominent Lake Ahtna Surface Elevations:

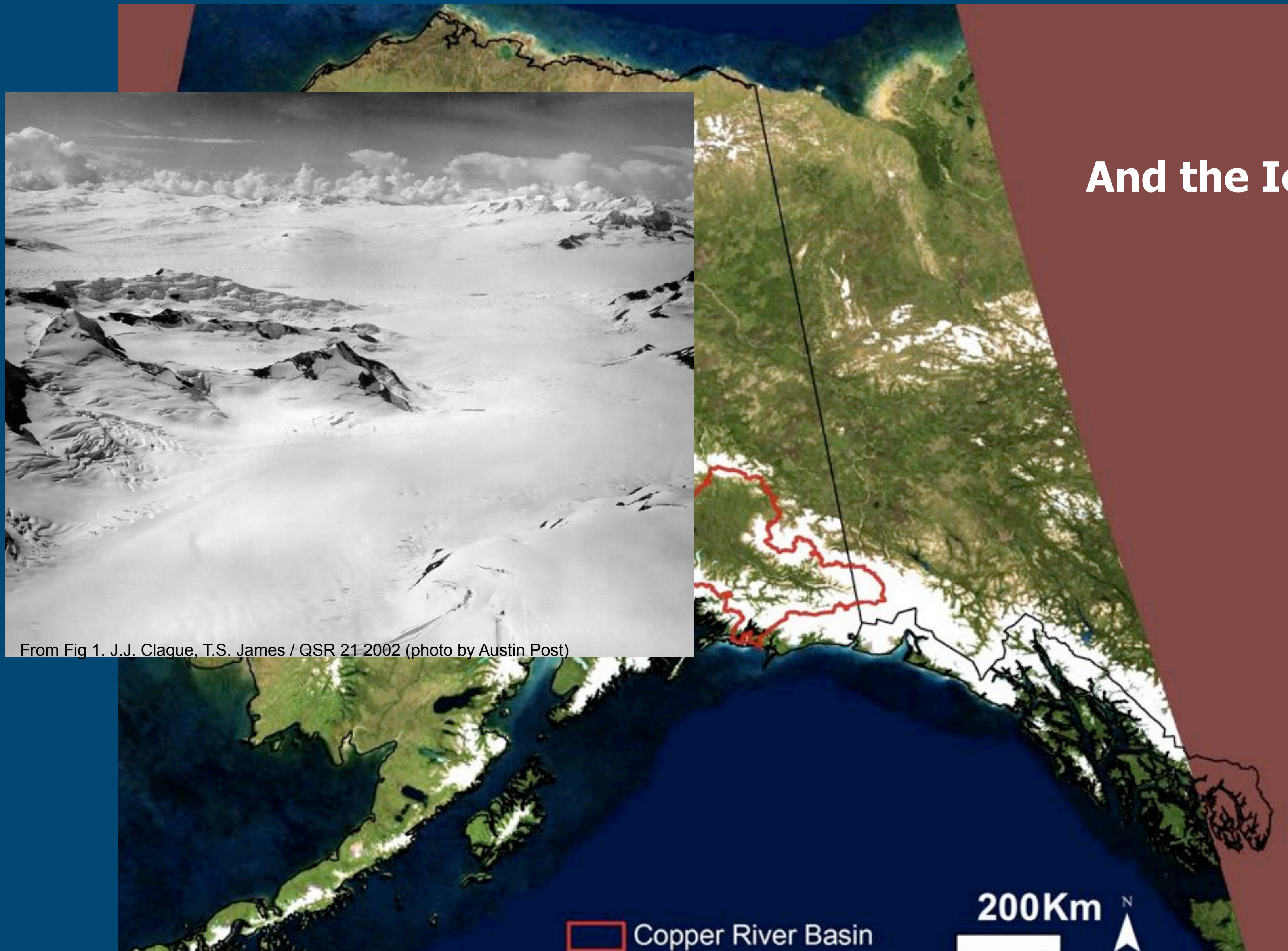
Lake Elevation (m)	Features Identified	Reference
975	Glacio-lake deposits	Karlstrom, 1964 Williams, 1989
914	Glacio-lake deposits	Williams, 1989
777	Glacio-lake deposits, shoreline	Williams & Galloway, 1986
747	Glacio-lake deposits, shoreline	Williams & Galloway, 1986
500	Glacio-lake deposits	Sirkin and Tuthill, 1987

Extraction of Lake Ahtna Lacustrine Deposits



Extraction of Lake Ahtna (Susitna) Lacustrine Deposits





From Fig 1. J.J. Clague, T.S. James / QSR 21 2002 (photo by Austin Post)

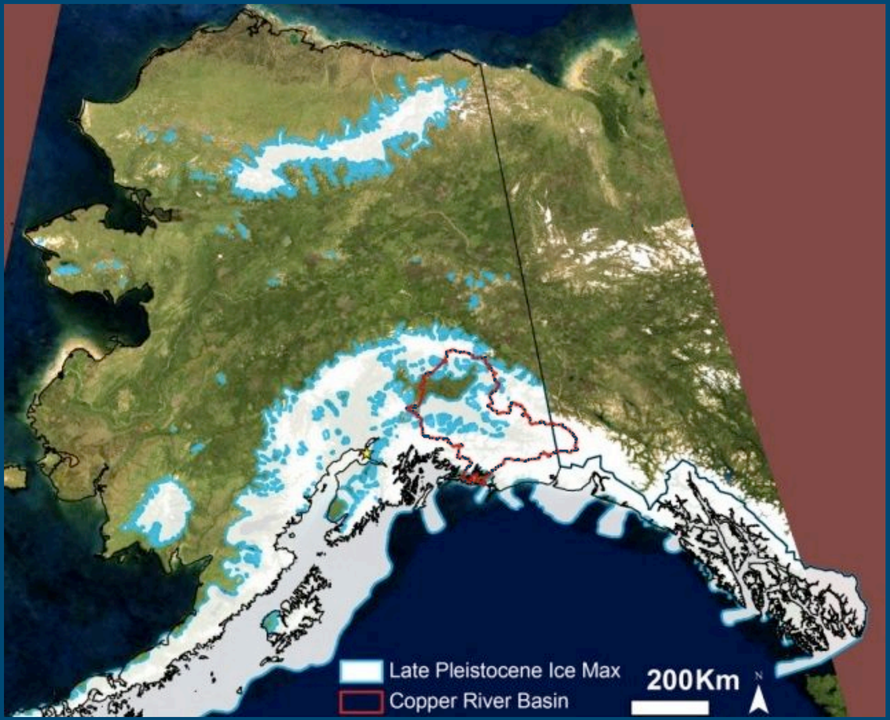
And the Ice?

Manley, W.F., and Kaufman, D.S., 2002, Alaska PaleoGlacier Atlas

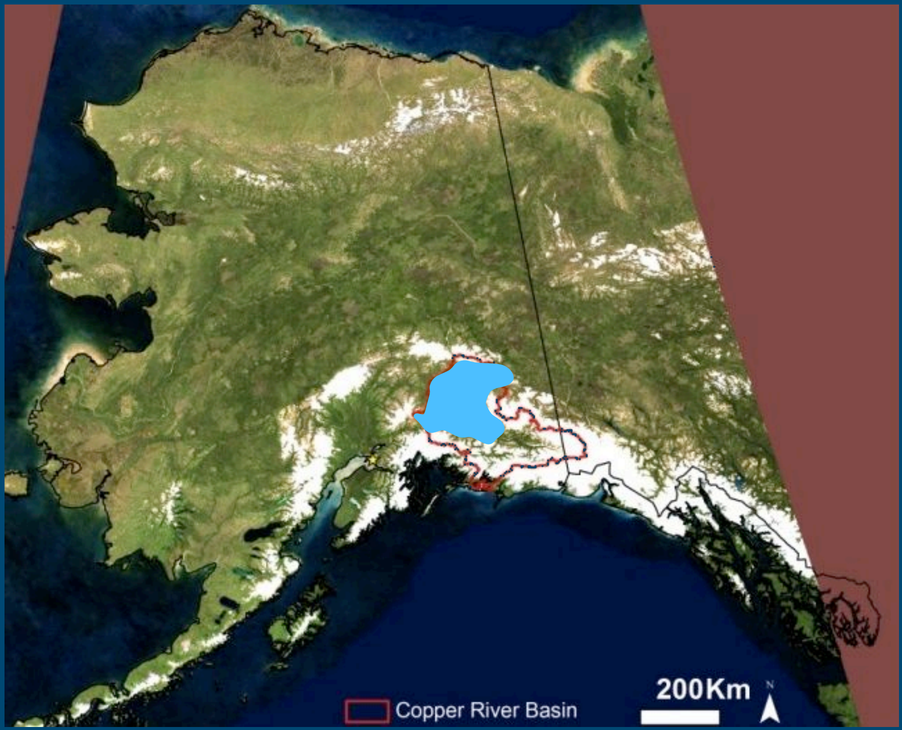
Lake Ahtna – (Susitna) Lake Evolution

- Several basin ice fluctuations throughout Late Pleistocene (30,000 – 10,000 y BP)
- Impoundment of CRB watershed formed huge proglacial lakes
- Last Late Pleistocene ice advance (& recession) formed the massive Glacial Lake Ahtna

Last Glacial Maximum (20,000y BP)



Recession of Ice to 10,000 y BP)



Lake Ahtna – (Susitna) Extent: Boundary Conditions Established

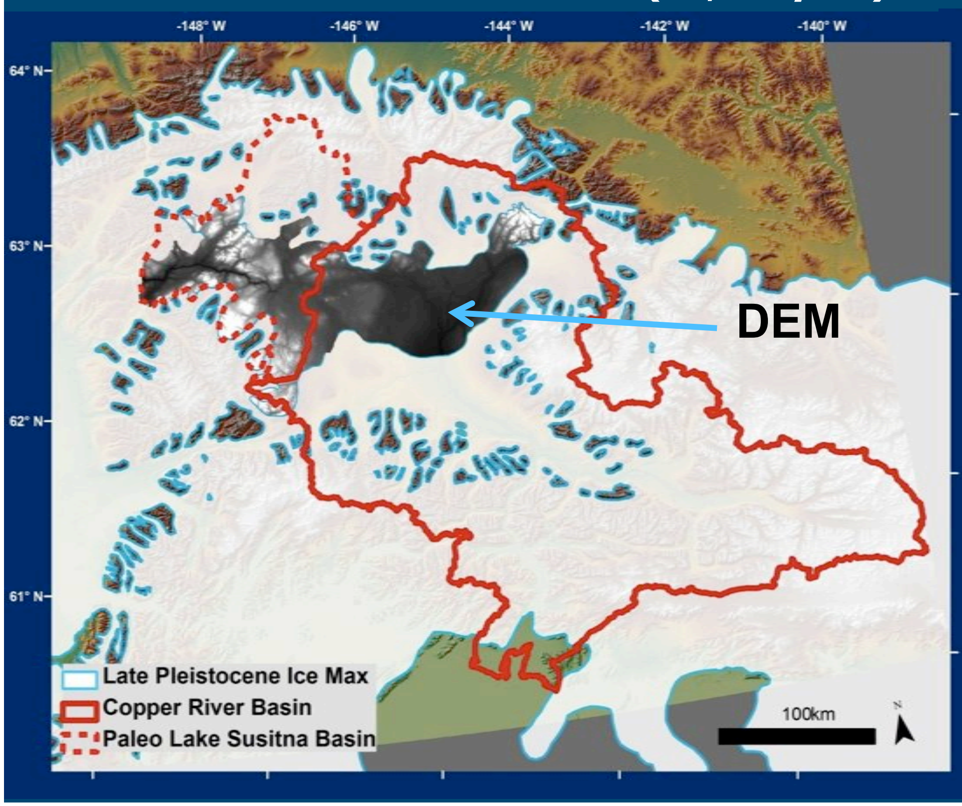
Minimum and Maximum extent of impounding ice

Five lake levels: 975m, 914m, 777m, 747m, 500m

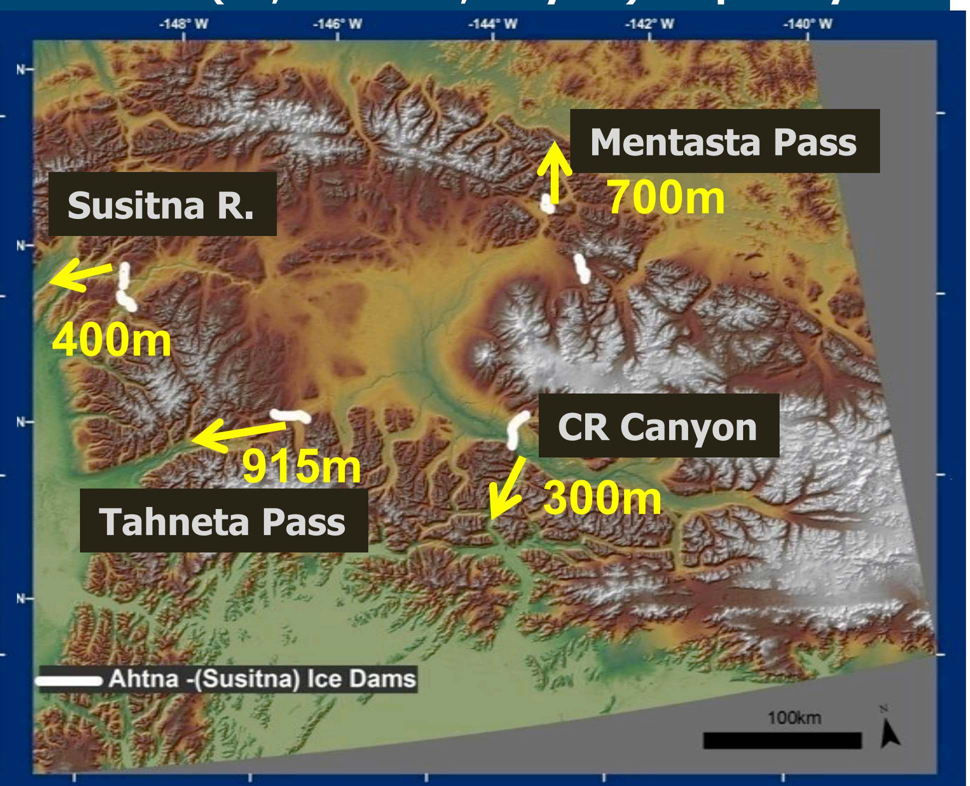
Carve out DEM

Complete areal and volume analyses and discharge rates

Max Ice: Last Glacial Maximum (20,000y BP)

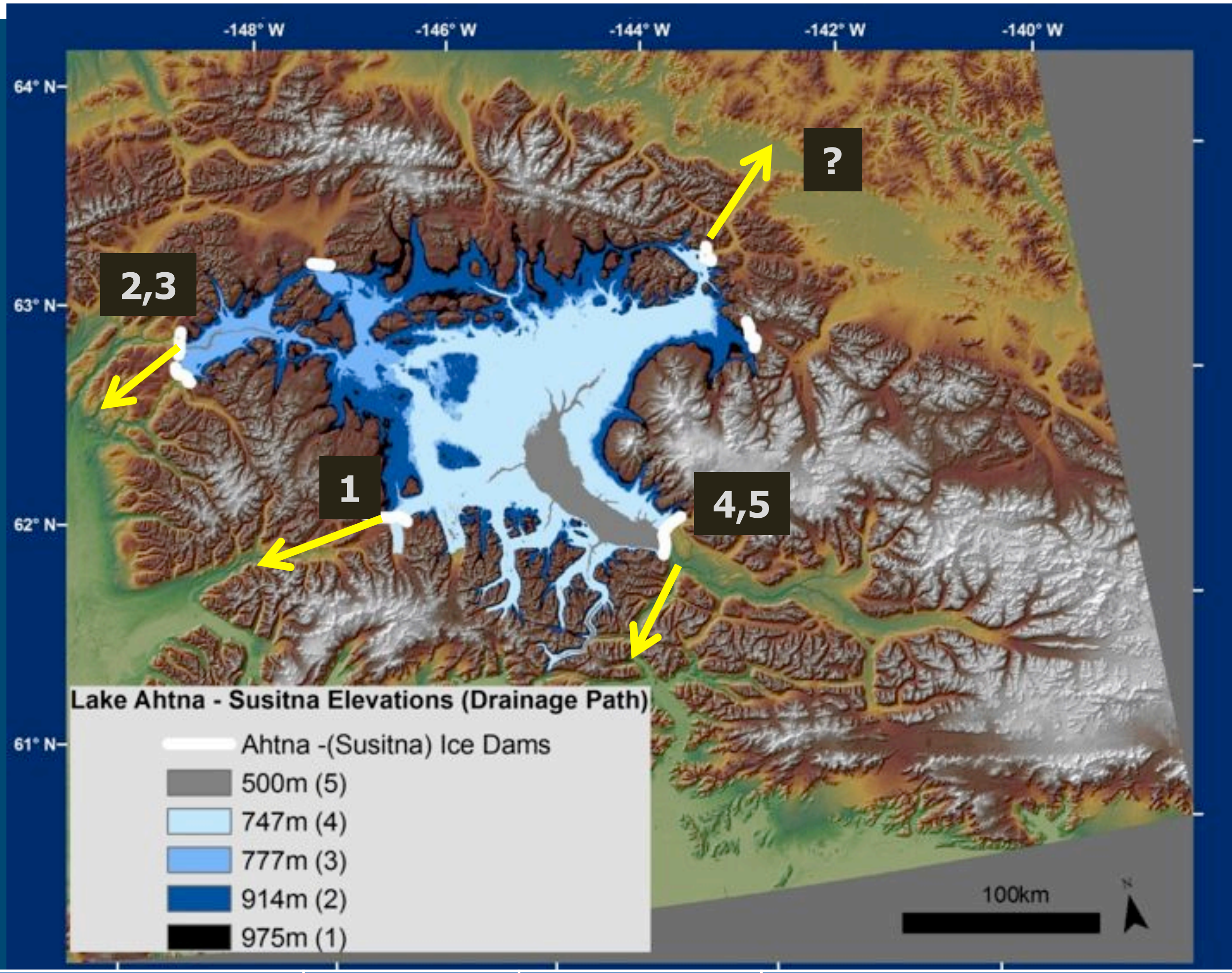


Min Ice: (20,000 to 10,000y BP) & Spillways



Lake Ahtna – (Susitna): Area – Volume - Discharge

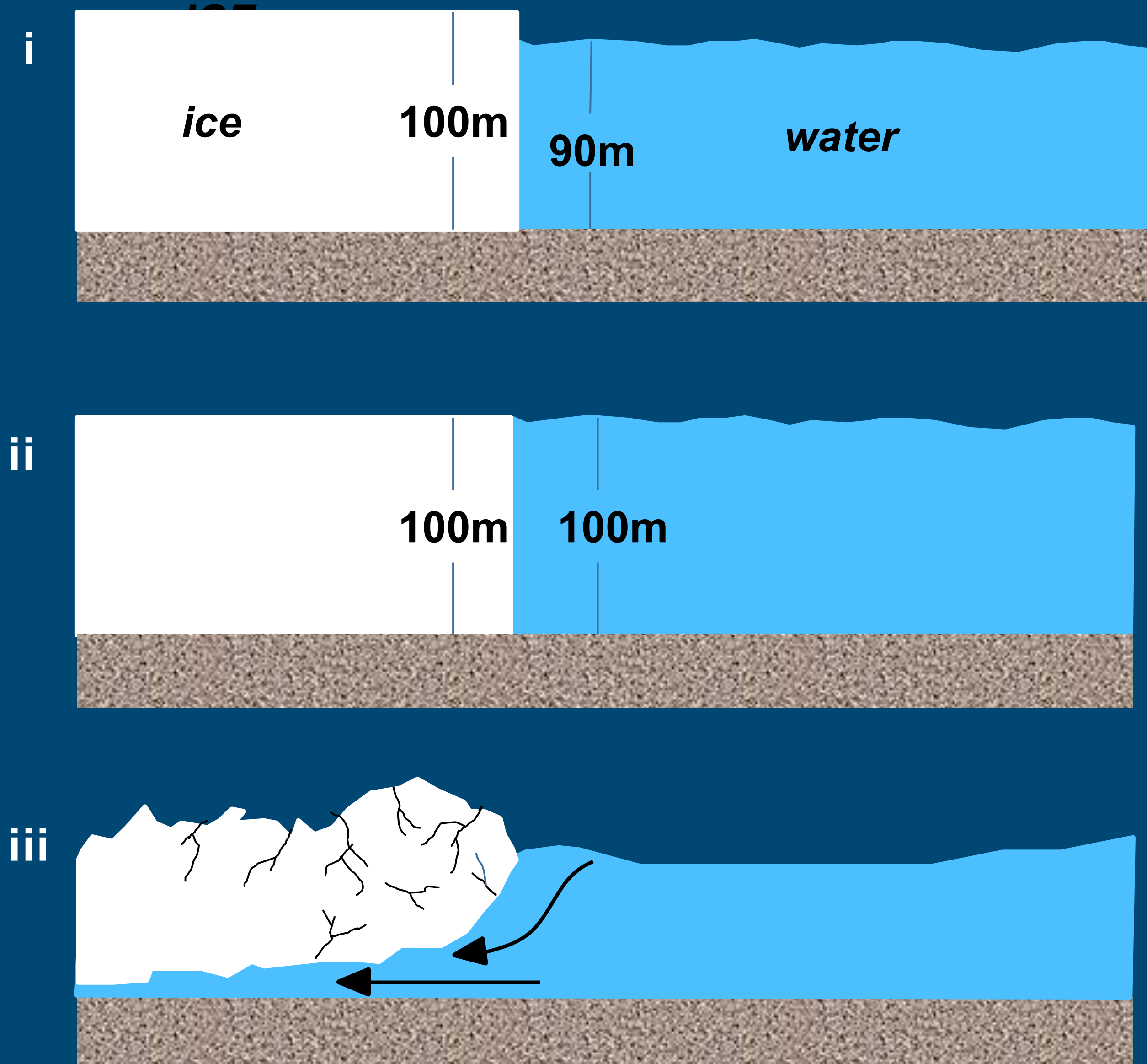
Lake	Drainage Path	Minimum Dam Height (m)	Lake Elevation (m) pre-discharge	Lake Elevation (m) post discharge	Lake Area (km^2) pre-discharge	Lake Area (km^2) post-discharge	Lake Volume (km^3) pre-discharge	Lake Volume (km^3) post-discharge	Water Discharged (km3)
Susitna (max ice)	Susitna	417	975	914	10583	9918	2723	2097	626
Susitna (max ice)	Susitna	349	914	777	9918	7206	2097	884	1213
Susitna (max ice)	Susitna	197	777	747	7206	6131	884	684	200
Susitna-Ahtna (min ice)	Tahneta	67	975	914	25074	22348	6217	4768	1449
Susitna-Ahtna (min ice)	Susitna	417	914	777	22348	15188	4768	2181	2587
Susitna-Ahtna (min ice)	Susitna	349	777	747	15188	12107	2181	1667	514
Ahtna (min ice)	Copper River	386	747	500	12107	1760	1667	152	1515
Ahtna (min ice)	Copper River	111	500	0	1760	0	152	0	152



Lake	Drainage Path (location)	From Elev (m)	To Elev (m)	Volume Discharge (10^3 x m^3)	*Peak Discharge Rate (10^6 m^3 s^{-1})
Susitna 1	**Tahneta (1)**	**975**	**914**	**1449**	**2**
Susitna 2	**Susitna R. (2)**	**914**	**777**	**2587**	**24**
Ahtna 1	**Susitna R. (3)**	**777**	**747**	**514**	**10**
Ahtna 2	**CR Canyon (4)**	**747**	**500**	**1515**	**55**
Ahtna 3	**CR Canyon (5)**	**500**	**0**	**142**	**8**

***Potential Discharge assuming catastrophic dam failure. Peak discharge rate unlikely in most cases**

SIMPLIFIED ICE DAM FAILURE



Hydrostatic maximum

Ice density = 0.9167 g/cm³ (0°C)
Water density = 0.9998 g/cm³

Hydrostatically unstable

buoyancy force > glacier weight (ρ g h)

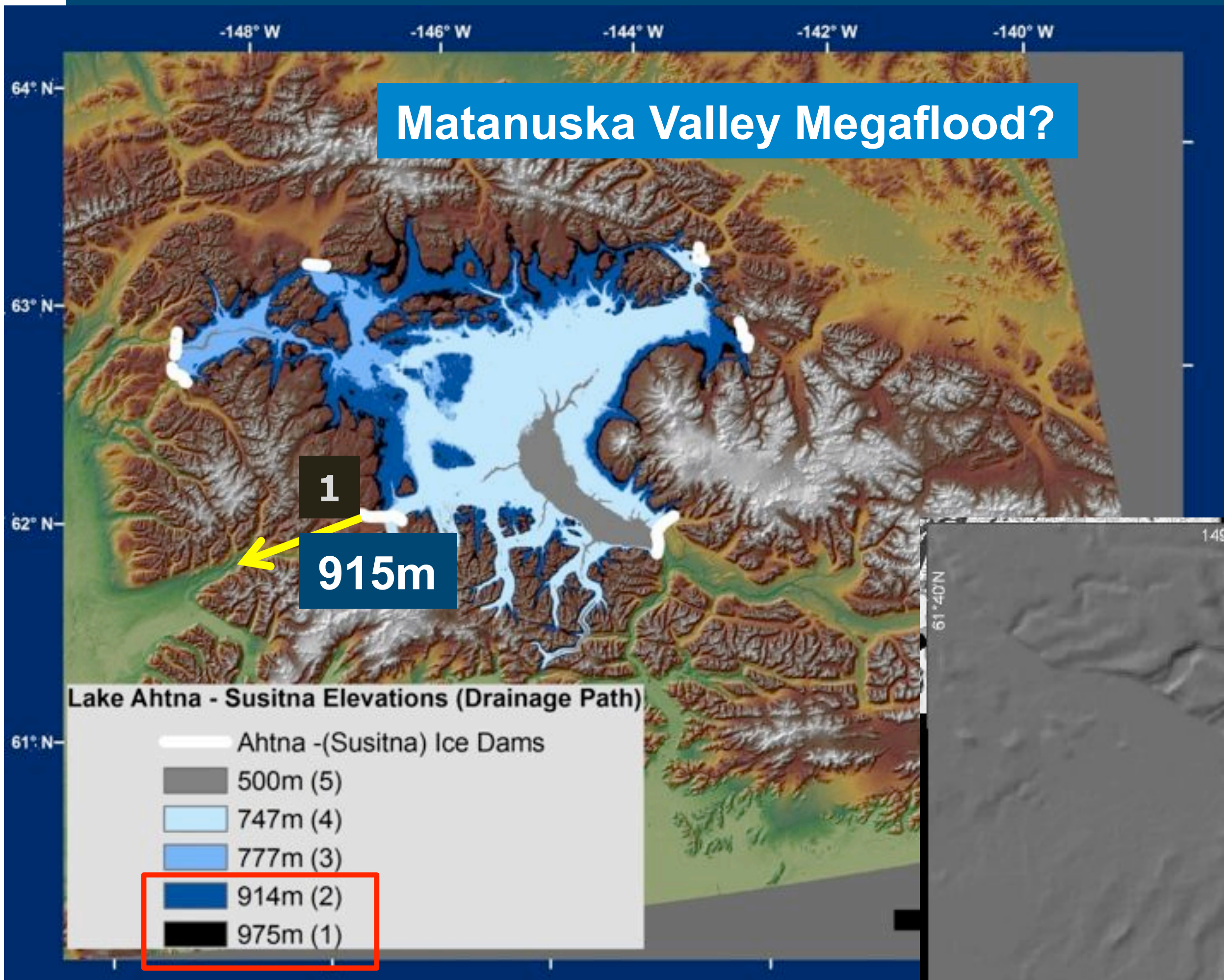
Ice dam failure

Lake Ahtna – (Susitna): Mega Lake Comparisons

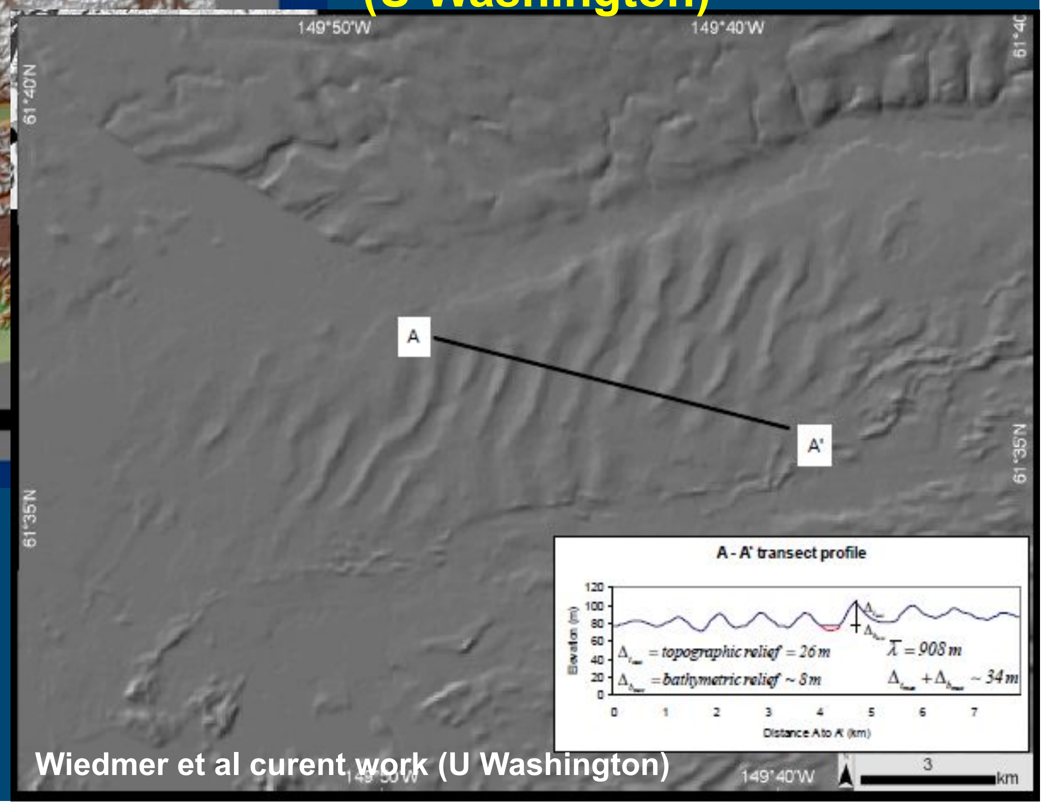
Location	Date	Volume (m^3)	Peak Discharge ($10^6\ m^3\ s^{-1}$)	Reference
Kuray, Altai Russia	L Pleist.	1.0×10^{12}	18	Baker at al 1993
L. Missoula (NW USA)	L Pleist.	2.2×10^{12}	17	O’Connor & Baker 1992
Darkhat L., Mongolia	L Pleist.	-	4	Grosswald, 1987 (in Rudoy 1998)
Jassater, Altai Russia	L Pleist.	-	2	Grosswald, 1987 (in Rudoy 1998)
L Ahtna-Susitna, Alaska	L Pleist.	*6.2×10^{12}	2	This work
Lake Agassiz, Canada	9900y BP	-	1.2	Smith & Fisher, 1993

*** Initial lake volume**

Lake Ahtna – (Susitna): Matanuska Valley megaflooding?



Wiedmer et al curent work (U Washington)



Lake Ahtna-Susitna: 975m decanted to 914m

High peak discharge

More to be accomplished:

- Resolve timing of impounding ice dams (mapping, surface age dating)
- Validate ice dam locations, heights (geomorpholgy, mapping, satellite DEM)
- Resolve megalake evolution for CRB and Susitna
- Resolve potential magnitude and anisotropy of isostatic rebound (model)
- Large scale flooding in surrounding spillways (field and satellite mapping)
- Investigate modern day mechanisms for ice damming in the CRB

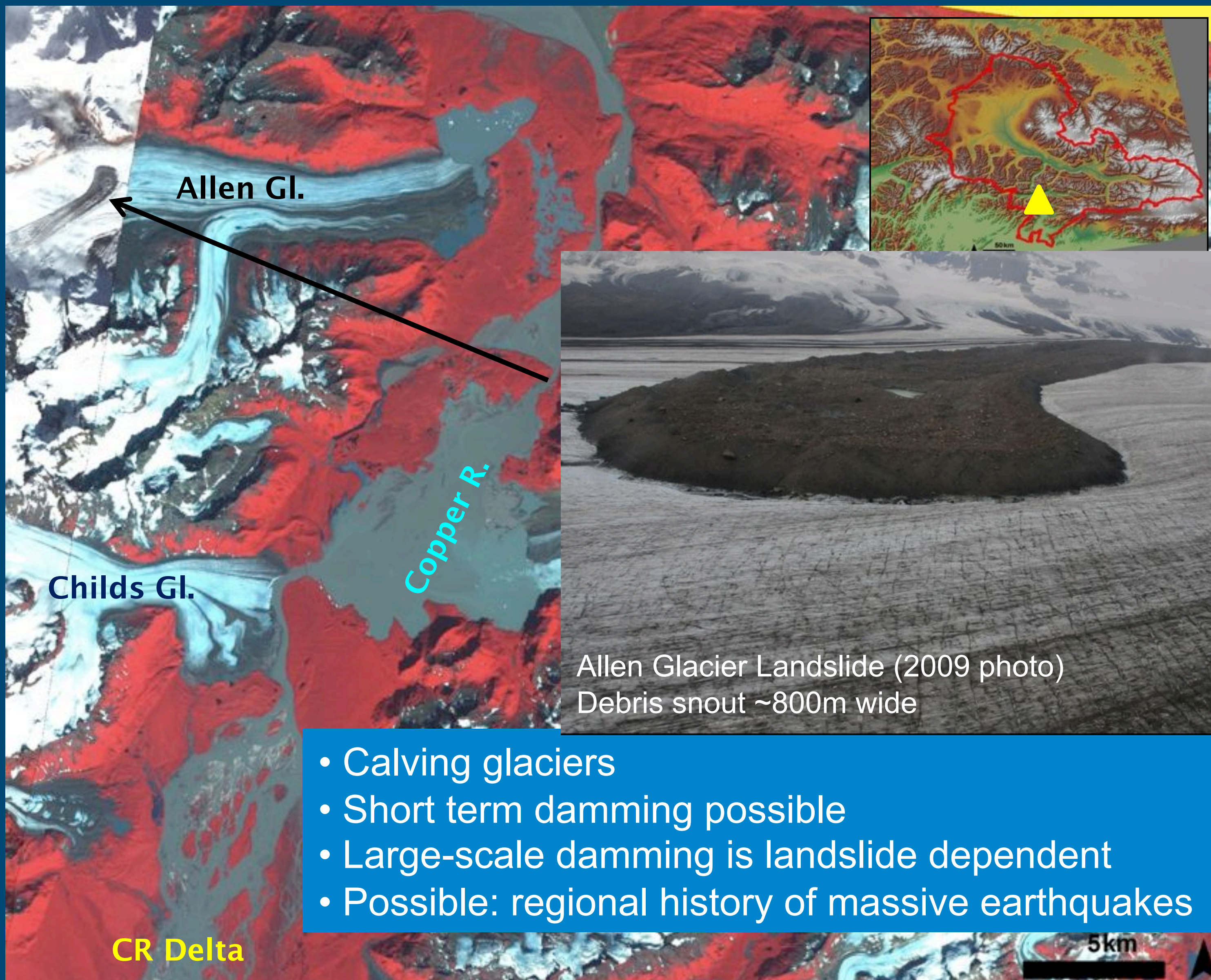
Current Ice-Dammed l

- Megalakes have passed
- Hundreds of small glacier damn

Iceberg Lake (photo Kirk Stone, 1951)

David Wolfe, work in progress (Alaska Pacific Univer

Lower Copper River Basin: Today's Glaciers



- Calving glaciers
- Short term damming possible
- Large-scale damming is landslide dependent
- Possible: regional history of massive earthquakes

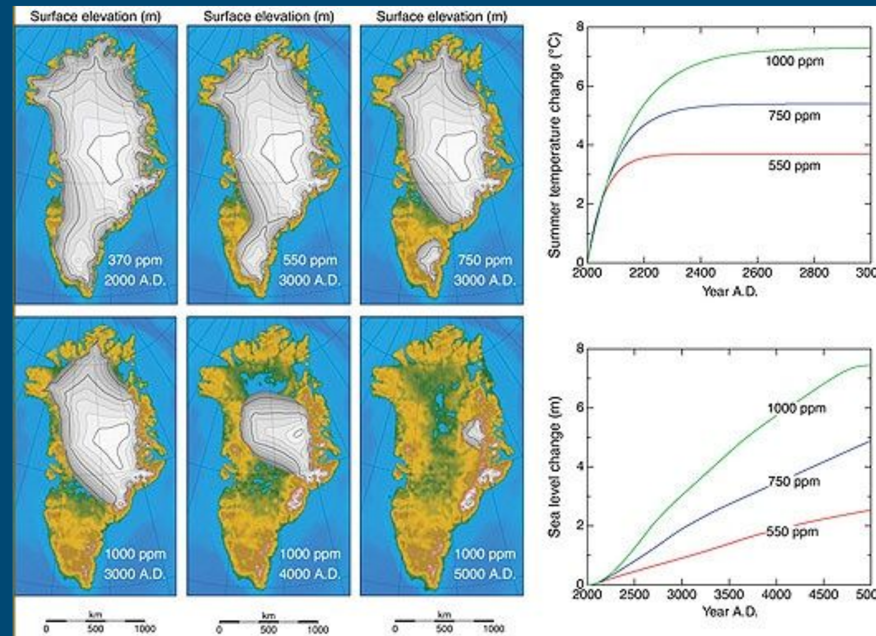
ASTER FCC 321rgb

CRB Offers an Excellent Analog for Deglaciation of Large Landmasses

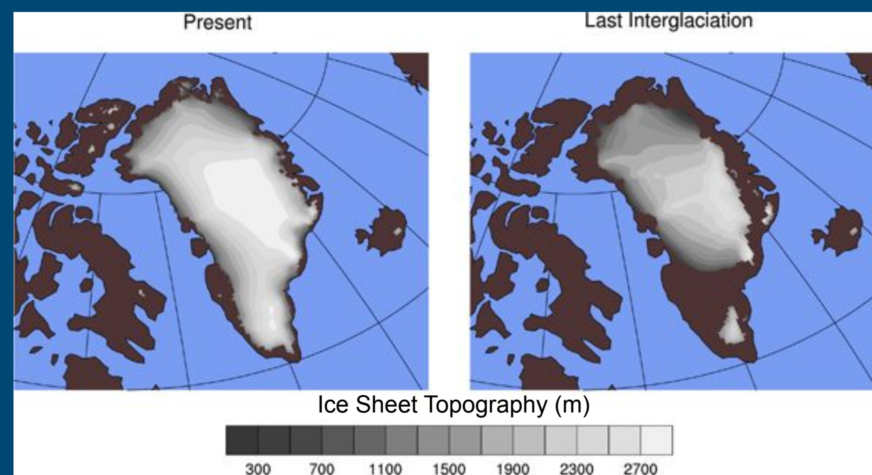
Photo by Jonathan Bamber

Megalake formation
Megaflood formation/mechanisms
Isostatic adjustment
Ecosystem evolution
Vegetational – Faunal succession

Possible future evolution of Greenland Ice Sheet



Alley, Richard B. et al. *Science* 310(5747): 456-460 (21 October 2005).



(Illustration Bette Otto-Bliesner, NCAR. http://www.ucar.edu/news/releases/2006/images/greenland_topo_ice.jpg)

SUMMARY:

- Lake Ahtna-(Susitna) volumes comparable to Lake Missoula
- Potential to discharge megaflood water volumes (10^2-10^3 km^3)
- Potential for future ice damming and flooding
- CRB outstanding analog for large-scale deglaciation and postglacial landscape and ecosystem evolution

http://www.pbs.org/wgbh/nova/megaflood/lake.html

Thank You

[redacted]