



Flushing Lake Atna: Late Quaternary Megafloods in South-Central Alaska

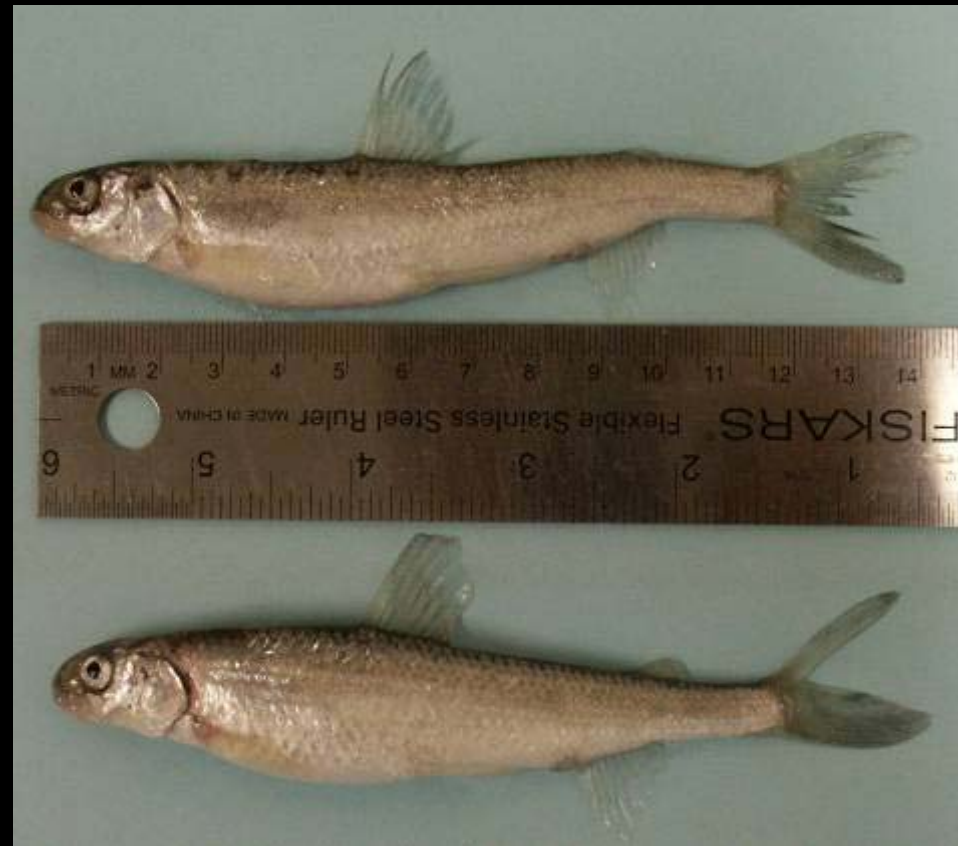
Michael Wiedmer, David R. Montgomery, Alan R. Gillespie, and Harvey Greenberg

School of Forest Resources and Department of Earth and Space Sciences,
College of the Environment, University of Washington

Two inspirations



Meadow Lakes near Wasilla, Alaska



Pygmy whitefish *Prosopium coulterii*

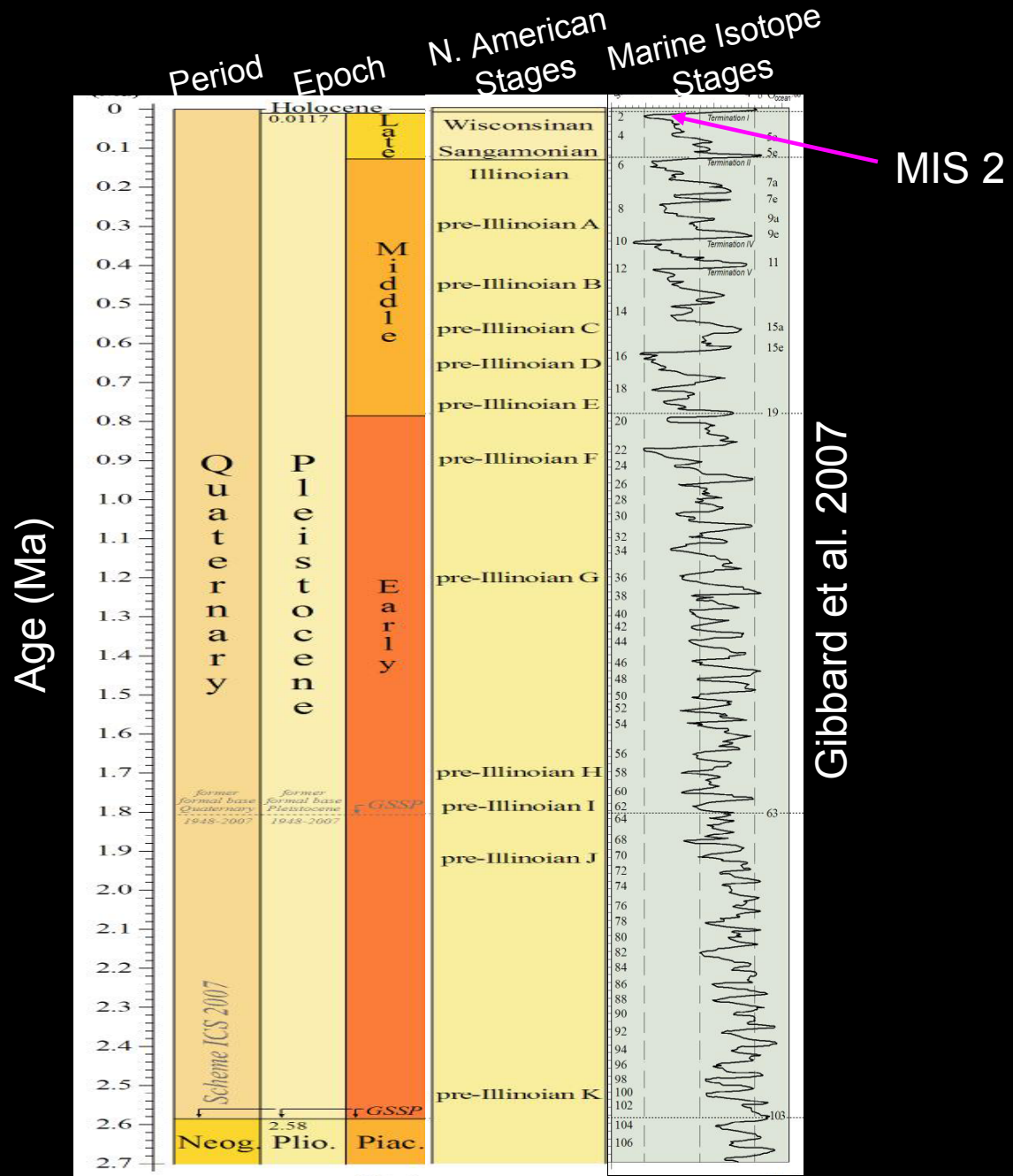
Flushing Lake Atna:

Late Quaternary

Megafloods in

South-Central Alaska

Geologic Time

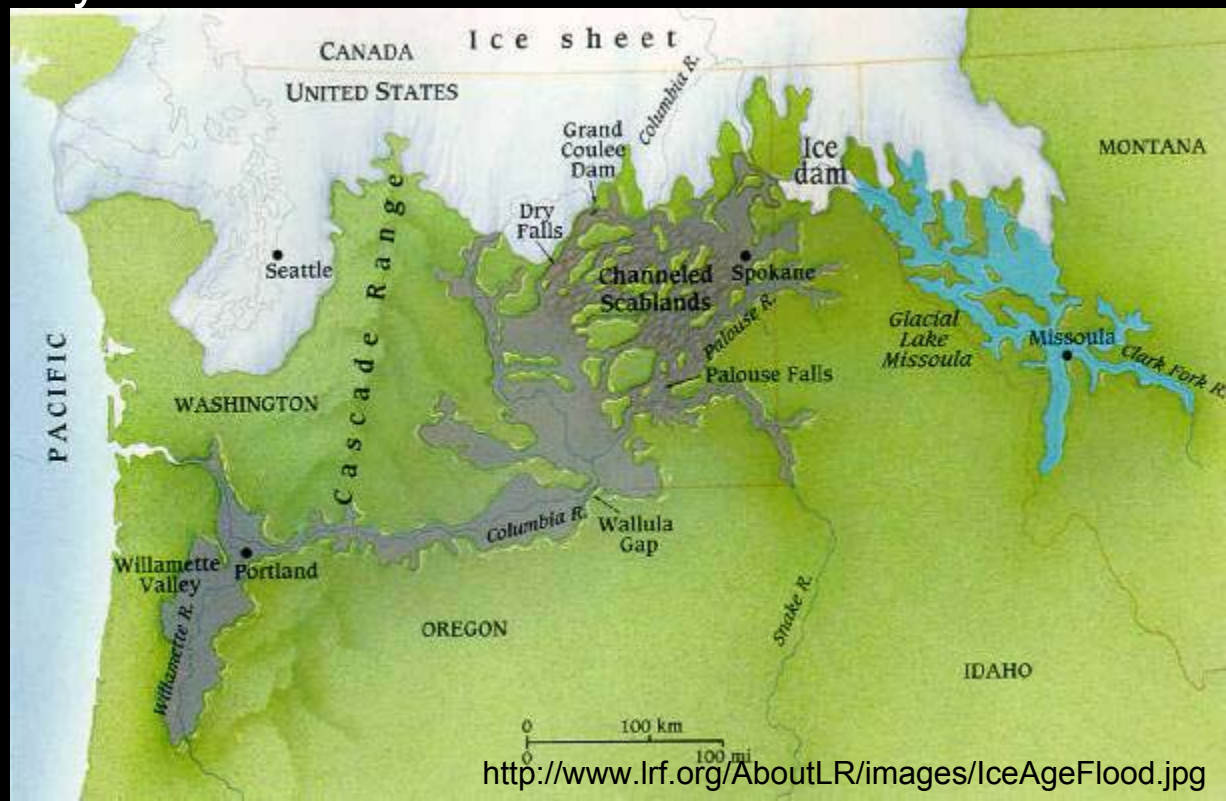


Flushing Lake Atna:
Late Quaternary

Megafloods in South-Central Alaska

What caused the largest megafloods?

- Large advancing ice sheets disrupted drainage systems
- Impounded massive lakes
- Ice dams inherently unstable
- Discharge exponentially dependent on breach depth
- Primarily in northern mid-latitudes



Megafloods in

South-Central Alaska

- Jökulhlaup
 - “gradual” ice tunnel enlargement *sensu* Baker et al. 1993
- Catastrophic dam failure
 - “instantaneous” breach

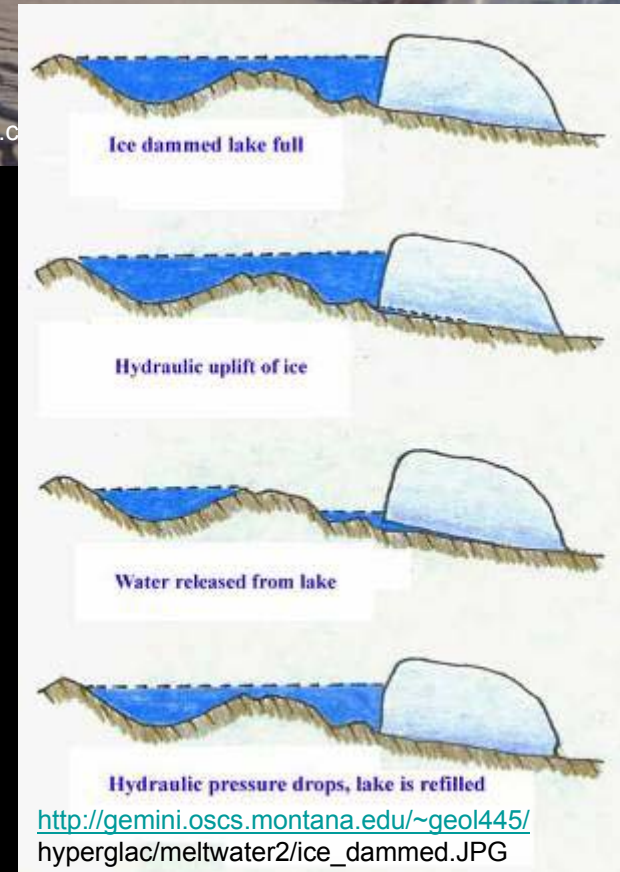
*Flushing Lake Atna:
Late Quaternary*

Megafloods in *South-Central Alaska*

Jökulhlaup initiation mechanisms



- Geothermal heating
- Floatation
- Piping
- Wasting



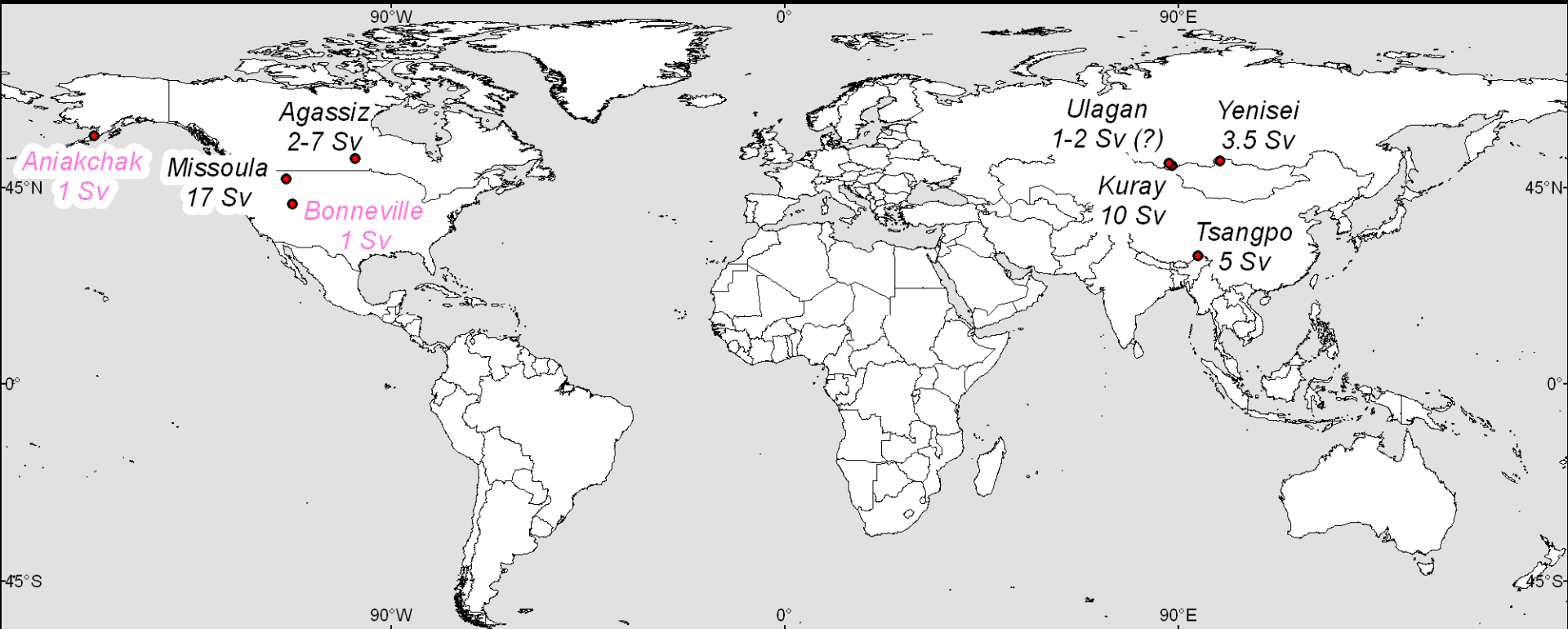
Megafloods in
South-Central Alaska

- Peak discharge (Q) $\geq 1 \times 10^6 \text{m}^3\text{s}^{-1}$ (Baker, 2009)
- = 1 Sverdrup (Sv; in honor of Harald Sverdrup)
 - Amazon R. discharge ≤ 0.37 Sv (Rodier and Roche, 1984)
 - Modern Columbia R. discharge ≤ 0.035 Sv (O'Connor and Costa, 2004)

Flushing Lake Atna:
Late Quaternary

Largest recognized Quaternary megafloods

Megafloods in South-Central Alaska



(Rudoy, 2002; Smith, 2003; Montgomery et al., 2004; O'Connor and Costa, 2004; Herget, 2005; Komatsu et al., 2009)

Several of these locations produced many outbursts, only the largest estimated floods are shown here.

Flushing Lake Atna:
Late Quaternary

Mega floods in South-Central Alaska

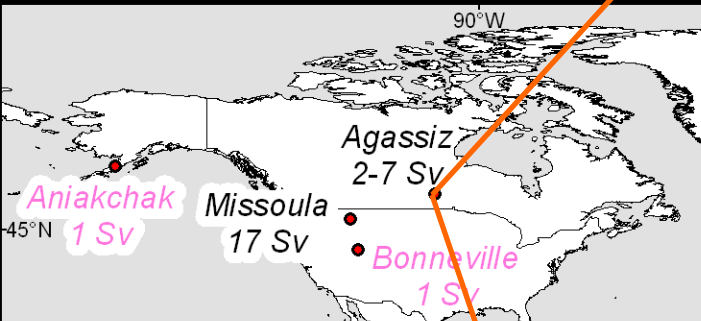


Mega floods carved landscapes, structured modern human land use patterns



Flushing Lake Atna:
Late Quaternary

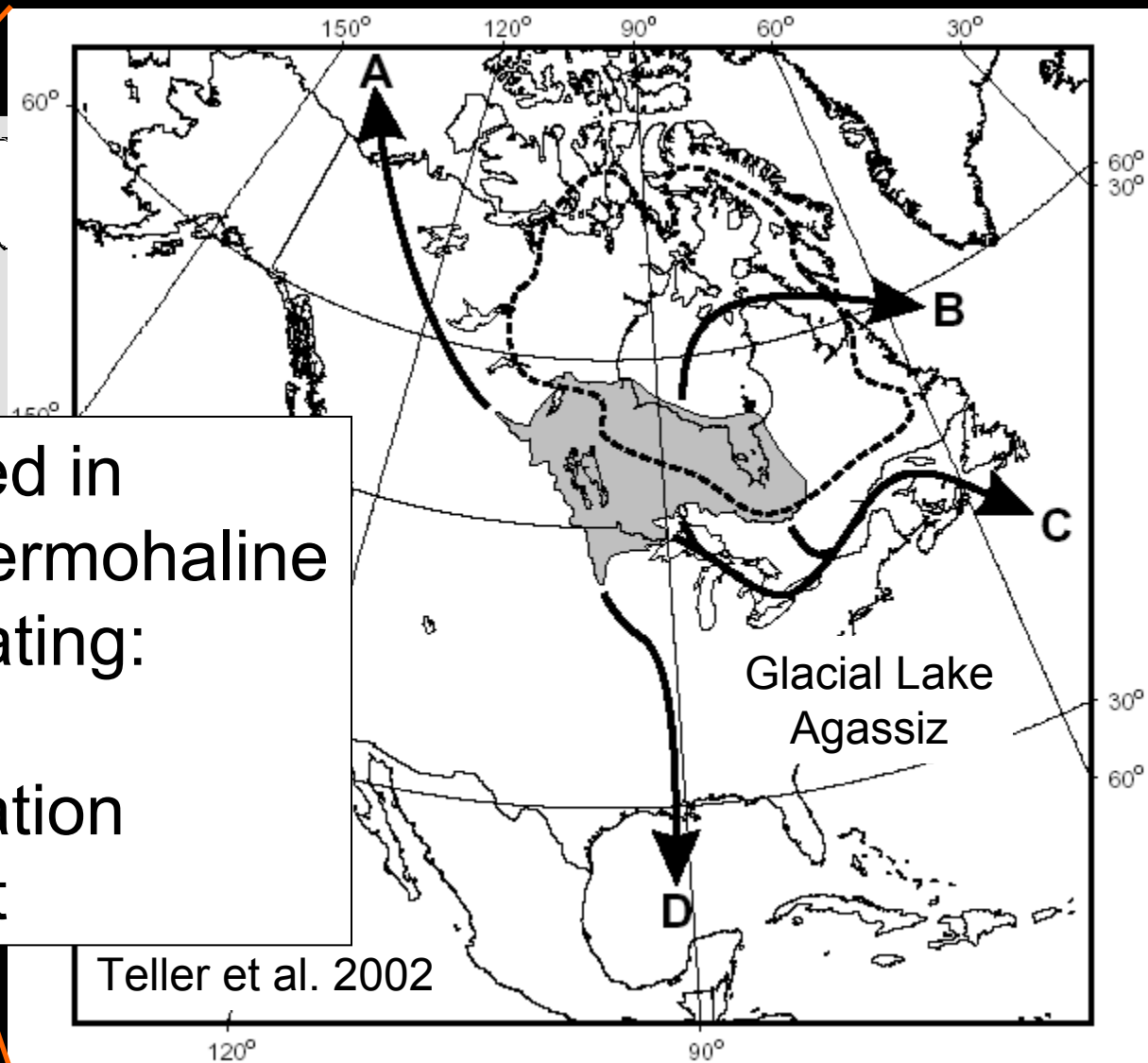
Megaflows in South-Central Alaska



Huge drainage volumes implicated in global climate change

Discharges implicated in disrupting marine thermohaline cycles, perhaps initiating:

- Younger Dryas
- Preboreal Oscillation
- 8.2 ka cold event

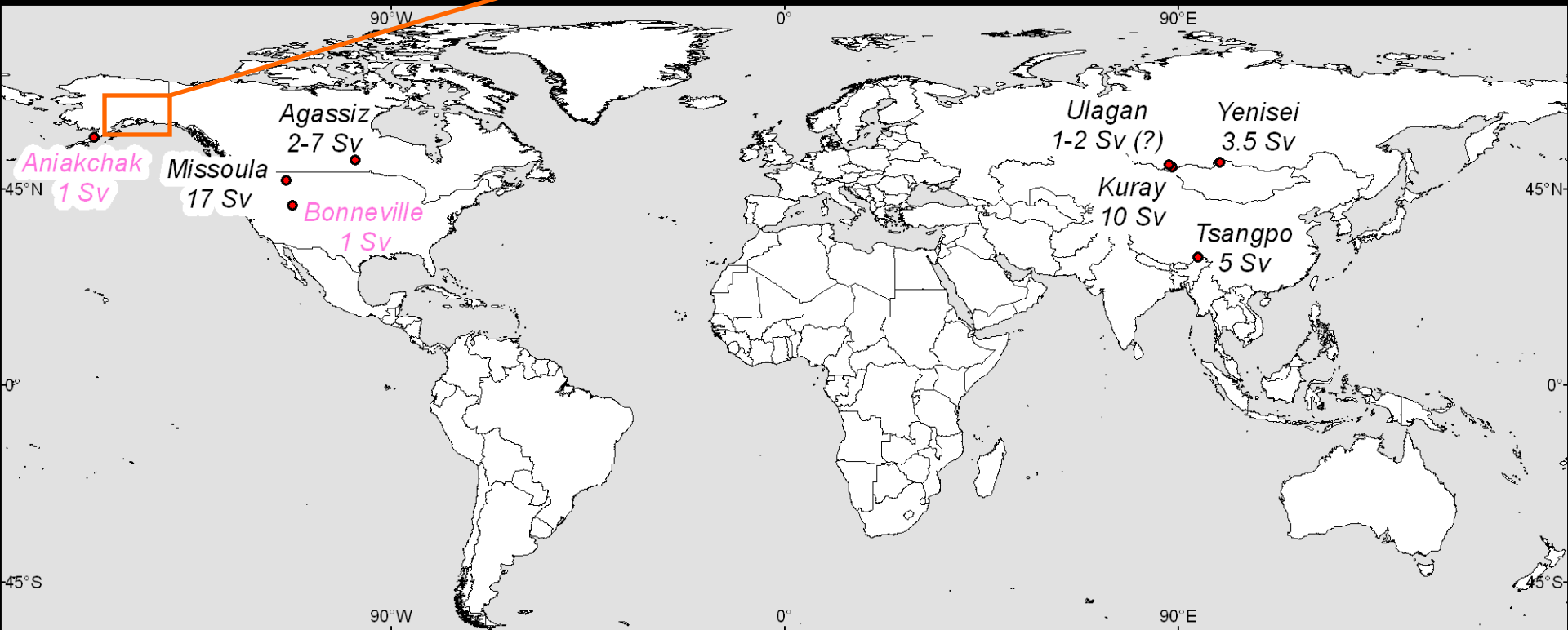


Teller et al. 2002

Flushing Lake Atna:
Late Quaternary
Megafloods in

South-Central Alaska

To this list of largest freshwater floods,
we propose to add previously undescribed
south-central Alaska megafloods



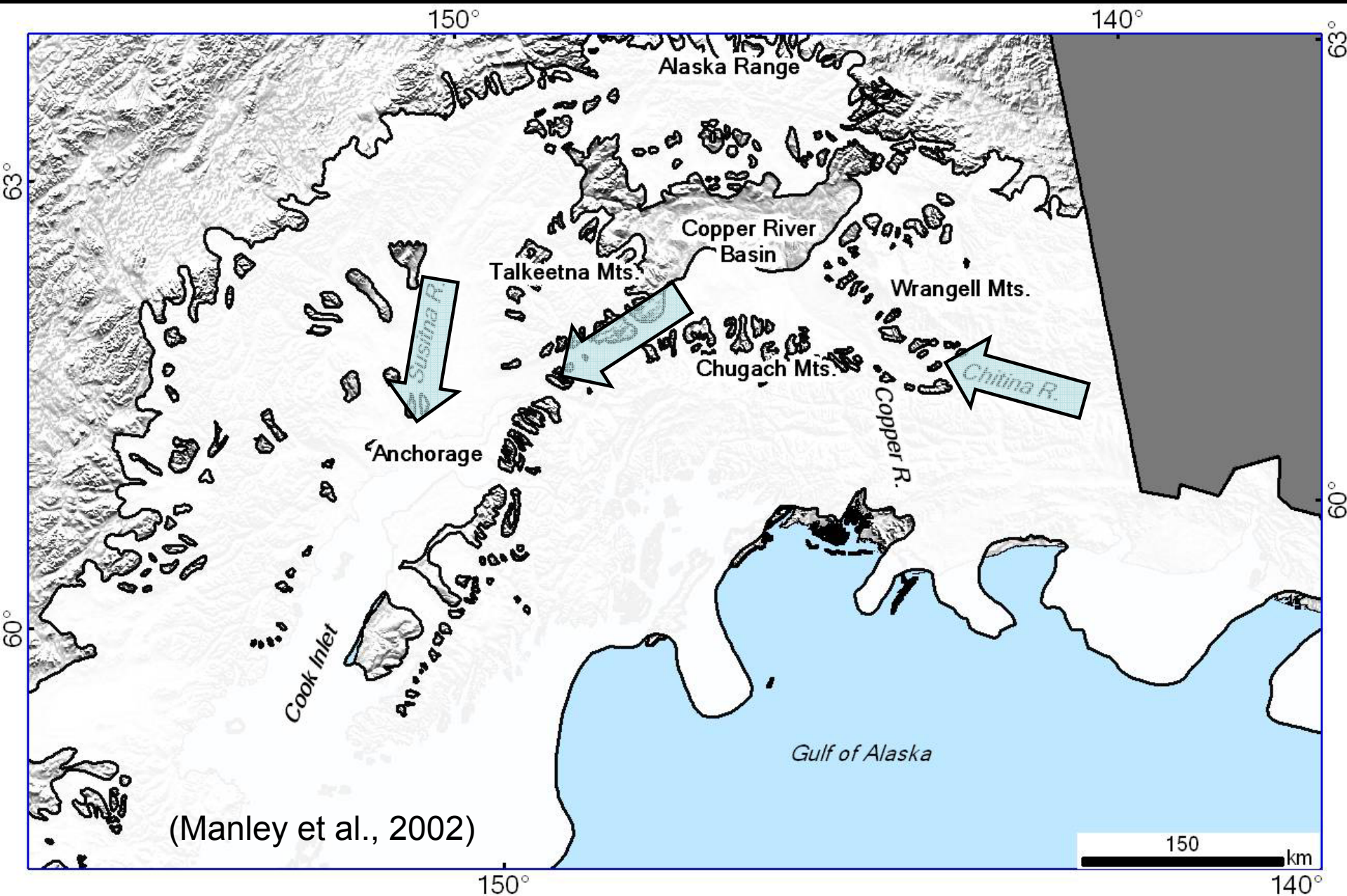
Wiedmer, M., Montgomery, D.R., Gillespie, A.R., and Greenberg, H.M., 2008, Evidence for Late Pleistocene Megafloods in Southcentral Alaska, USA Geological Society of America Abstracts with Programs, Volume 40, p. 219

Wiedmer, M., Montgomery, D.R., Gillespie, A.R., and Greenberg, H.M., *In Review*, Late Quaternary megafloods from Glacial Lake Atna, Southcentral Alaska, U.S.A: Quaternary Research

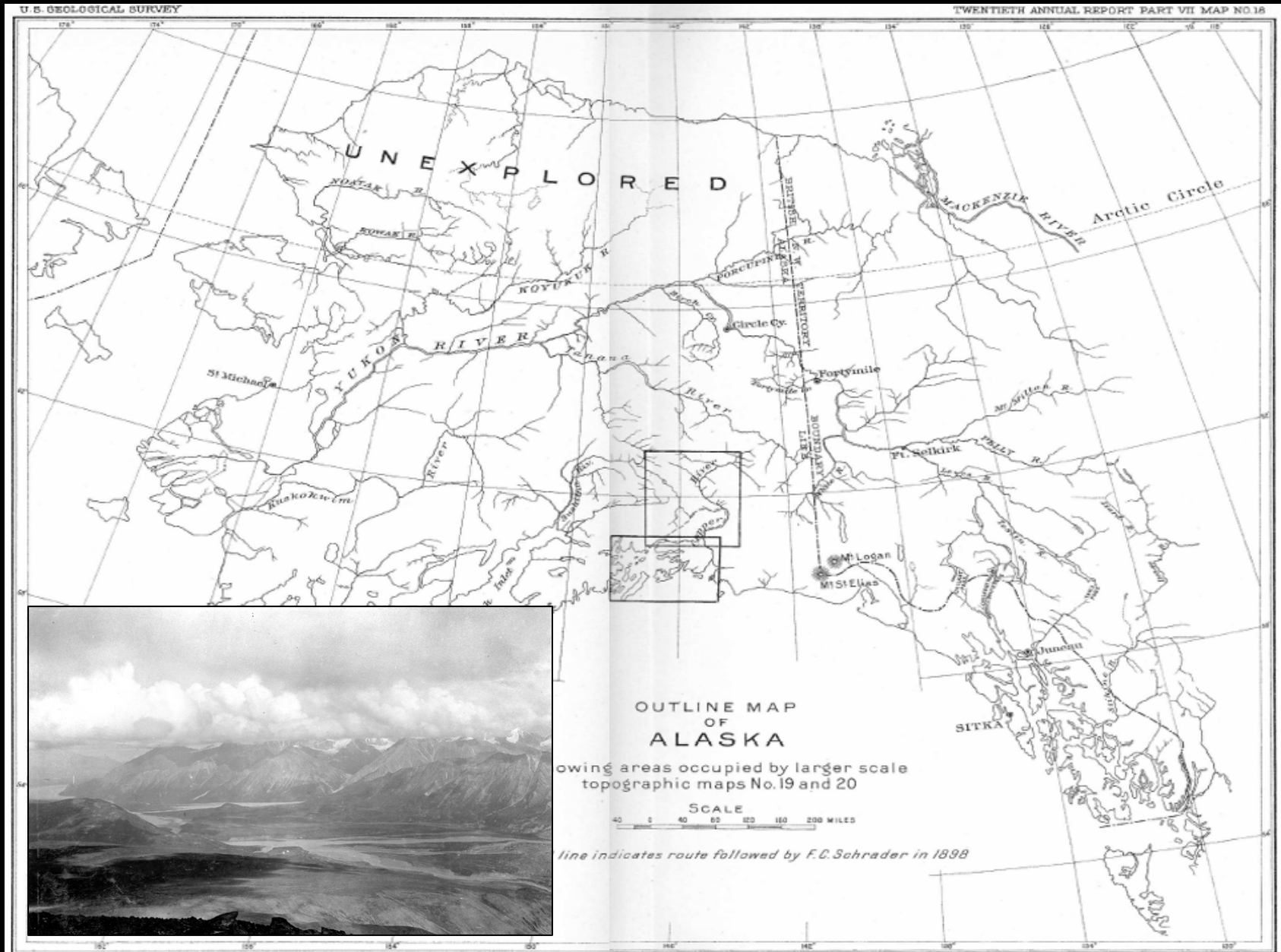
Modern south-central Alaska Terrain



Wisconsinan south-central Alaska Terrain



First geologist to visit Alaska's Copper River Basin (CRB) was F. C. Schrader, a member of the 1898 Abercrombie Expedition



In 1900, Schrader reported:

“The unconsolidated silts and gravel of the Copper River Basin probably exceeds 1,000 feet in maximum thickness. The extent of the beds covering, probably, more than 2,000 square miles leads to the view that they were most probably deposited *in some large lake or branch of the sea*. The beds are considered to be *Pleistocene* in age.”



In 1901, Schrader reported:

“Just kidding about the big lake.”

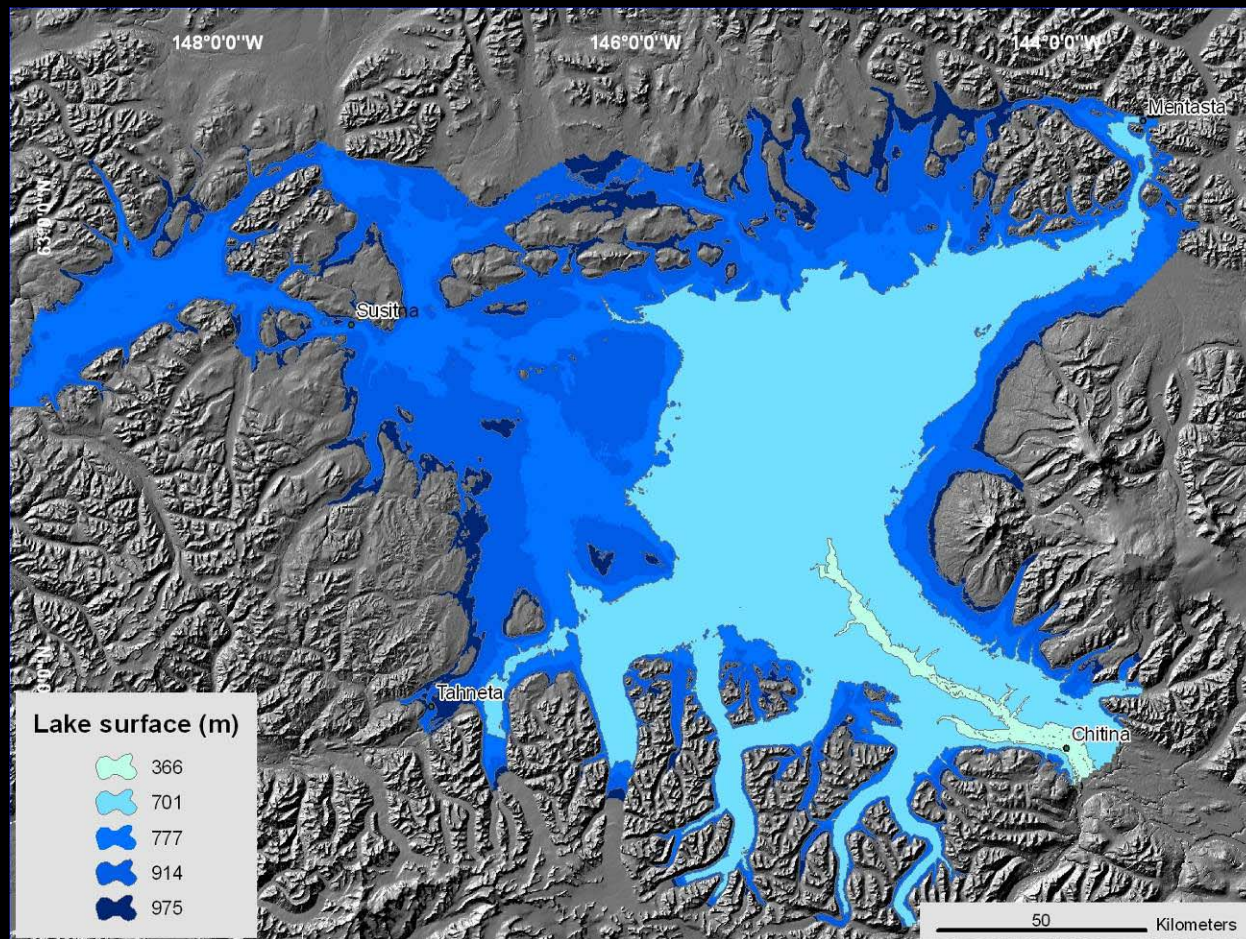


In 1965, for the CRB Nichols reported:



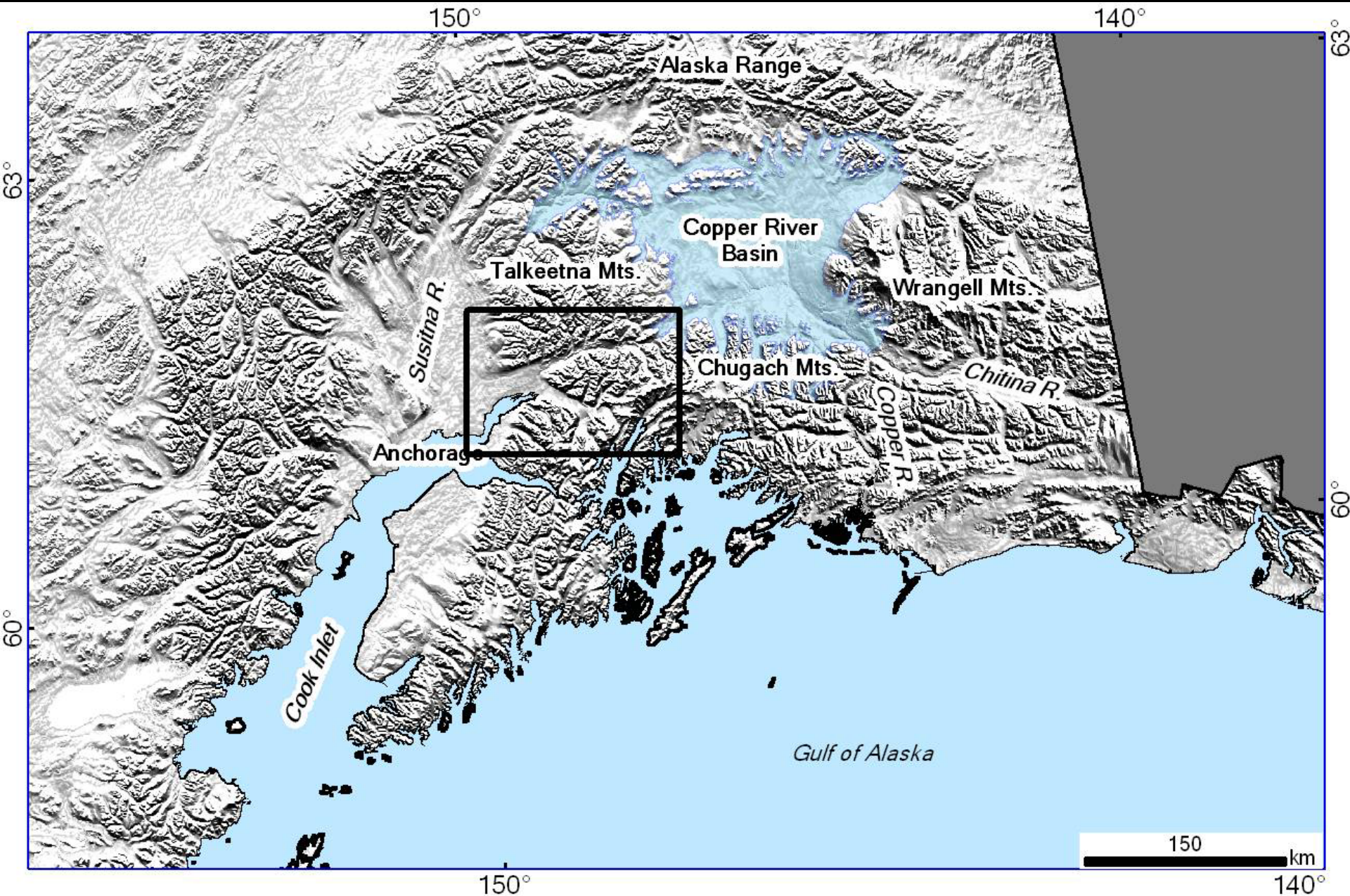
- evidence of 5 Pleistocene glacial advances and retreats
- each with extensive proglacial lakes
- last advance formed “Glacial Lake Atna” (first use of the name)

Latest Lake Atna:

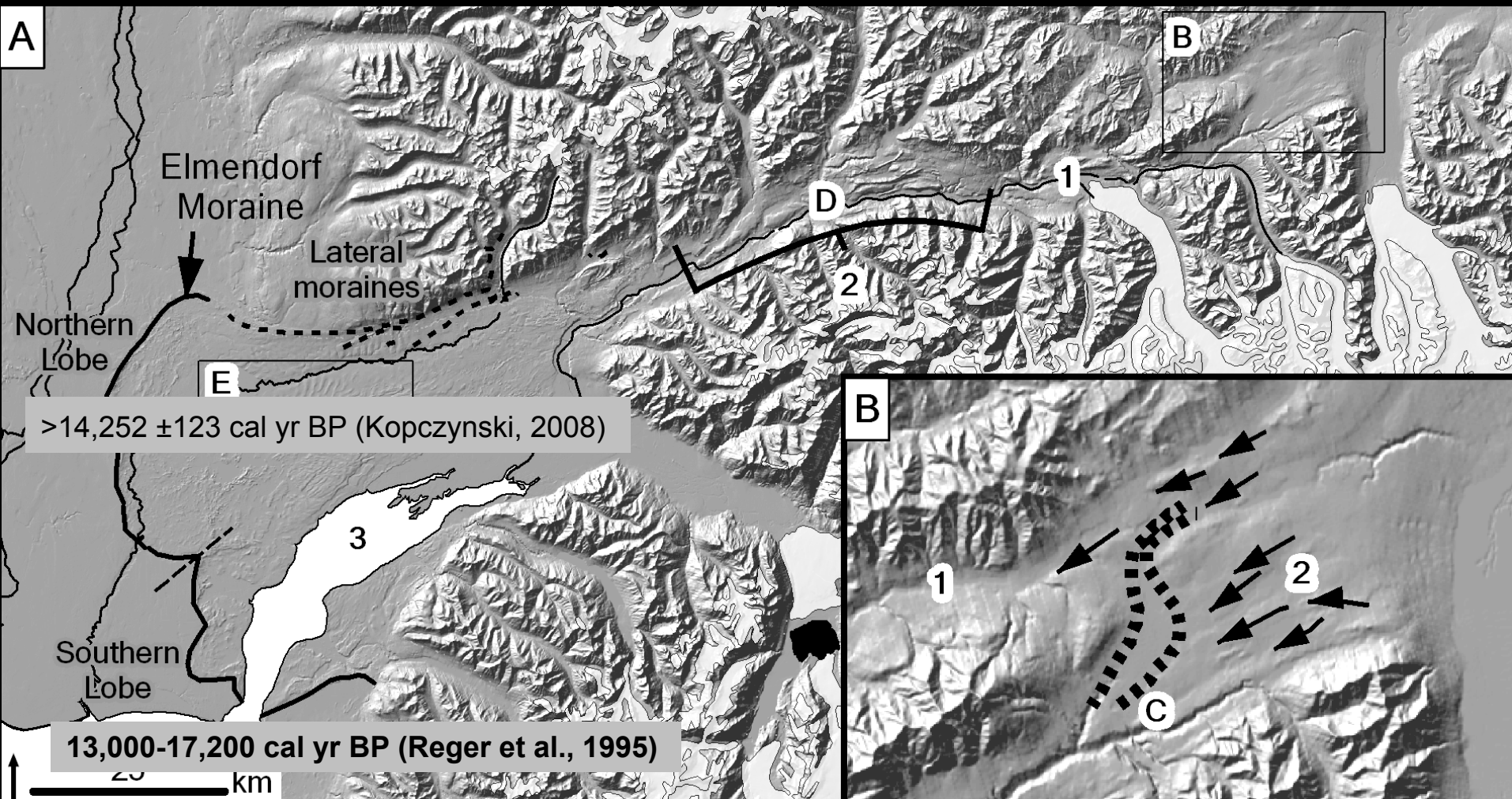


- Formed $>58,600 \pm 1100$ ^{14}C yr BP (Ferrians, 1984)
- Extent fluctuated before finally draining $>10,270-11,090$ cal yr BP (Rubin and Alexander, 1960)
- Multiple dominant lake levels

Matanuska Valley:



Matanuska Valley flood evidence:



B: Tahnetta Pass (907 m). Williams and Galloway (1986) identified an 8-km-wide flow path at ≤ 975 m from the CRB through Tahnetta Pass to the Matanuska Valley. Within this broad path they mapped shorelines of a distinct spillway at ~ 914 m

Matanuska Valley flood evidence:



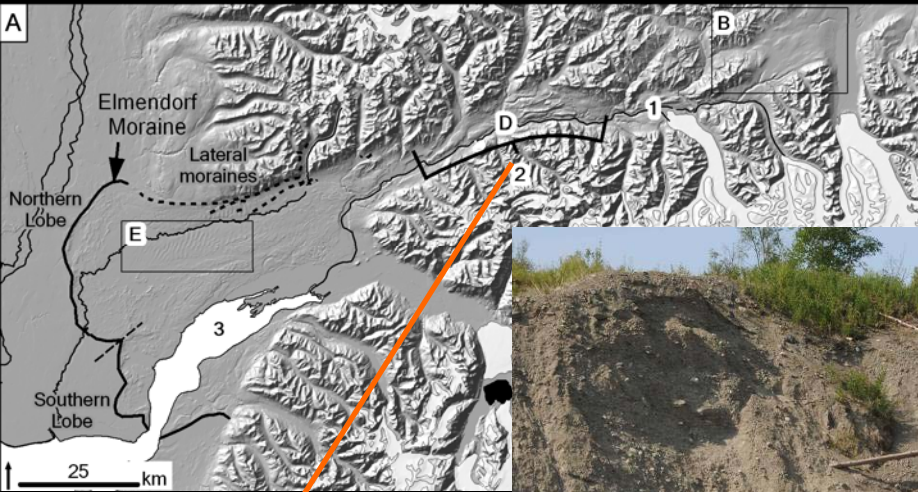
In unconsolidated CRB deposits immediately east of Tahneta Pass, a series of subparallel curvilinear longitudinal grooves ≤ 12 km long, ≤ 700 m wide, and ≤ 10 m deep converge toward the upper Matanuska Valley. These grooves are morphologically similar to those in other megaflood routes (Baker, 1978; Gupta et al., 2007) and appear to be confined elevations below 975 m. If produced by glacial ice, we would expect grooves higher up the valley slopes.

Matanuska Valley flood evidence:



C: An isolated streamlined bedrock-cored hill rises above the Tahnetta Pass floor. The base elevation of the hill prow is ~914 m, the length:width ratio is 3.2; comparable to Channeled Scablands streamlined island ratios representing an equilibrium form offering minimum drag and scour is apparent on each side of the hill.

Matanuska Valley flood evidence:

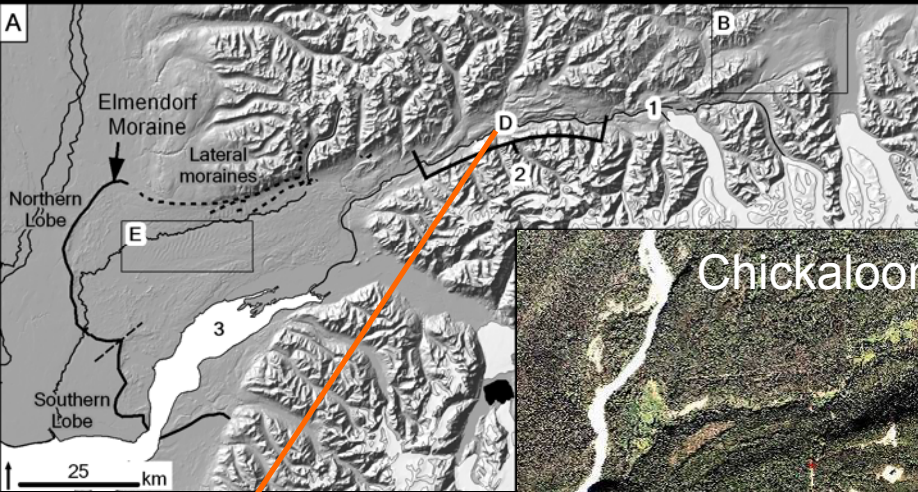


Till: Poorly sorted, unstratified, often angular glacial debris



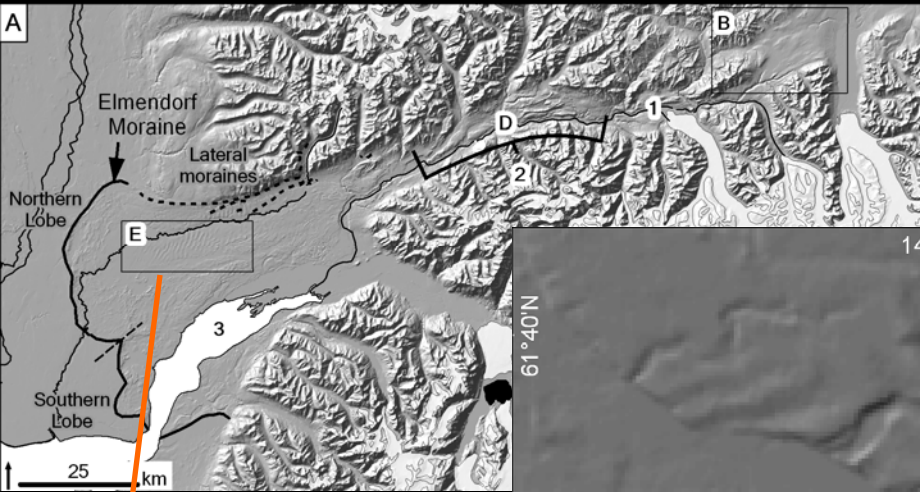
2: Although absence of both till and recessional moraines through the middle reaches of the Matanuska Valley (Williams, 1986) is consistent with flood scour, it is also consistent with catastrophic disruption prior to significant glacial recession.

Matanuska Valley flood evidence:

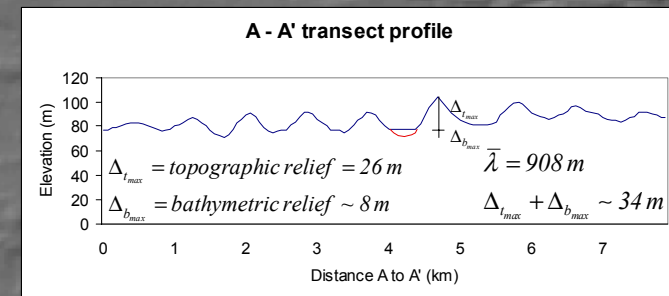
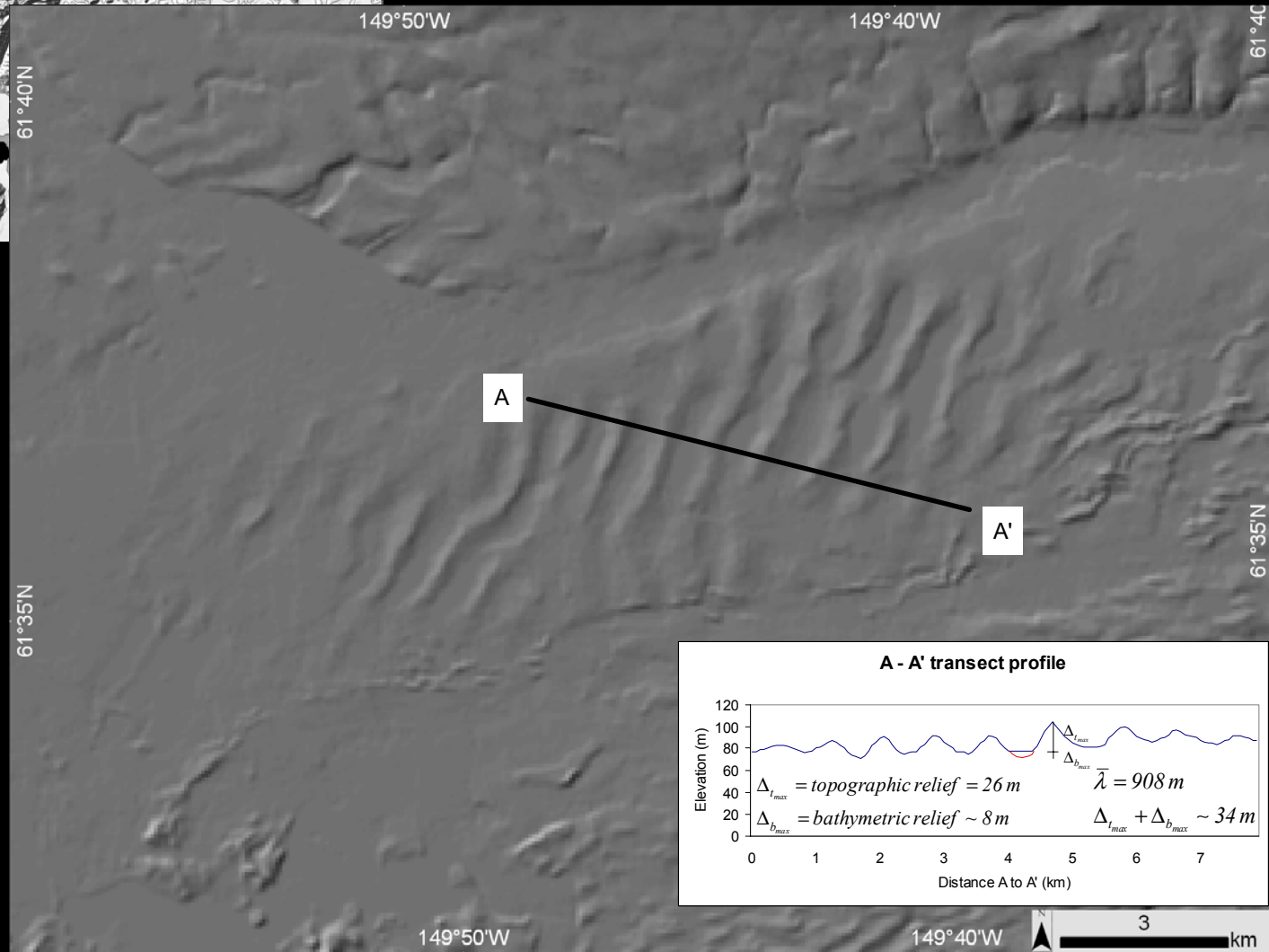


D: Another **airfoil-shaped hill** with L:W ratio of 3.2. Crescentic scour on the upstream side, oblique channel crossing longitudinal crest, and downstream tapering streamlines on adjacent channel floor are typical of similar “islands” in Channeled Scablands (Baker, 1978). Both Mat. Valley streamlined hills are in topographic highs, have no sediment on upper surfaces, and are in confined valleys where glacial flow would be rapid. If these hills were glacially formed crag-and-tail drumlins, we would expect L:W ratios of ~10+ (Briner, 2005; Kerr, 2007)

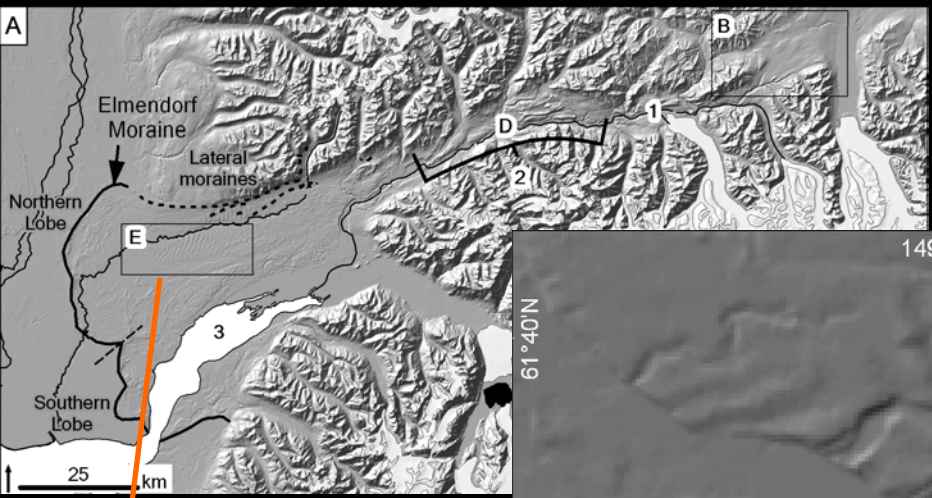
Matanuska Valley flood evidence:



~25 transverse
ridges
Height ≤ 34 m
Chord 0.9 km
Crestline ≤ 7 km
Stoss $2.1 \pm 0.8^\circ$
Lee $2.3 \pm 0.8^\circ$



Matanuska Valley flood evidence:



Few exposures within ridges
One behind Gorilla Fireworks
And behind an auto recycler

Fluvial materials deposited in dynamic environment:



Visible packet of foreset beds ~ 5 m high

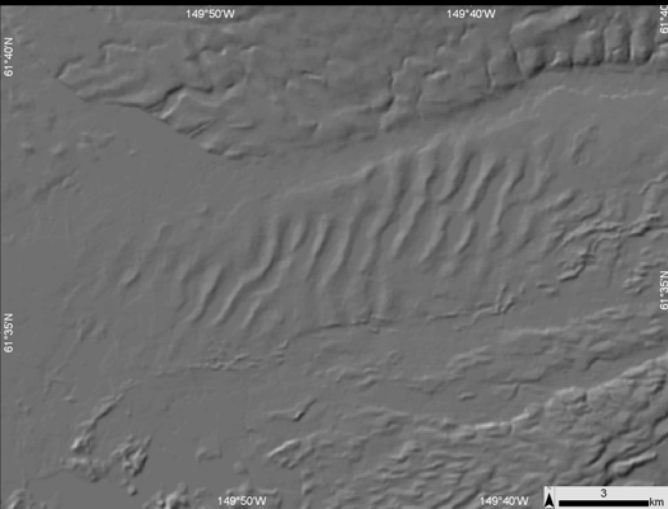


Fluvial section with clean sand to cobble foresets dipping 20 degrees ~west (down valley).



Scarce boulders ≥ 1 m

Previous interpretations of transverse ridges:

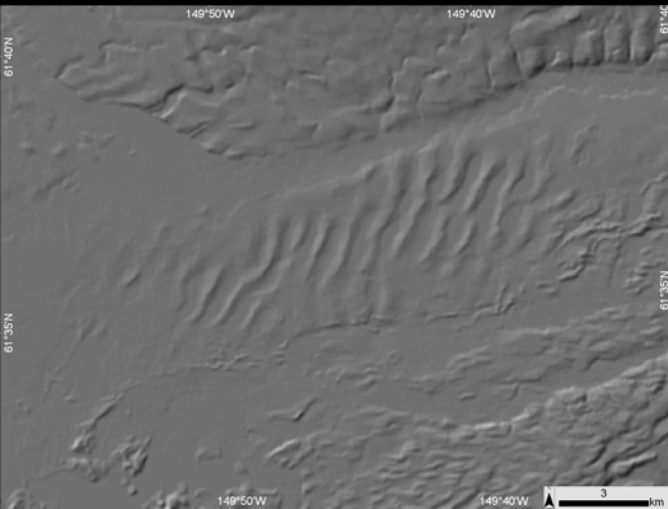


Folded medial moraine (Trainer, 1953)

However, not consistent with:

- Fluvial deposits
- Y-junctions
- Chord length regularity and height trends

Previous interpretations of transverse ridges:

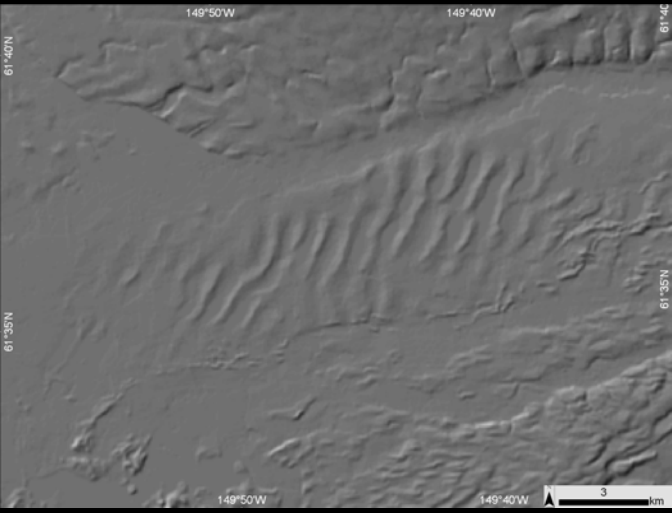


Rogen moraine (Reger and Updike, 1983)

However, not consistent with:

- Fluvial deposits
- Y-junctions
- Chord length regularity and height trends
- Lack of crescent-shaped distal margins
- Lack of fluting and/or hummocky surfaces
- Lack of terminal ridge horns

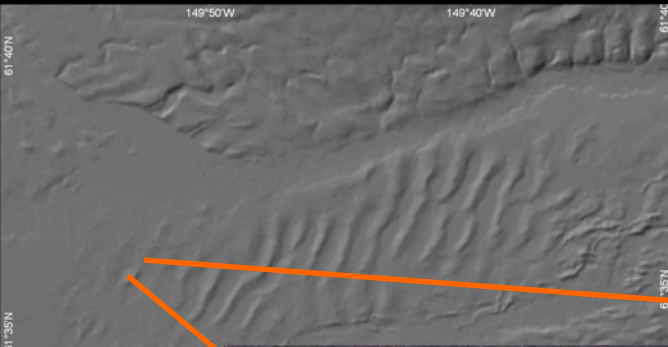
We propose they are water formed dunes:



Dunes are signature features of megaflood routes

“DeGreer Moraines” superposed on large dunes

(≤ 3 m high) subparallel ridges, symmetrical in cross section uniform in ridge morphology. These smaller ridges are spaced < 100 m apart, are constructed of well-washed poorly bedded gravelly alluvium



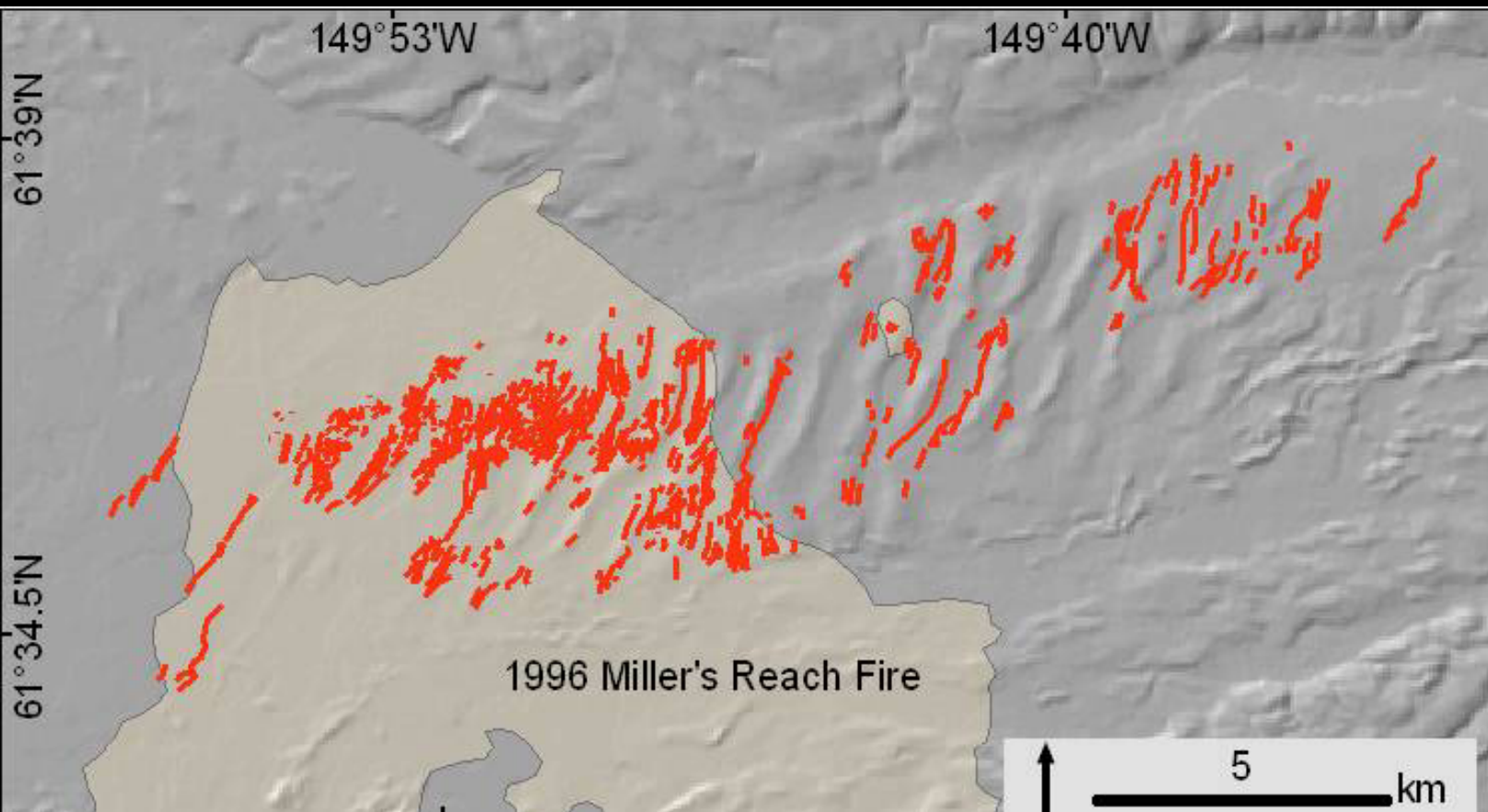
“DeGreer Moraines”: Bad News!



DeGreer moraines are thought to be recessional glacial moraines recording annual glacial retreat.

But we think the flood came after the Matanuska Glacier began retreating, so the flood should have erased these ridges!

“DeGreer Moraines”: Bad News?



When we mapped the DeGreer moraines we found they are restricted to the footprint of the large dunes and are oriented in concert with the larger “parent” dune.

Suggests a common genesis

“DeGreer Moraines”: Smaller water formed dunes?

Analyses of modern river bedforms suggests:

- Superposed dunes are generated during rapidly decreasing discharges.
- Where 2 orders of transverse bedforms are preserved, they differ in scale by ~1 order of magnitude (Allen and Collinson, 1974).
- *In height and chord length, the 2 orders of Wasilla dunes also differ by ~1 order of magnitude and are built of alluvium!*
 - Superposed dunes seen on Channeled Scablands Great Pangborn Bar (Waite, pers. com. 2009)

Classification of 2 orders of dunes

TABLE 6.— *Classification scheme recommended by the SEPM Bedforms and Bedding Structures Research Symposium*

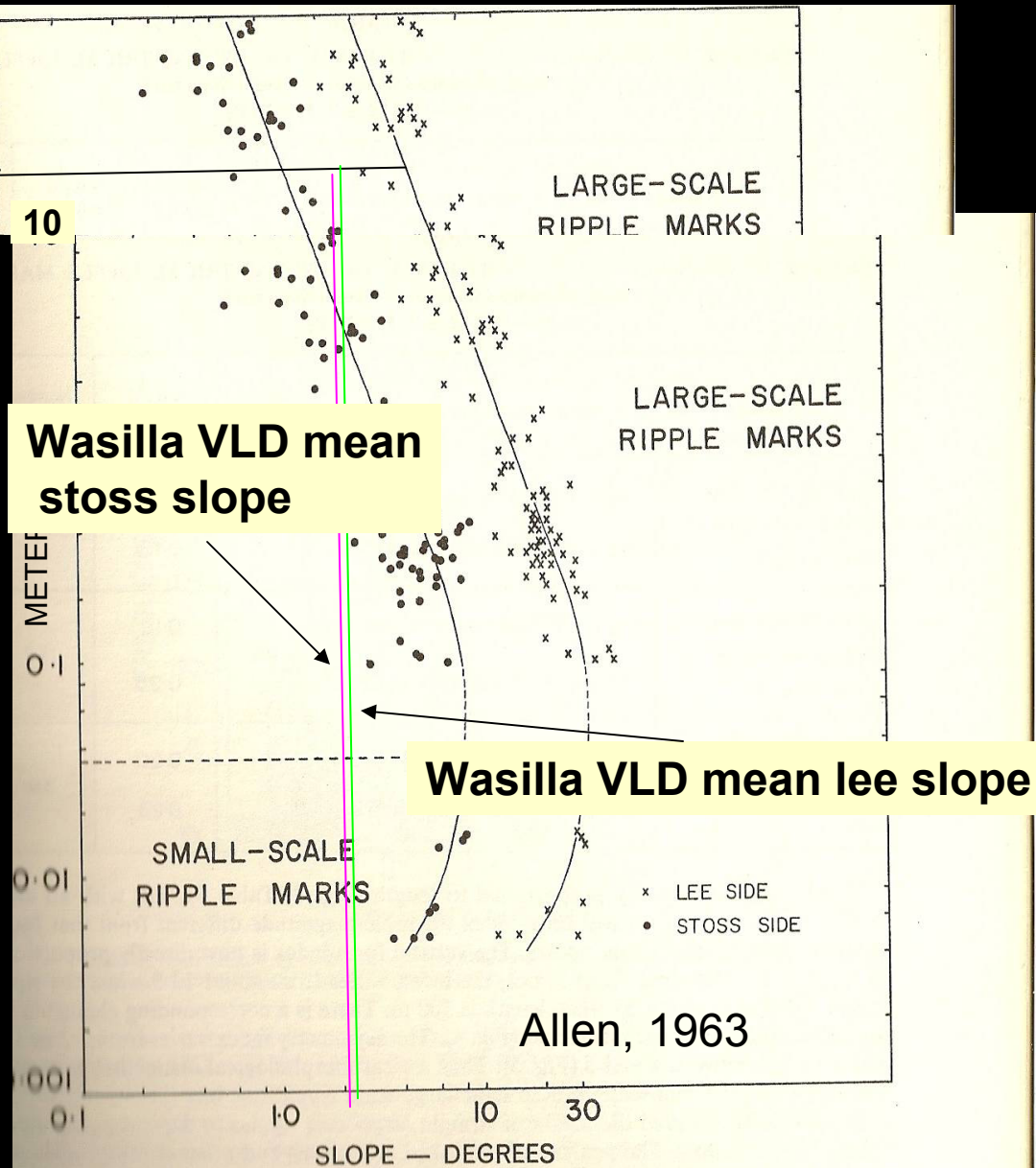
Subaqueous Dune				
First Order Descriptors (necessary)				
Size: Spacing =	small 0.6–5 m;	medium 5–10 m;	large 10–100 m;	very large >100 m
Height* =	0.075–0.4 m;	0.4–0.75 m;	0.75–5 m;	>5 m
Shape	2-Dimensional			
	3-Dimensional			
Second Order Descriptors (important)				
– Superposition: simple or compound (sizes and relative orientation)				
– Sediment characteristics (size, sorting)				
Third Order Descriptors (useful)				
– Bedform profile (stoss and lee slope lengths and angles)				
– Fullbeddedness (fraction of bed covered by bedforms)				
– Flow structure (time-velocity characteristics)				
– Relative strengths of opposing flows				
– Dune behavior-migration history (vertical and horizontal accretion)				

Ashley et al. 1990

* Height calculated using the equation $H = 0.0677L^{0.8098}$ (Flemming 1988).

= 2-D symmetric very large compound subaqueous dunes
(VLD)

Empirical relation between dune height and slope

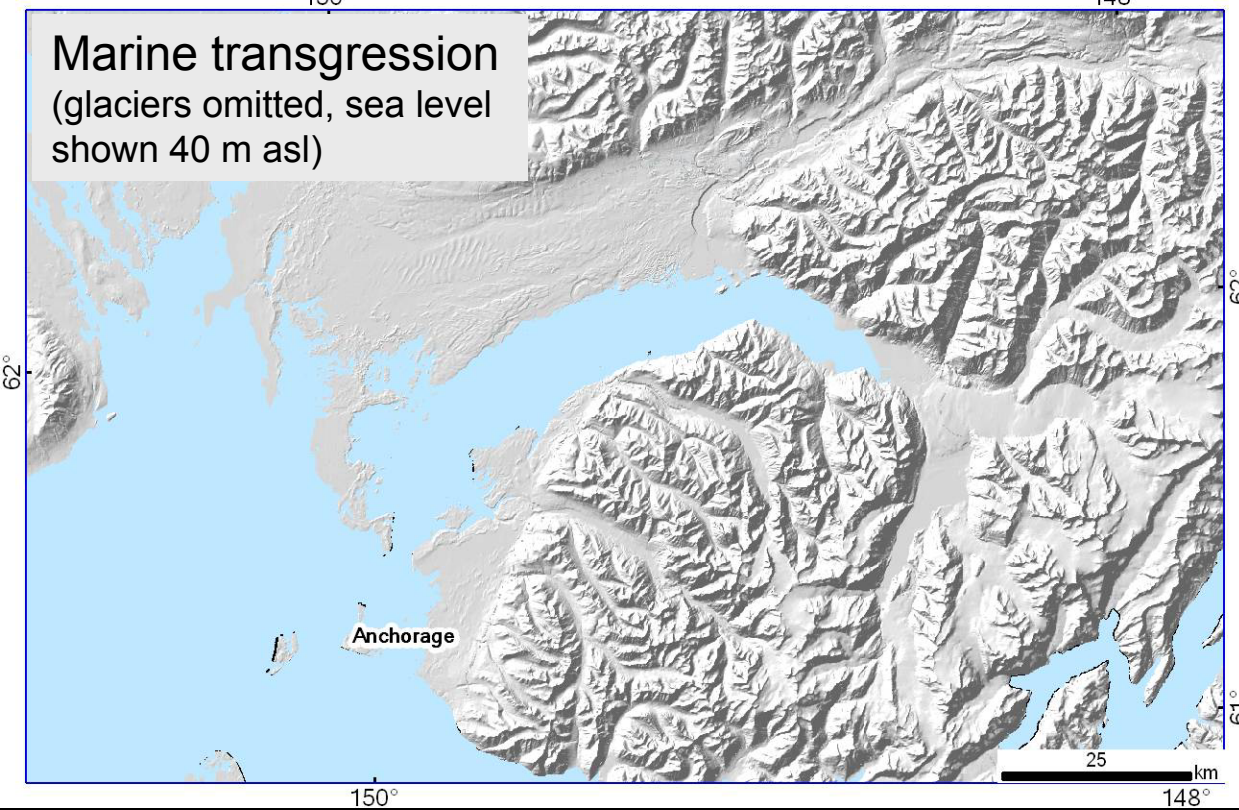


Wasilla VLD stoss and lee slopes conform reasonably well with empirically derived relationships between slope and dune height

Also good fit with predicted mean dune height and dune chord relationships (Allen 1968; not shown)

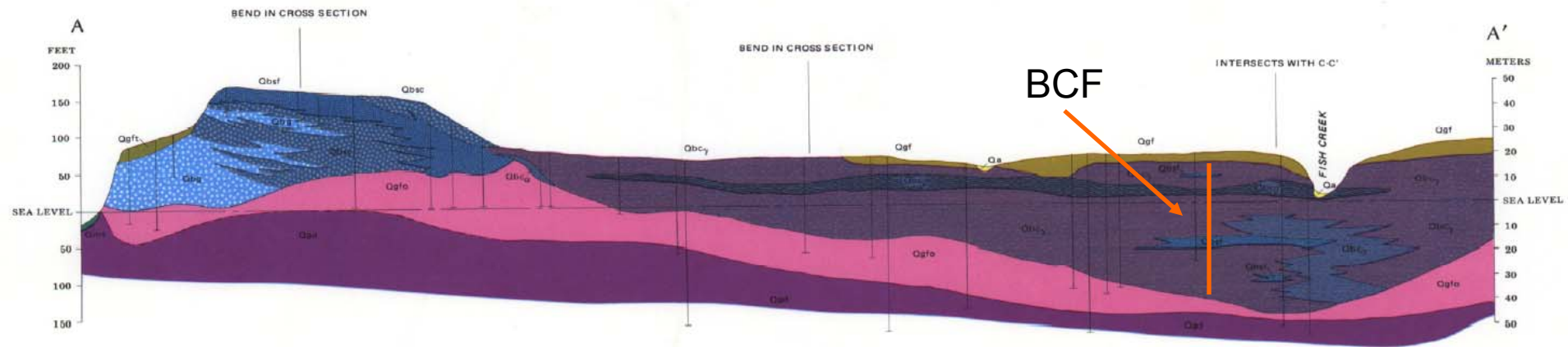
4. Ripple steepness related to height for modern straight small-scale and straight large-scale asymmetrical ripple marks. Sources of data: Cornish (1901a), Kindle (1917), Van Veen (1935), Hantzschel (1938), Stride and Cartwright (1958).

Marine transgression
(glaciers omitted, sea level
shown 40 m asl)

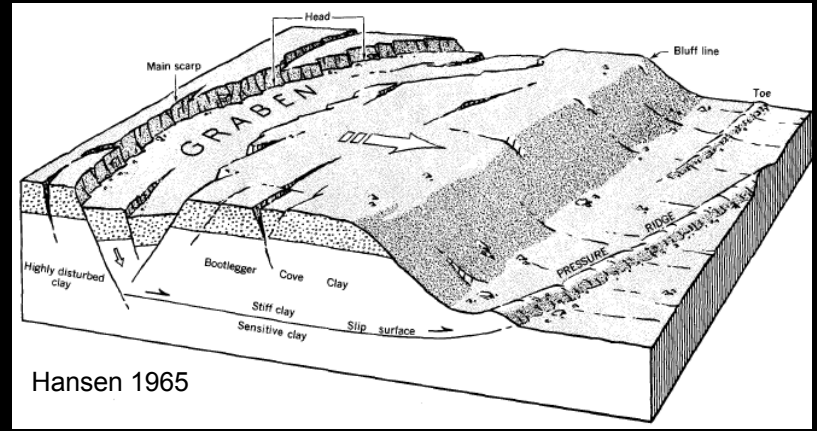


Supporting evidence

The Cook Inlet-Susitna Lowlands were isostatically depressed, marine and estuarine waters transgressed into the Anchorage area as glaciers receded, depositing ≥ 60 m of unconsolidated clays, silts, and sands = Bootlegger Cove Formation (BCF); 7 recognized BCF facies developed in response to energetic fluctuations of the depositional environment.



Supporting evidence



Hansen 1965

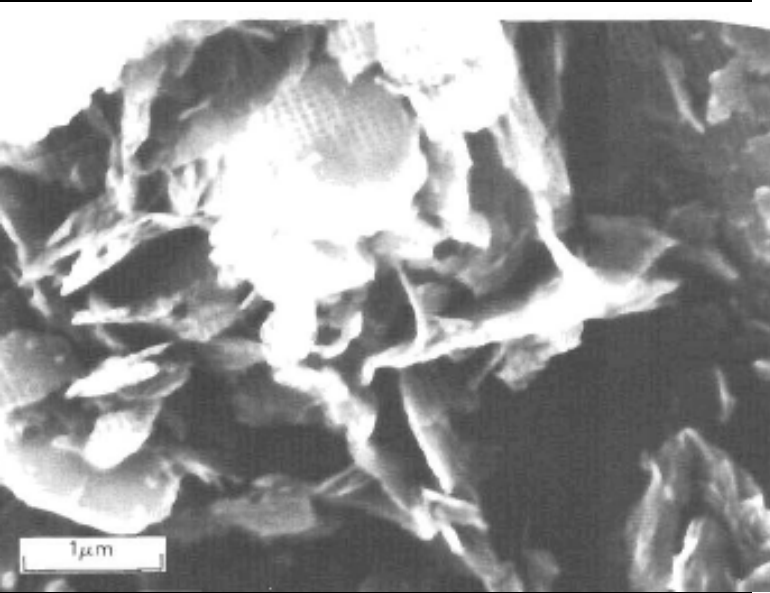
Slip surface of translatory slides
confined to specific sensitive BCF facies



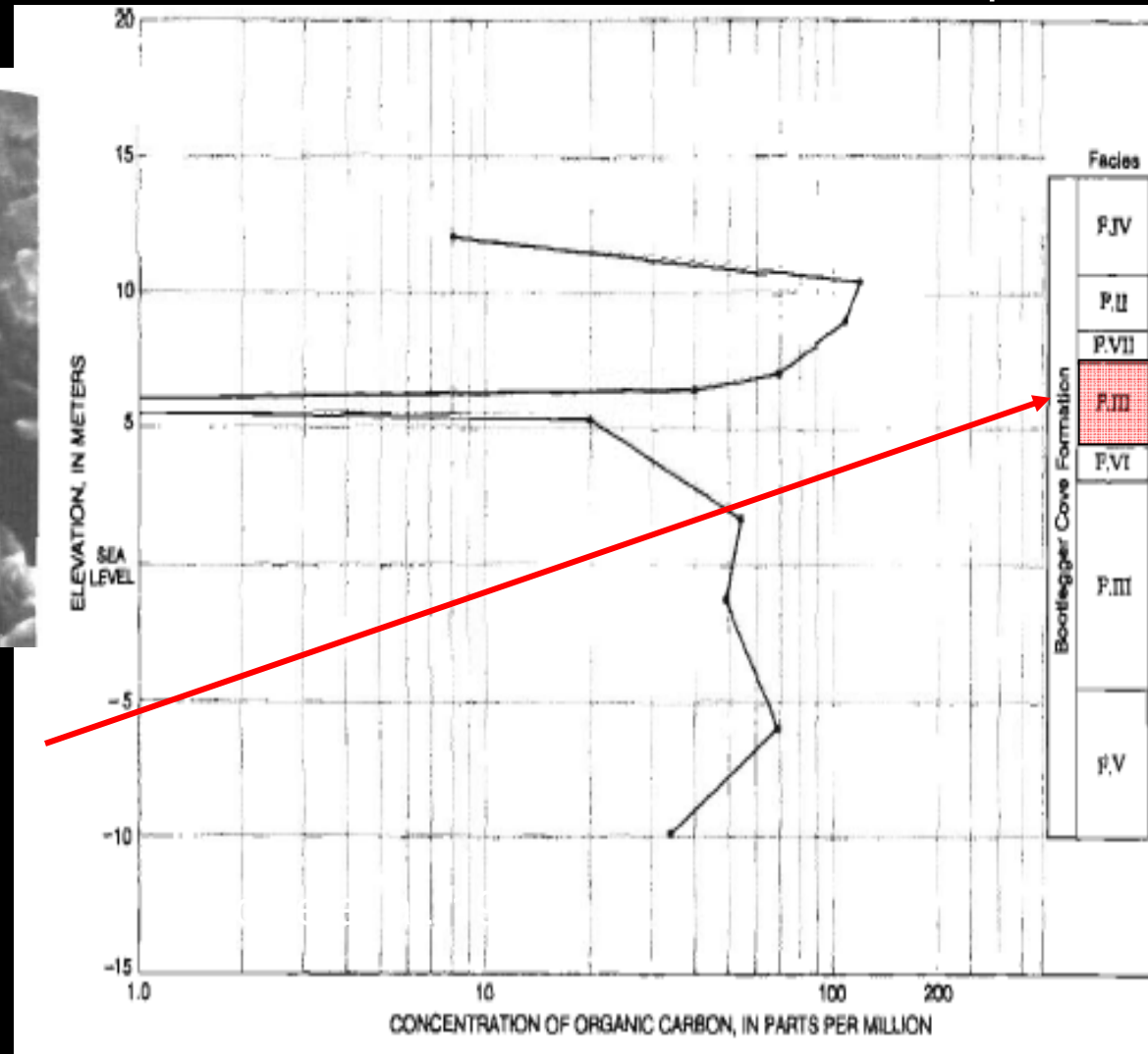
The magnitude 9.2 1964
Alaska earthquake caused
massive damage in
Anchorage, primarily
through catastrophic
landslides, caused by
failure of a narrow zone
within the BCF: Facies III

Supporting geotechnical evidence

Specific BCF strata under Anchorage may have been deposited in a turbulent, freshwater pulse.



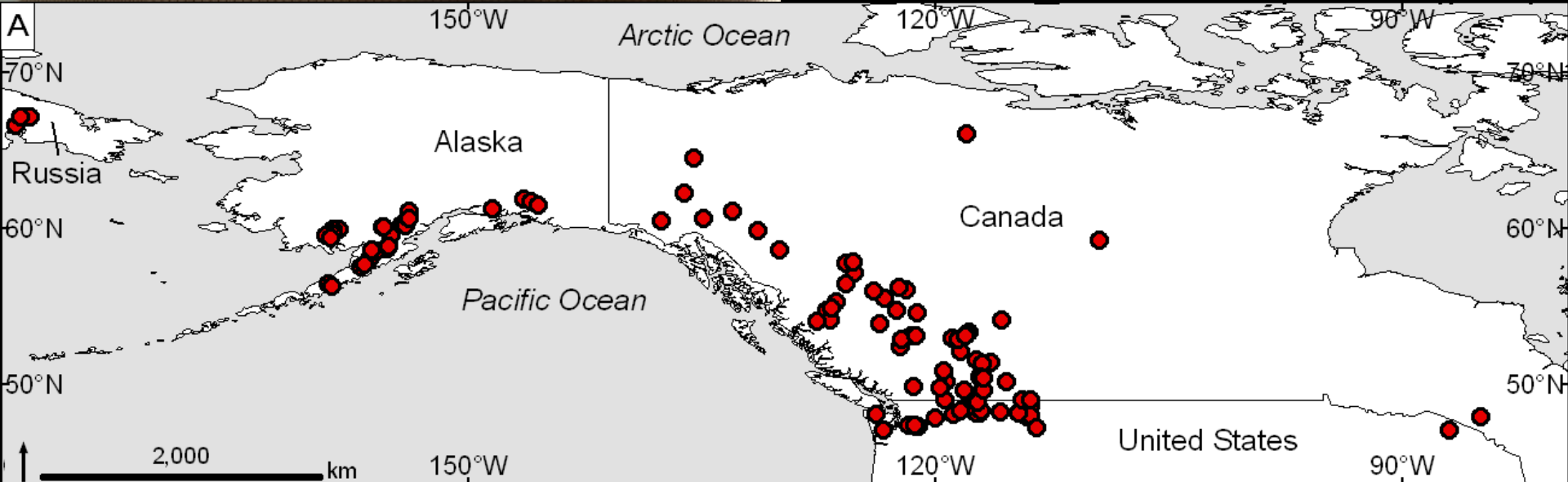
Microfabric of sensitive facies a “card-house” of flocculated clays: deposition in a turbulent environment?



Pore water chemical and isotopic signature of sensitive facies indicates non-marine source, not consistent with leaching.

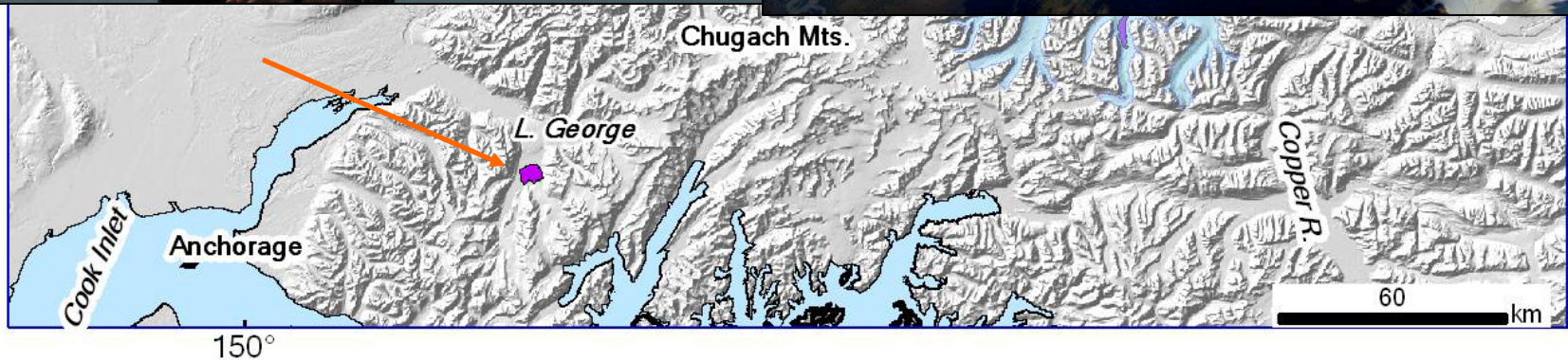
Supporting biogeographic evidence

Pygmy whitefish *Prosopium coulterii*



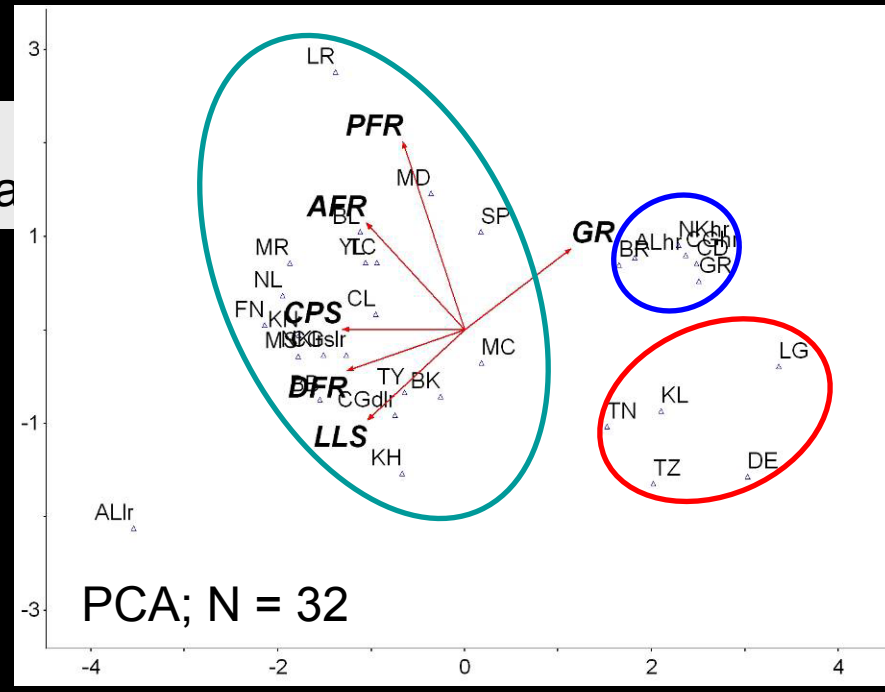
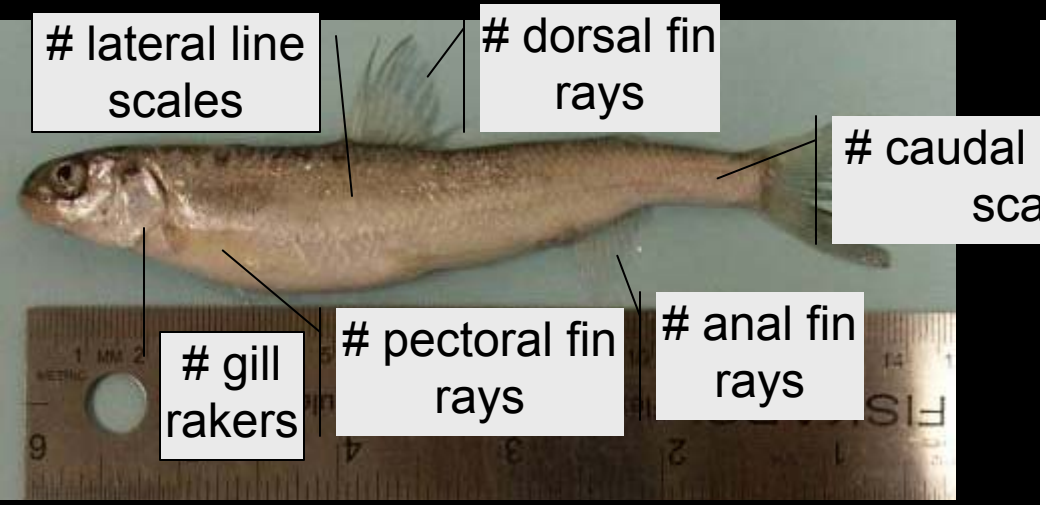
Global documented distribution of pygmy whitefish. Highly disjunct distribution, typically deep lakes and glacially fed rivers, most within the footprint of the Laurentide and Cordilleran ice sheets

Supporting biogeographic evidence

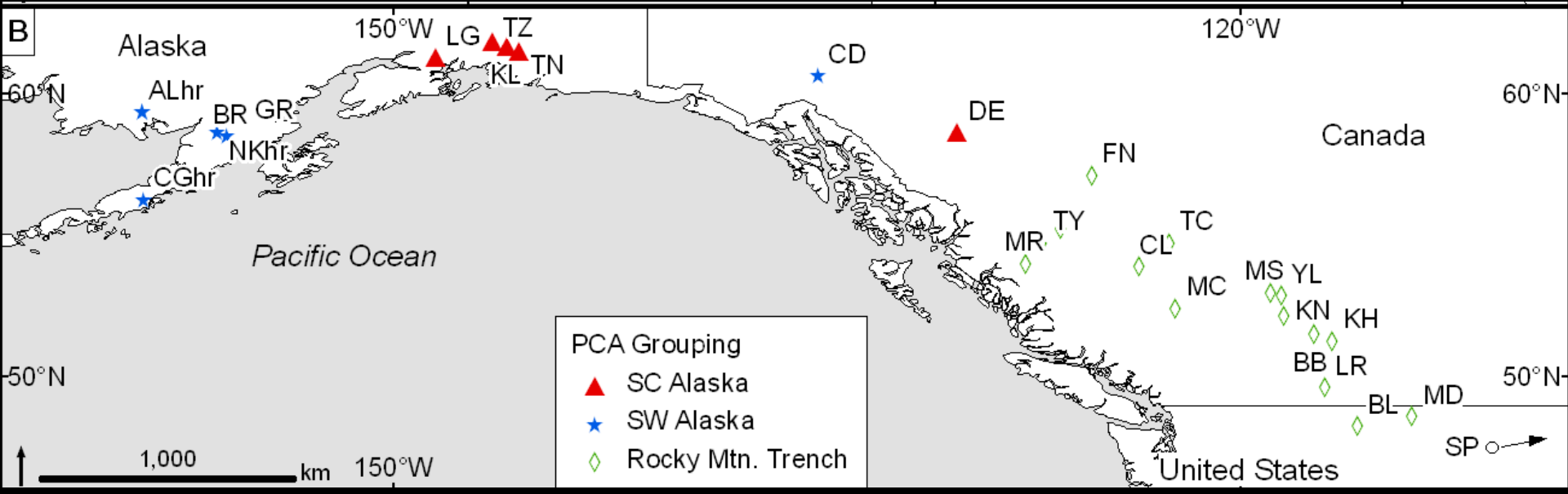


In 2005, Wiedmer found pygmy whitefish in Lake George, a proglacial lake in the Cook Inlet basin. This is the only reported occurrence in the entire basin.

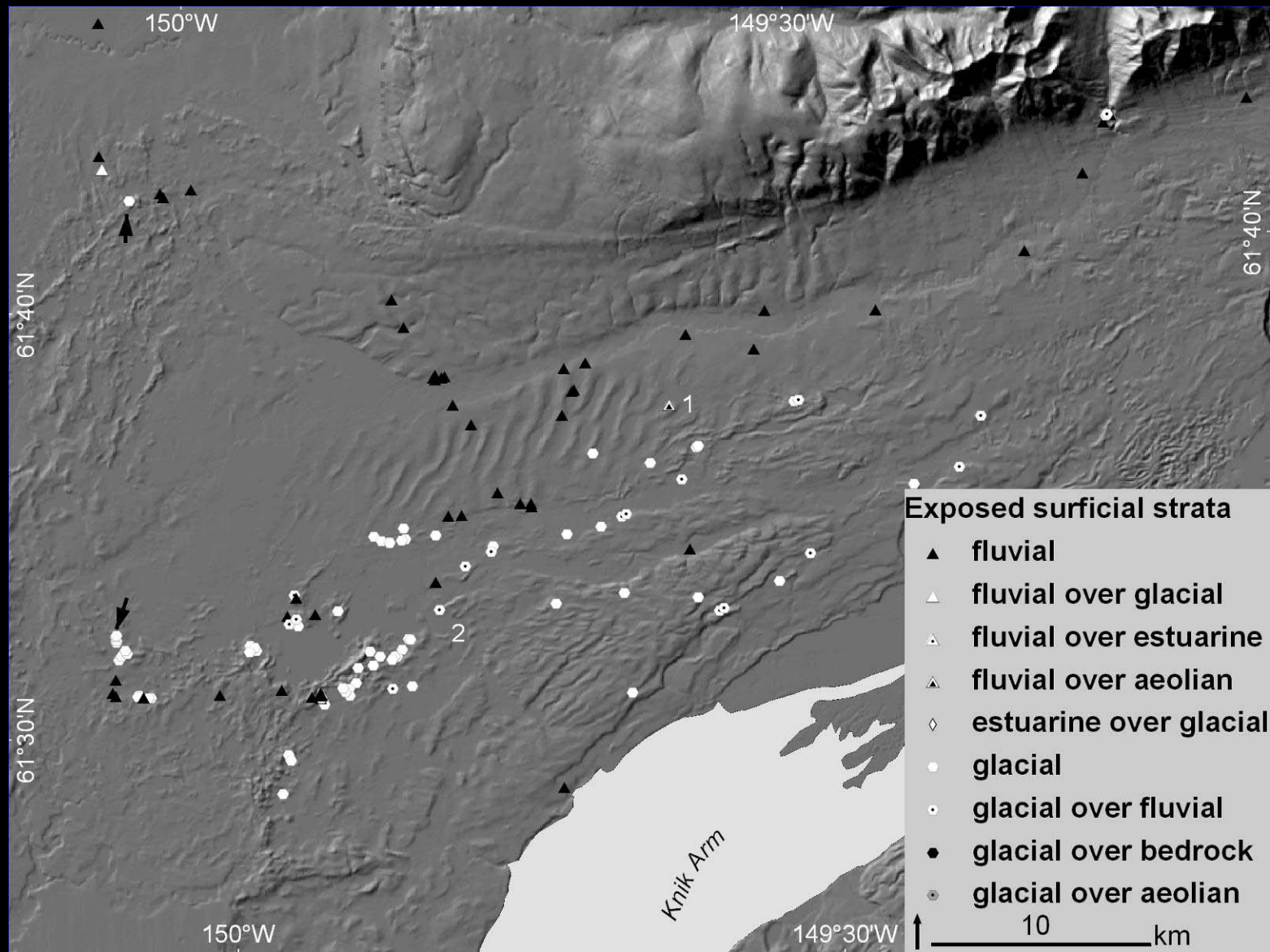
Supporting biogeographic evidence



Pygmy whitefish meristic analysis suggests an affinity between the Lake George population and those in the CRB

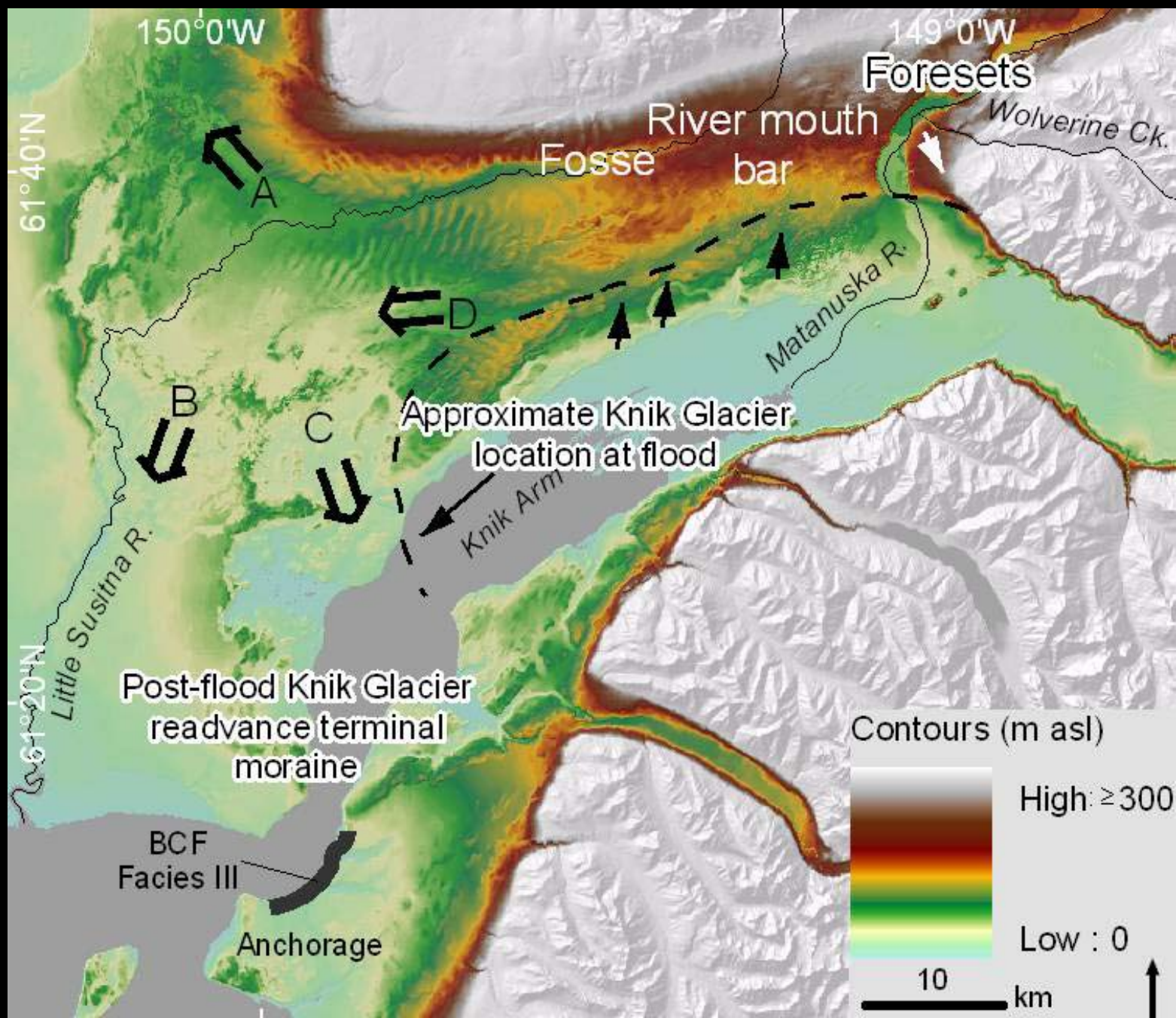


Boots on the ground

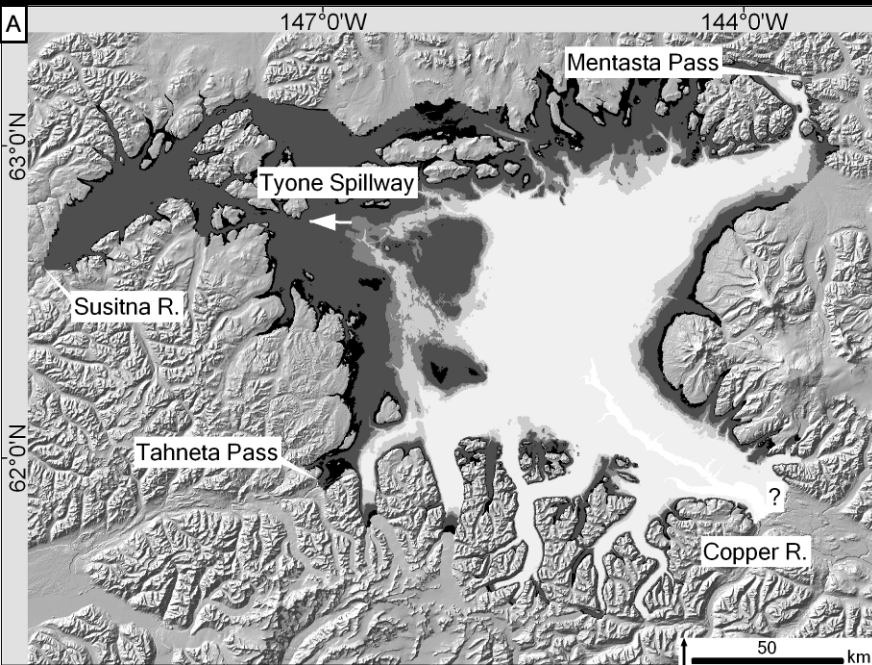


Surficial geology mapping supports interpretation that Matanuska Valley fluvial material dominates the northern portion of the region and Knik Glacier diamict (including readvance over fluvial) dominates the southern portion.

Flood reconstruction

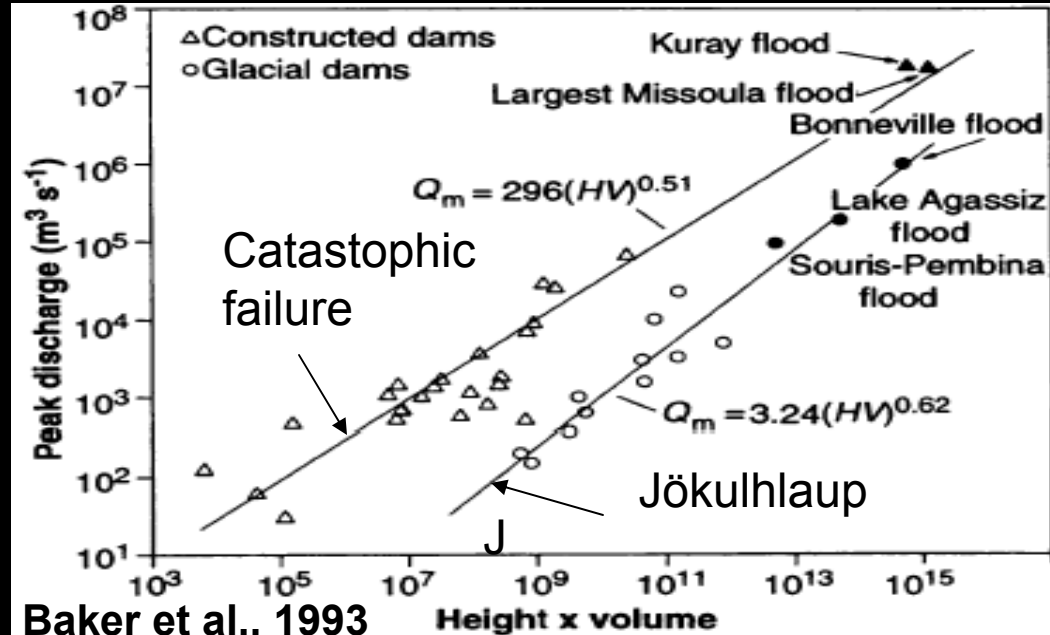


Reconstructing Lake Atna discharge volumes and fluxes



Lake surface elevation (m)	Note	Outlet
975	Highest reported lake level	
914	Highest stable level	Tahnetta Pass/Matanuska Valley
777	Temporary lake level	Susitna
747	Stable lake level	Susitna
701	Stable lake level	Mentasta Pass/Tok River
366	Lowest mapped shoreline	Copper River

Discharge a function of water level at dam and volume of impounded water and dam failure mode.

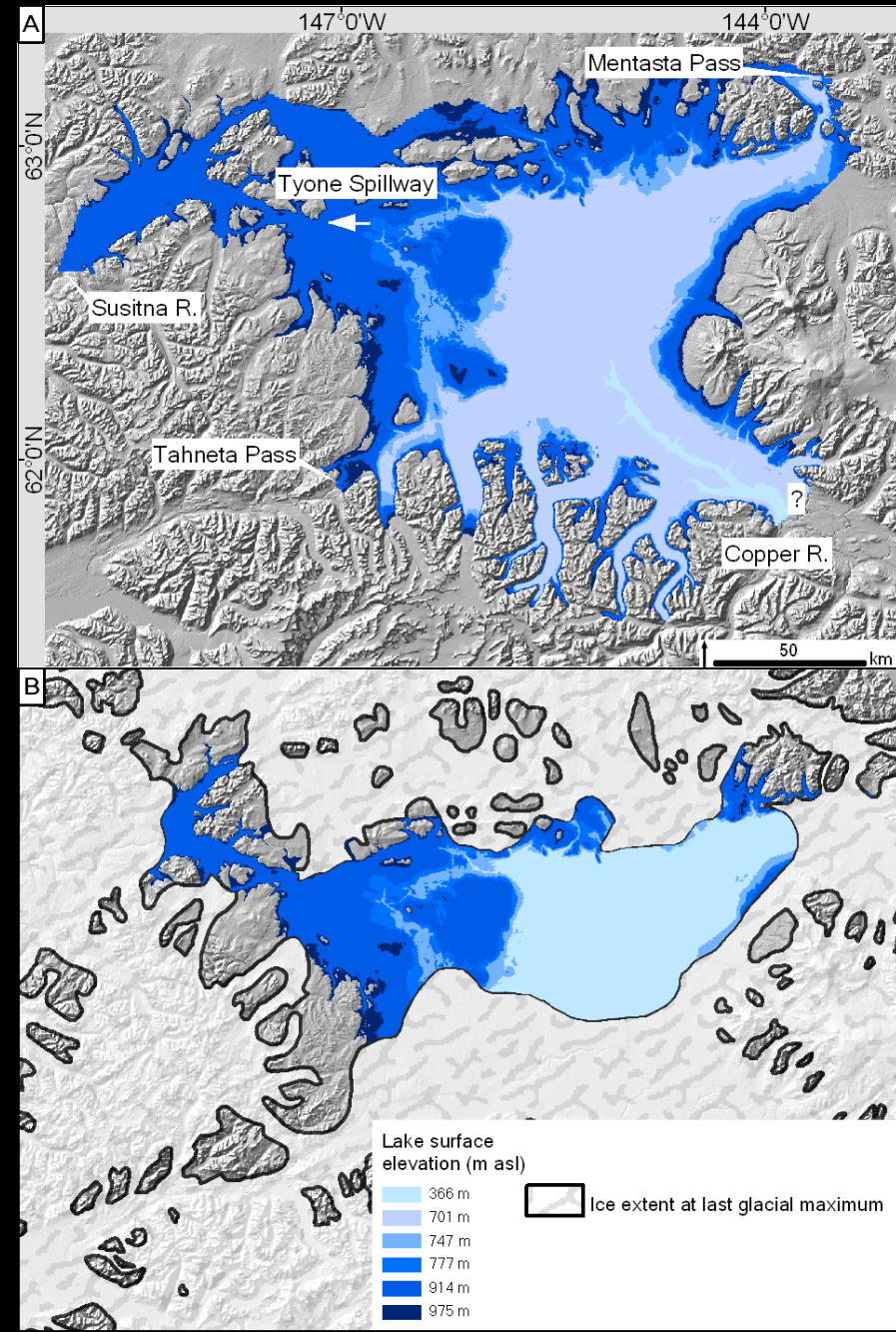


Baker et al., 1993

Reconstructing Lake Atna discharge volumes and fluxes

We know the glacier front extended into the CRB (otherwise there would be no Lake Atna), but we do not know how far, so for each key lake level we calculate lake volume for 2 bounding conditions:

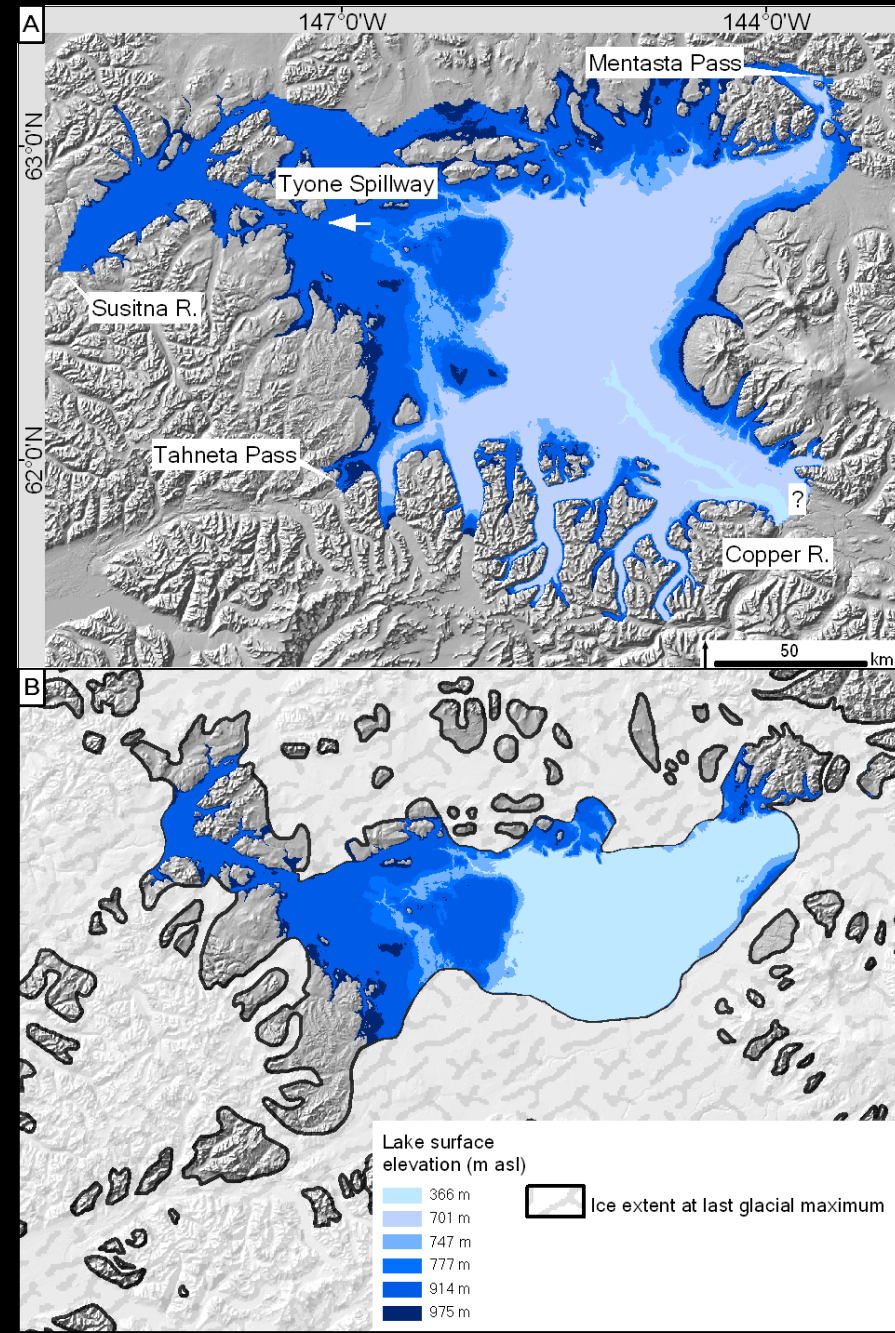
- No ice in basin
- Last glacial maximum (Manley, 2002)



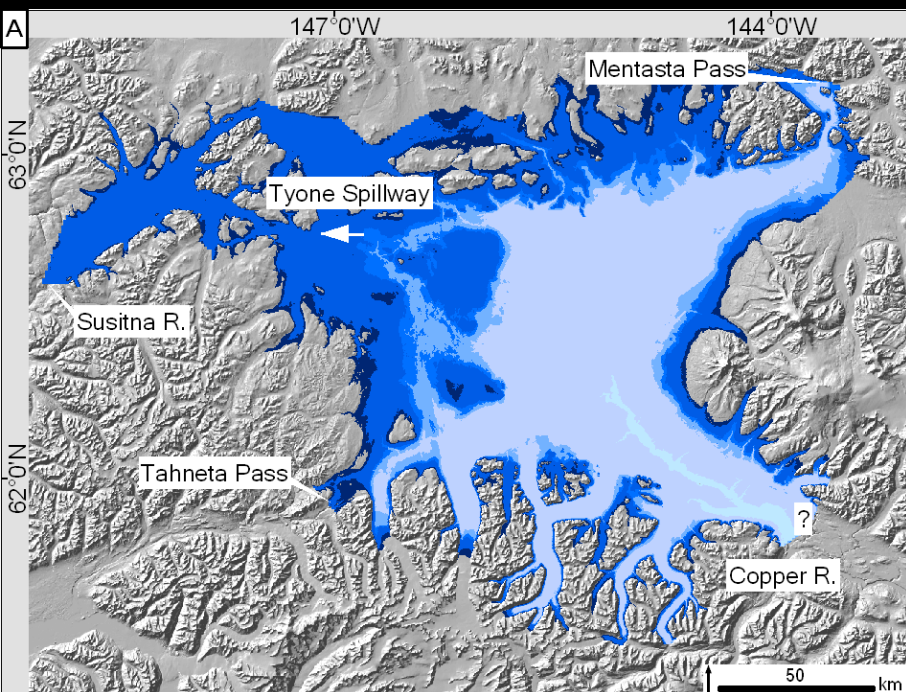
Reconstructing Lake Atna discharge volumes and fluxes

We know the glacier front extended into the CRB (otherwise there would be no Lake Atna), but we do not know how far, so for each key lake level we calculate lake volume for 2 bounding conditions:

- No ice in basin
- Last glacial maximum (Manley, 2002)
- Estimating duration:
 $t = V \times 0.5Q^{-1}$
Where t = time,
 V = decant volume, and
 Q = peak discharge (O'Connor et al., 2002)



Reconstructing Lake Atna discharge volumes and fluxes

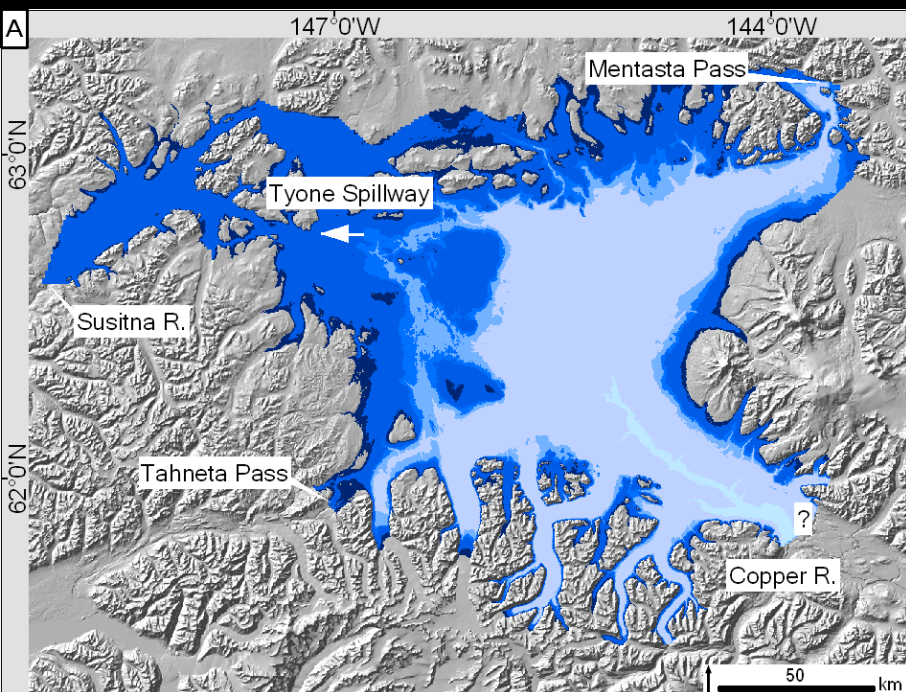


Previous largest floods

Location	Peak Discharge (Sv)
Missoula	17
Kuray	10
Lake Agassiz	2-7
Tsangpo	5
Yenisei	3.5
Ulagan	1-2 Sv?
Aniakchak	1
Bonneville	1

Outlet	Lake surface elevation		Initial area (10^3 km 2)	Initial volume (10^3 km 3)	Dam height (m)	Decant volume (10^3 km 3)	Maximum discharge		Duration	
	(m)	(m)					(10^6 m 3 s $^{-1}$)	(10^6 m 3 s $^{-1}$)	days	days
	pre-flood	post-flood					jökulhlaup	catastrophic failure	jökulhlaup	catastrophic failure
Tahnetta Pass	975	914	8.9-24.0	2.3-6.0	61	0.5-1.4	0.1-0.3	2.0-3.3	83-121	6-10
Susitna River	914	777	8.3-21.6	1.7-4.6	346	1.0-2.6	0.7-1.2	7.0-11.3	36-51	3-5
Mentasta Pass	747	701	4.6-11.5	0.5-1.6	46	0.2-0.5	0.07-0.1	1.0-1.6	68-96	4-7
Copper River	366	160	0.4	0.03	206	0.03	0.05	0.8	13	1

Reconstructing Lake Atna discharge volumes and fluxes

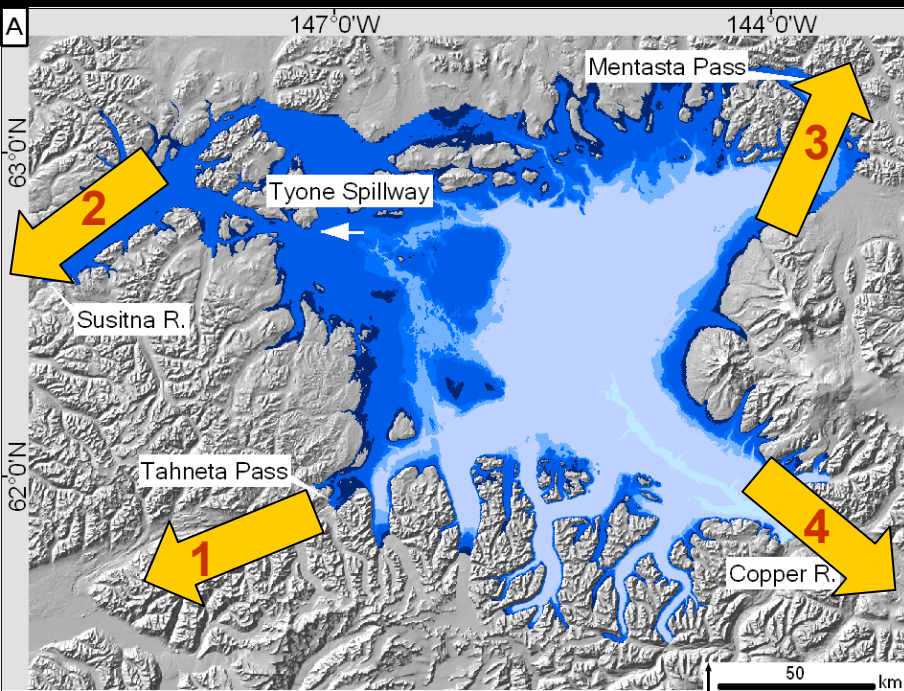


Updated? largest floods

Location	Peak Discharge (Sv)
Missoula	17
Susitna	10
Kuray	10
Lake Agassiz	2-7
Tsangpo	5
Yenisei	3.5
Matanuska	2.5
Ulagan	1-2 Sv?
Tok R.	1+?

Outlet	Lake surface elevation (m)		Initial area (10 ³ km ²)	Initial volume (10 ³ km ³)	Dam height (m)	(10 ³ km ³)		(10 ⁶ m ³ s ⁻¹)		days	
	pre-flood	post-flood				jökulhlaup	catastrophic failure	jökulhlaup	catastrophic failure		
Tahnetta Pass	975	914	8.9-24.0	2.3-6.0	61	0.5-1.4	0.1-0.3	2.0-3.3	83-121	6-10	
Susitna River	914	777	8.3-21.6	1.7-4.6	346	1.0-2.6	0.7-1.2	7.0-11.3	36-51	3-5	
Mentasta Pass	747	701	4.6-11.5	0.5-1.6	46	0.2-0.5	0.07-0.1	1.0-1.6	68-96	4-7	
Copper River	366	160	0.4	0.03	206	0.03	0.05	0.8	13	1	

Reconstructing Lake Atna drainage chronology



~40,000 year lifespan, connection to 4 separate major drainages (Matanuska, Susitna, Tanana/Yukon, and Copper), and indication that the basin was a source for broadly distributed whitefish, suggests Lake Atna may have been an important Quaternary fresh water refugia

Outlet

Discharge period

After

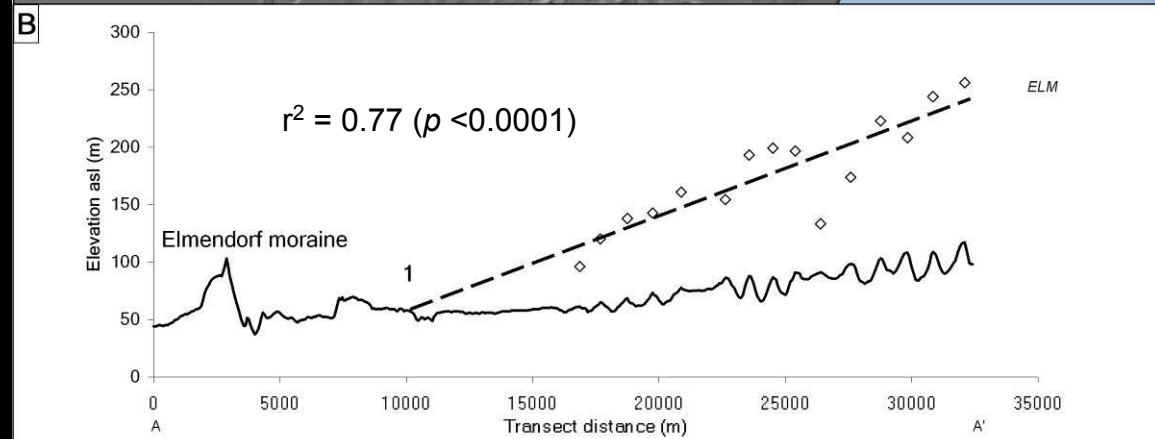
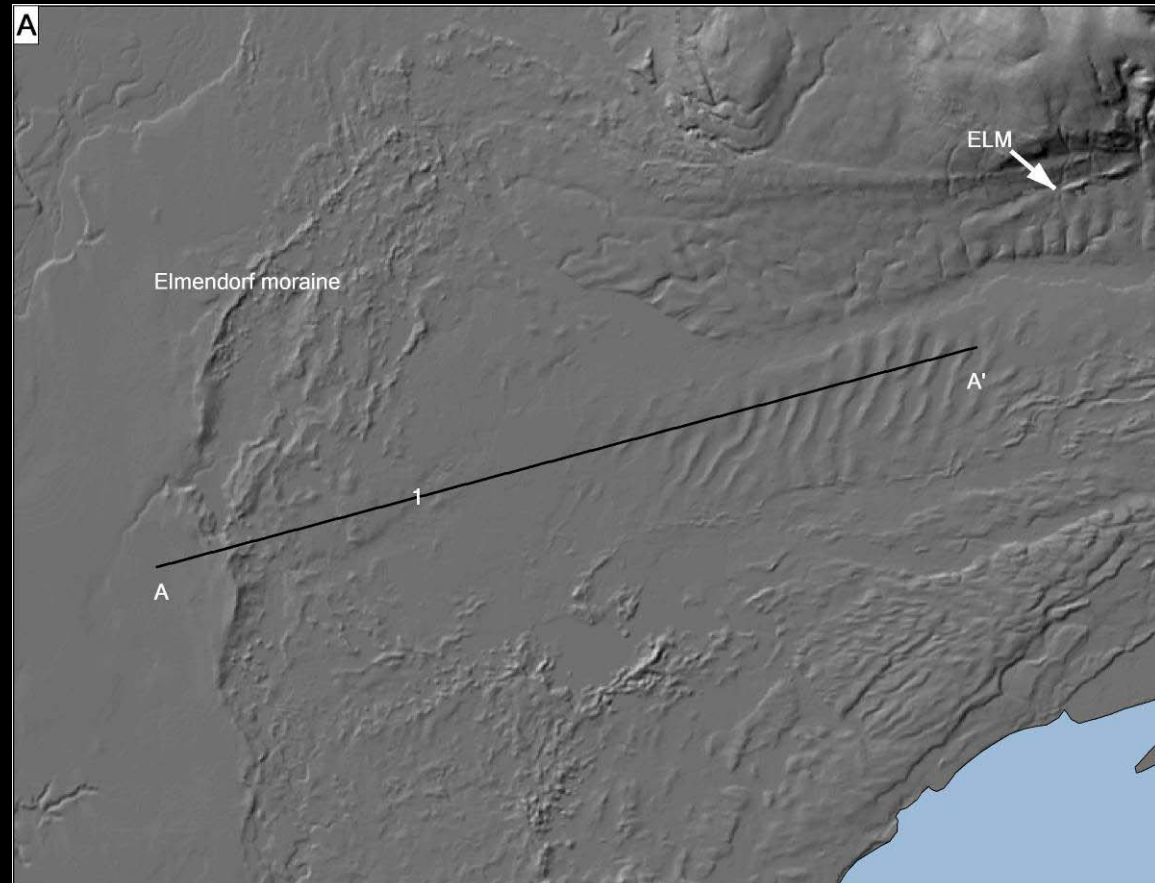
Before

Outlet	After	Before
Tahnetta Pass	21,730±390 ¹⁴ C yr BP (Thorson et al., 1981)	15,170–16,290 cal yr BP (Rubin and Alexander, 1960)
Susitna River	21,730±390 ¹⁴ C yr BP (Thorson et al., 1981) After Tahnetta Pass	15,170–16,290 cal yr BP (Rubin and Alexander, 1960)
Mentasta Pass	Above	~13,300–13,900 cal yr BP (Ager and Brubaker, 1985)
Copper River	Above	10,270-11,090 cal yr BP (Rubin and Alexander, 1960)

Flow depths over Wasilla VLD train: one estimation method

Estimated flood water surface elevation, based on Allen's (1968) empirically derived equation relating dune height H and water depth D : $H = 0.086D^{1.19}$ (units in feet). ELM = elevation of transition along the truncated right-lateral recessional moraine from a sharp crested form (above) to a smooth, apparently eroded form.

Decreasing water surface elevation suggests flood flows at the Matanuska Valley mouth spread laterally north into the Susitna Valley and south around the terminus of the Knik Glacier and did not overtop the central Elmendorf Moraine. *ELM* shows location and elevation of truncated recessional moraine.



Summary: lines of evidence supporting a ~26-15.5 ka megaflood from glacial Lake Atna down the Matanuska Valley

1. L. Atna max. levels ~60 m above pass between the CRB and Matanuska R.
 - a) Max. elevations of mapped broad flow path and incised channel banks through Tahnetta Pass match Lake Atna's max. and highest prolonged surface elevations.
2. Lack of expected till and presence of fluvially streamlined islands in the Matanuska Valley suggest large scouring flows.
3. ~25 transverse very large compound dunes built of steeply dipping foresets indicate flood flows ≤ 136 m deep in the lower Matanuska Valley.
4. Marine/estuarine deposits opposite the flood path mouth include a "card-house" microfabric with interstitial freshwater.
5. L. George, adjacent to the Matanuska Valley, supports pygmy whitefish more closely related to CRB lake populations than to other populations.

We conclude that ≤ 1400 km³ of Lake Atna decanted through Tahnetta Pass, at a rate of ≤ 3.3 Sv. A later discharge down the Susitna River may have been 3-4 times greater, making glacial Lake Atna a serial generator of some of Earth's largest freshwater floods.

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