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

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"Glacial Lake Missoula" by Bryon Pickering
Copper River Basin, South-Central Alaska

Lake deposits recognized (Schrader 1900)

Lake Ahtna named (Nichols 1965)

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

Lake extent / volume estimates absent

MODIS Blue Marble image base
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
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
- Worldclass wildlife
- Sub-arctic tundra

CR Delta Ecologic Zone
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

Valdez roadcut silt

Silt rhythmites

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)

Strandlines difficult to trace around the basin

- different unit erosion susceptibilities
- complexity of lake margin / glacier geomorphic features
- non-isotropic isostatic rebound
## Five Prominent Lake Ahtna Surface Elevations:

<table>
<thead>
<tr>
<th>Lake Elevation (m)</th>
<th>Features Identified</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>975</td>
<td>Glacio-lake deposits</td>
<td>Karlstrom, 1964 Williams, 1989</td>
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<tr>
<td>914</td>
<td>Glacio-lake deposits</td>
<td>Williams, 1989</td>
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<tr>
<td>777</td>
<td>Glacio-lake deposits, shoreline</td>
<td>Williams &amp; Galloway, 1986</td>
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<tr>
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<td>Williams &amp; Galloway, 1986</td>
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<tr>
<td>500</td>
<td>Glacio-lake deposits</td>
<td>Sirkin and Tuthill, 1987</td>
</tr>
</tbody>
</table>
Extraction of Lake Ahtna Lacustrine Deposits

- Glacio-lacustrine deposits (Karlstrom 1964)
- Copper River Basin
- Paleo Lake Susitna Basin

Scale: 100km
Extraction of Lake Ahtna (Susitna) Lacustrine Deposits

Susitna Basin

Tyone Spillway (~747m)

Legend:
- Lake Susitna deposits (Williams, 1989)
- Glacio-lacustrine deposits (Karlstrom 1964)
- Copper River Basin
- Paleo Lake Susitna Basin
And the Ice?

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
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

Mentasta Pass

Susitna R.

Tahneta Pass

CR Canyon

400m

915m

700m

300m
## Lake Ahtna – (Susitna): Area – Volume - Discharge

<table>
<thead>
<tr>
<th>Lake</th>
<th>Drainage Path</th>
<th>Minimum Dam Height (m)</th>
<th>Lake Elevation (m)</th>
<th>Lake Area (km²)</th>
<th>Lake Volume (km³)</th>
<th>Water Discharged (km³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Susitna (max ice)</td>
<td>Susitna</td>
<td>417</td>
<td>975</td>
<td>914</td>
<td>10583</td>
<td>9918</td>
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<tr>
<td>Susitna (max ice)</td>
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<td>914</td>
<td>777</td>
<td>9918</td>
<td>7206</td>
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<tr>
<td>Susitna (max ice)</td>
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<td>197</td>
<td>777</td>
<td>747</td>
<td>7206</td>
<td>6131</td>
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<td>Susitna-Ahtna (min ice)</td>
<td>Tahneta</td>
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<td>975</td>
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<td>Ahtna (min ice)</td>
<td>Copper River</td>
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<td>0</td>
<td>1760</td>
<td>0</td>
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<tr>
<td>Lake</td>
<td>Drainage Path (location)</td>
<td>From Elev (m)</td>
<td>To Elev (m)</td>
<td>Volume Discharge (10^3 \times m^3)</td>
<td>*Peak Discharge Rate (10^6 \text{ m}^3 \text{ s}^{-1})</td>
<td></td>
</tr>
<tr>
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<tr>
<td>Susitna 1</td>
<td>Tahneta (1)</td>
<td>975</td>
<td>914</td>
<td>1449</td>
<td>2</td>
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<tr>
<td>Susitna 2</td>
<td>Susitna R. (2)</td>
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<td>777</td>
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<td>24</td>
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<tr>
<td>Ahtna 1</td>
<td>Susitna R. (3)</td>
<td>777</td>
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<td>10</td>
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<tr>
<td>Ahtna 2</td>
<td>CR Canyon (4)</td>
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<td>500</td>
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<tr>
<td>Ahtna 3</td>
<td>CR Canyon (5)</td>
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<td>0</td>
<td>142</td>
<td>8</td>
<td></td>
</tr>
</tbody>
</table>

*Potential Discharge assuming catastrophic dam failure. Peak discharge rate unlikely in most cases.
**SIMPLIFIED ICE DAM FAILURE**

**i**

Ice

100m

90m

Water

Hydrostatic maximum

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

**ii**

100m

100m

Hydrostatically unstable

buoyancy force > glacier weight (ρ g h)

**iii**

Ice dam failure

100m
## Lake Ahtna – (Susitna): Mega Lake Comparisons

<table>
<thead>
<tr>
<th>Location</th>
<th>Date</th>
<th>Volume (m$^3$)</th>
<th>Peak Discharge ($10^6$ m$^3$ s$^{-1}$)</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kuray, Altai Russia</td>
<td>L Pleist.</td>
<td>$1.0 \times 10^{12}$</td>
<td>18</td>
<td>Baker at al 1993</td>
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<tr>
<td>L. Missoula (NW USA)</td>
<td>L Pleist.</td>
<td>$2.2 \times 10^{12}$</td>
<td>17</td>
<td>O’Connor &amp; Baker 1992</td>
</tr>
<tr>
<td>L. Ahtna-Susitna, Alaska</td>
<td>L Pleist.</td>
<td>*$6.2 \times 10^{12}$</td>
<td>2</td>
<td>This work</td>
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<tr>
<td>Lake Agassiz, Canada</td>
<td>9900y BP</td>
<td>-</td>
<td>1.2</td>
<td>Smith &amp; Fisher, 1993</td>
</tr>
</tbody>
</table>

* Initial lake volume
Lake Ahtna – (Susitna): Matanuska Valley megaflooding?

Wiedmer et al current 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 (geomorphology, 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 Lakes

- Megalakes have passed
- Hundreds of small glacier dammed lakes

Iceberg Lake (photo Kirk Stone, 1951)

Glacier dammed ice marginal lake changes

~2003 Lake discharge = 0.133 km³
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

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

Possible future evolution of Greenland Ice Sheet


Photo by Jonathan Bamber

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Thank You