ESS 203 - Glaciers and Global Change

Friday February 5, 2021

Outline for today

- Today's highlights on Monday
  - Madelyn Ulvin
- Highlights of last Monday's class
  - Gavin Hamilton

Highlight reporters

- Remember to turn in your ~100-word reports

- Glacier flow and sliding
- Regelation
- Fracture and crevasses

HW 14 – Chapter 5 and James Croll

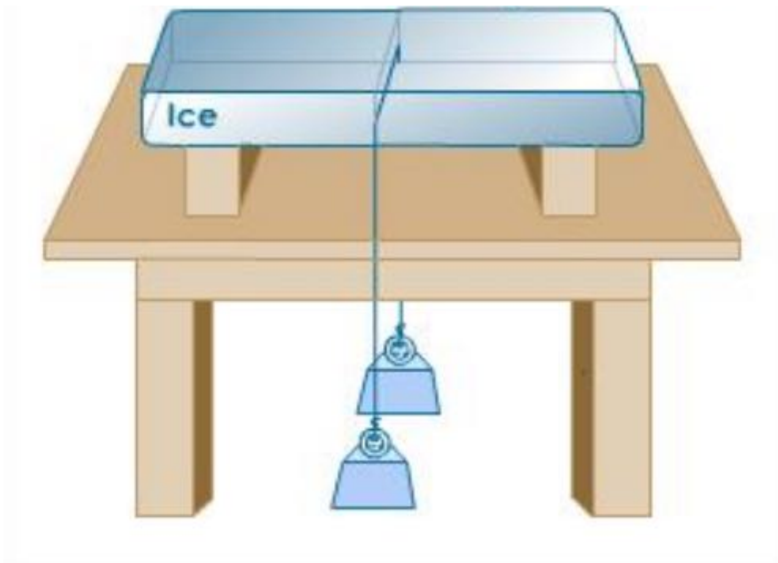
For Monday:

Please read Chapter 5 (pages 65-88) in text *Frozen Earth*.

- In a couple of sentences, explain why Macdougall thinks James Croll was an "unlikely" scientist.
- In a page or less, outline Croll's contribution to ideas about why ice ages happen.

(There was no HW 13 from Wednesday (Class #13), which was Midterm #1.)

Regelation (“refreezing” in French)



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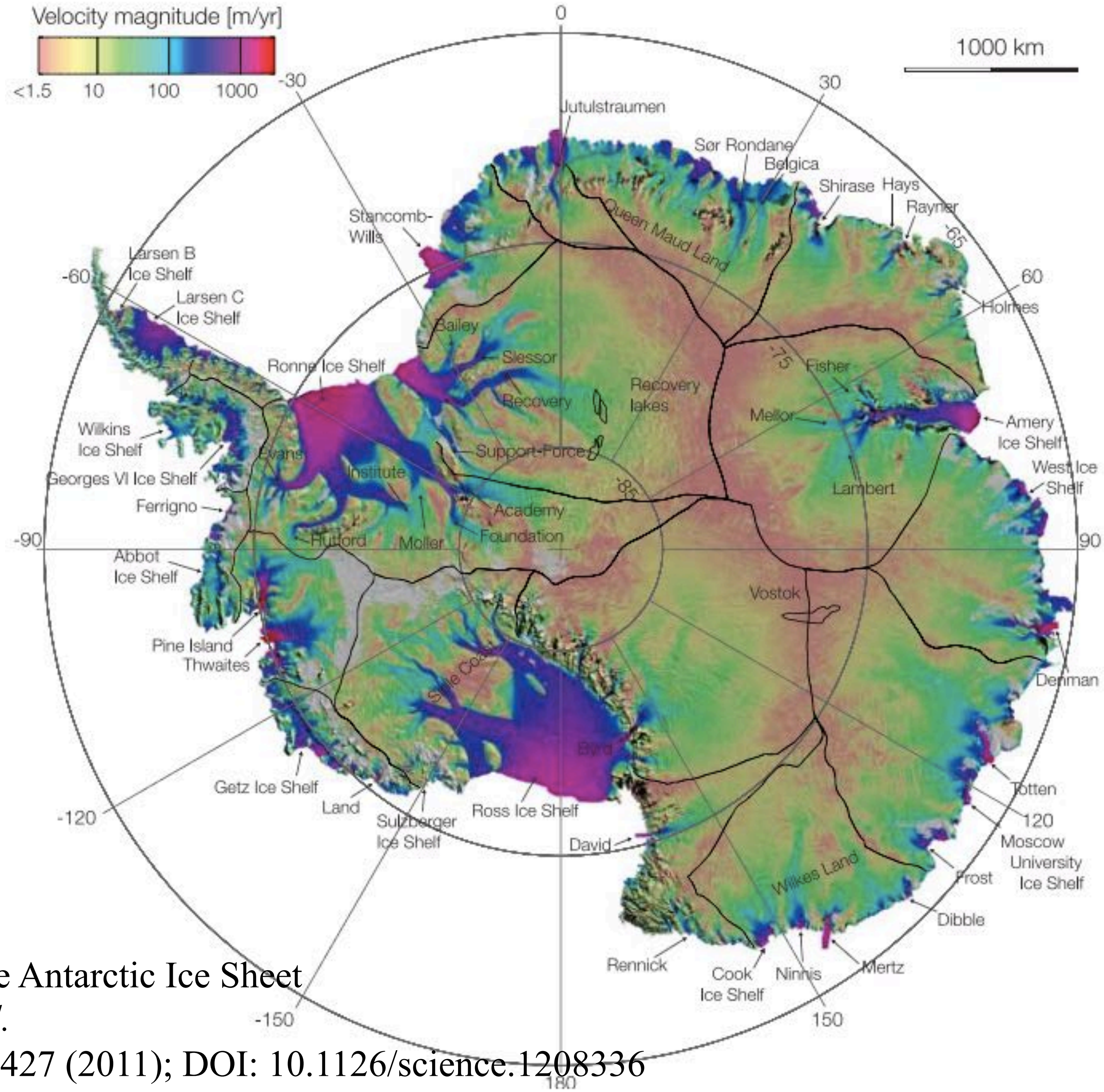
Demo

- What is going to happen?

Why understand glacier flow?

1. Big outlet glaciers flow to the ocean and break off as icebergs. The rate that ice is lost depends on the flow speed of those glaciers as they approach the ocean.
2. Ice cores tells a climate story. But the oldest ice in a core may have come from far away. But where, exactly?
3. Various things were lost on glaciers long ago. Where should we look for them now?

1.



Ice Flow of the Antarctic Ice Sheet
E. Rignot *et al.*
Science 333, 1427 (2011); DOI: 10.1126/science.1208336

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2.

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UWNEWS

This is a typical press release, as described in your group-project instructions.

ENVIRONMENT | NEWS RELEASES | RESEARCH | SCIENCE

February 19, 2016

UW part of team that drilled first deep ice core at the South Pole

Hannah Hickey
UW News

This January — high summer at the South Pole — a University of Washington glaciologist helped lead a project that surpassed its goal to drill the first deep ice core at the planet's southernmost tip, providing material to help solve a climate puzzle.

Eric Steig, a UW professor of Earth and space sciences, returned to Seattle this month after being chief scientist for the final stretch of the National Science Foundation-funded effort at the Antarctic station.

"We had a very, very successful field

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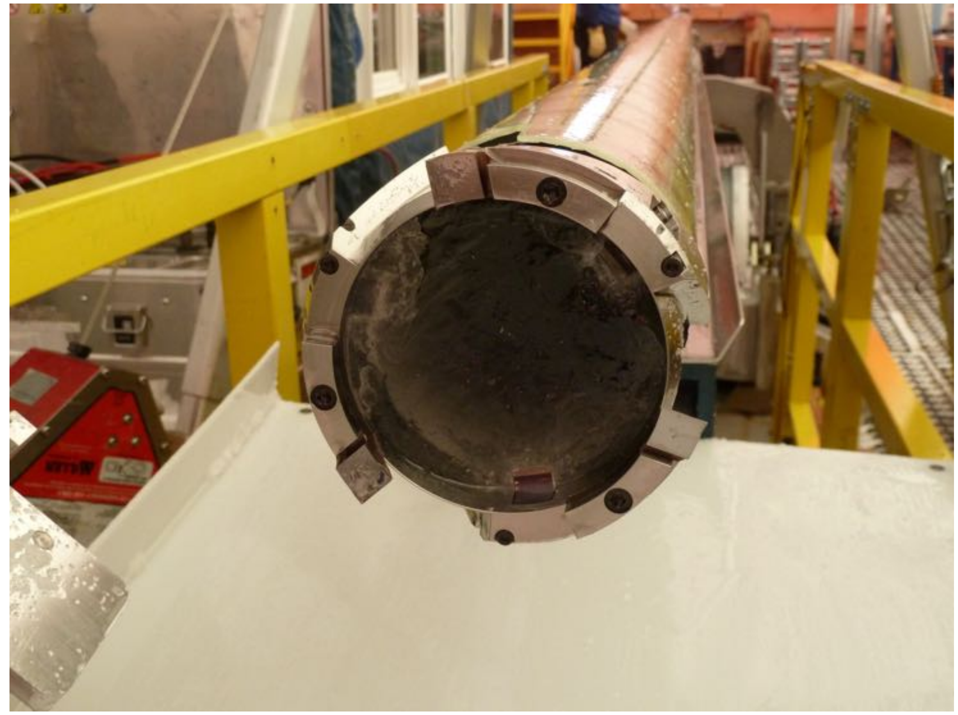
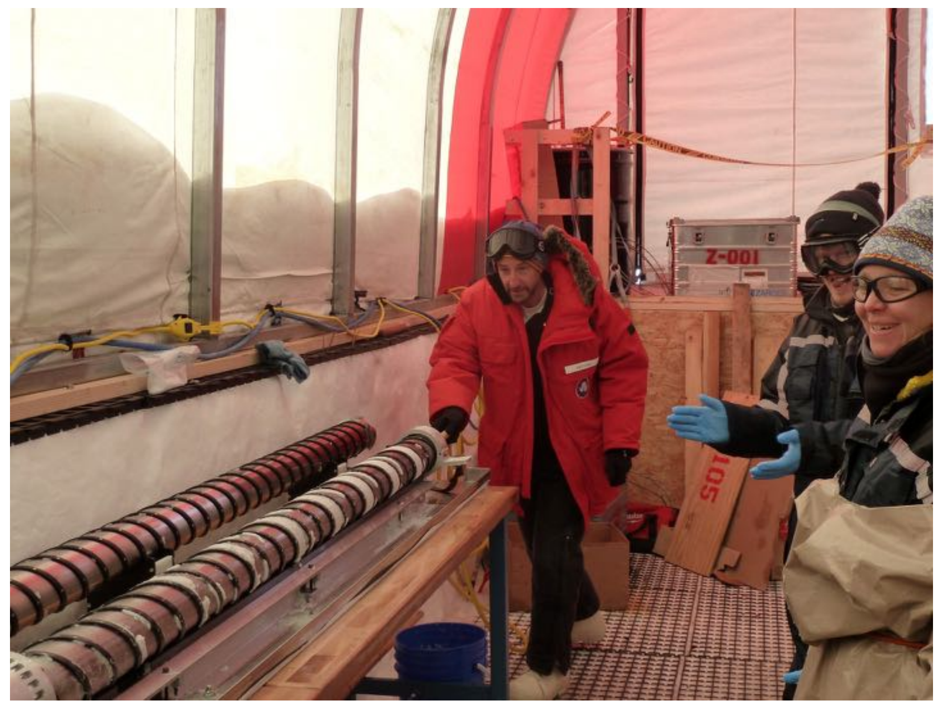
www.washington.edu/news/2016/02/19/uw-part-of-team-that-drilled-first-deep-ice-core-at-the-south-pole/

South Pole Ice Core (spicecore.org)



Jan 23 2016, 5 years ago

- drilling phase ended
- Depth 1751 meters
- Last core is in the drill barrel.



Eric Steig, UW Prof, pushes the last core out of the drill barrel.

- 40,000 year climate record
- Core has been analyzed at US NICL in Denver and in Labs around the country.
- Lots of great climate science now being published.

AGU100 ADVANCING EARTH AND SPACE SCIENCE

Geophysical Research Letters

RESEARCH LETTER

10.1029/2018GL078253

Holocene Ice-Flow Speedup in the Vicinity of the South Pole

David A. Lilien[1,2], T. J. Fudge[1], Michelle R. Koutnik[1], Howard Conway[1], Erich C. Osterberg[3], David G. Ferris[3], Edwin D. Waddington[1], and C. Max Stevens[1]

[1]Department of Earth and Space Sciences, University of Washington, Seattle, WA, USA, [2]Applied Physics Laboratory, University of Washington, Seattle, WA, USA, [3]Department of Earth Sciences, Dartmouth College, Hanover, NH, USA

Key Points:

- We used a new method to combine ice core and geophysical measurements to constrain ice-flow history near the South Pole over the past 10 ka
- Ice-flow speeds in the 70-km upstream of the South Pole increased by ~15% during the Holocene
- Accumulation patterns and ice-flow direction in the 70-km upstream of the South Pole have remained nearly constant during the Holocene

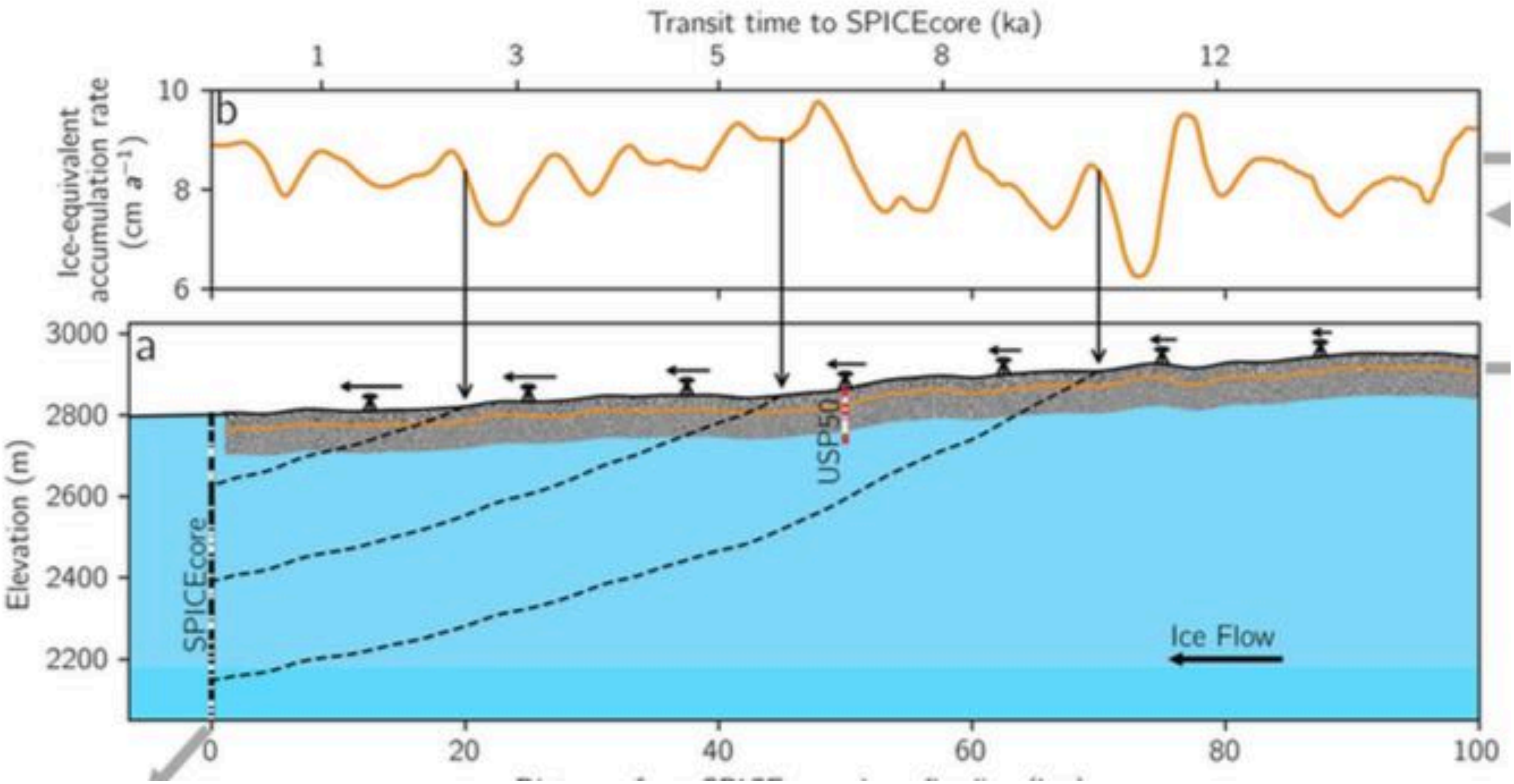
Supporting Information:

- Supporting Information S1
- Table S1
- Table S2

Abstract The South Pole Ice Core (SPICEcore) was drilled at least 180 km from an ice-flow divide. Thus, the annual-equivalent layer thicknesses in the core are affected by spatial variations in accumulation upstream in addition to temporal variations in regional accumulation. We use a new method to compare the SPICEcore accumulation record, derived by correcting measured layer thicknesses for thinning, with an accumulation record derived from new GPS and radar measurements upstream. When ice speeds are modeled as increasing by 15% since 10 ka, the upstream accumulation explains 77% of the variance in the SPICEcore-derived accumulation (versus 22% without speedup). This result demonstrates that the ice-flow direction and spatial pattern of accumulation were stable throughout the Holocene. The 15% speedup in turn suggests a slight (3–4%) steepening or thickening of the ice-sheet interior and provides a new constraint on the evolution of the East Antarctic Ice Sheet following the glacial termination.

We need to understand the flow to infer the climate history

Ice core records climate – but climate at more distant locations, the deeper we look in the core



Why understand glacier flow?

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3.

The New York Times

Melting Ice Uncovers 1946 Wreckage of U.S. Plane in Swiss Glacier

By Palko Karasz

Aug. 16, 2018

The C-53 Dakota was en route to Marseille from Munich, when weather forced it to land on snow at 8,000 ft in the accumulation area of Gauli Glacier.

All 7 occupants were rescued after 5 days by the Swiss air force, and the wreckage was buried by moee snow.
The flowing glacier has moved the plane debris about two miles, where it is now melting out in the ablation zone.

https://www.nytimes.com/2018/08/16/world/europe/switzerland-plane-crash-glacier.html

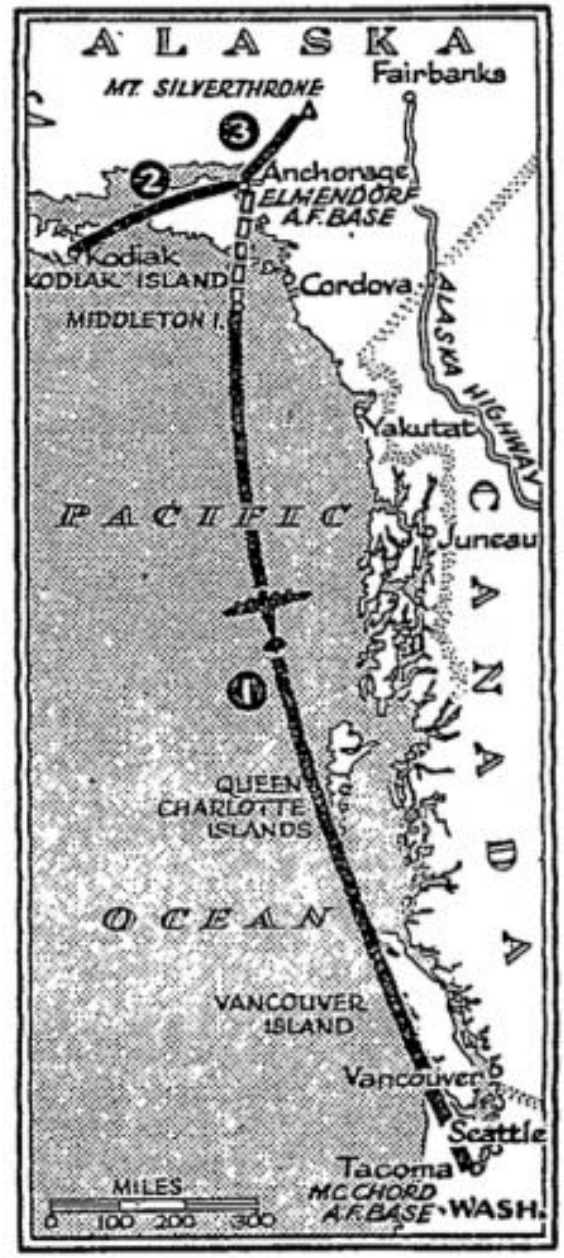
More fragments from 1952 Air Force plane crash found in Alaska glacier

By Associated Press

June 29, 2020

The C-124 Globemaster, en route from Tacoma to Anchorage, crashed into Mount Gannett north of Anchorage on Nov. 22, 1952 during bad weather, killing all 41 passengers and 11 crew members.

The wreckage is now emerging from the ablation area of Colony Glacier. DNA analysis of the human remains is underway to identify the victims.



This essay made possible by:
The State of Washington
Washington State Department of Archeology and Historic Preservation

Curtis Commando C-46/R5C

Courtesy United States Air Force National Museum

Mount Rainier

Photo by Stan Shebs, Licensed under CC BY-SA 3.0

https://historylink.org/File/7820

A Curtis Commando R5C transport plane crashes into Mount Rainier, killing 32 U.S. Marines, on December 10, 1946.

By Daryl C. McClary | Posted 7/29/2006 | HistoryLink.org Essay 7820

On December 10, 1946, six Curtis Commando R5C transport planes carrying more than 200 U.S. Marines leave San Diego en route to Seattle. The aircraft, flying entirely by instruments at an altitude of 9,000 feet, encounter heavy weather over southwestern Washington. Four turn back, landing at the Portland Airport; one manages to land safely in Seattle, but the sixth plane, carrying 32 Marines, vanishes. Search-and-rescue aircraft, hampered by continuing bad weather, are unable to fly for a week and ground searches prove fruitless. After two weeks, the search for the missing aircraft is suspended. The Navy determines that the plane was blown off course by high winds and flew into the side of Mount Rainier (14,410 feet). In July 1947, a ranger at Mount Rainier National Park spots wreckage on South Tahoma Glacier. Search parties examine the debris and confirm that it came from the missing plane. Four weeks later, the bodies are found high on the face of the glacier, but hazardous conditions force authorities to abandon plans to remove them for burial. The 32 U.S. Marines remain entombed forever ?n Mount Rainier. In 1946, it was the worst accident, in numbers killed aboard an aircraft, in United States aviation history and remains Mount Rainier's greatest tragedy.

Share →

A Curtis Commando R5C transport plane crashes into Mount Rainier, killing 32 U.S. Marines, on December 10, 1946.

Honoring the Fallen

On Wednesday, August 27, 1947, Captain A. O. Rule, Commandant of Naval Air Station Sand Point, announced the official decision to cease all recovery efforts on South Tahoma Glacier. A dispatch from the Navy Department, Washington, D.C., concurred with the decision and approved mass burial at the site. In effect, the 32 Marines would stay where they died, among the wreckage of the Curtis R5C.

Officials at Mount Rainier National Park affirmed that there were no predatory animals or insects on the glacier at 10,500 feet and the wreckage and bodies would be covered by several feet of snow which would start falling at that altitude in early September. "By next spring, this snow will be compressed into several feet of glacier ice and there should be no visible evidence of this tragedy left" (*Seattle Post-Intelligencer*).

But the glacier is always moving ···

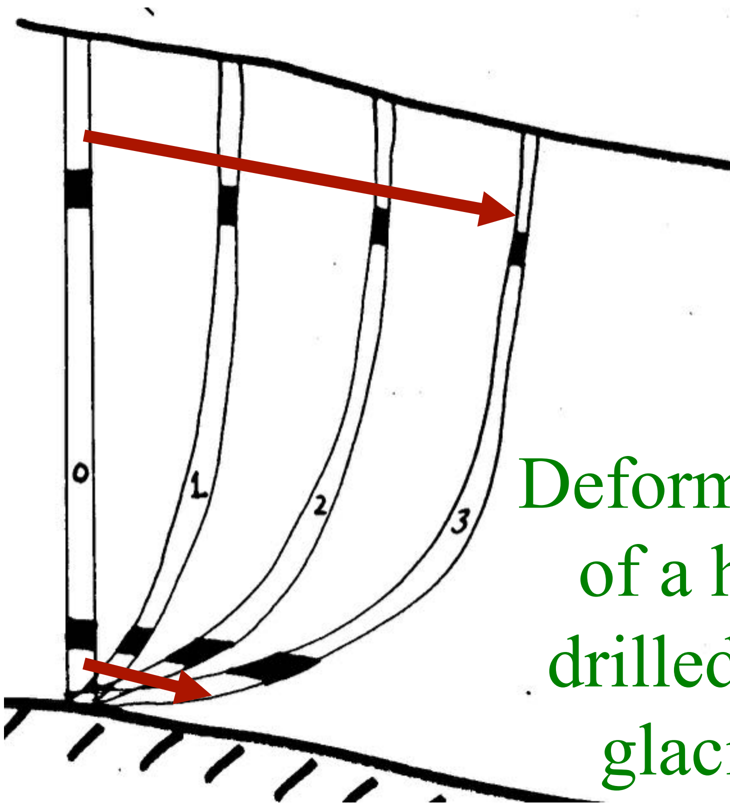
https://historylink.org/File/7820

Dynamics of Flow

- Glacier with steep surface slope flows faster than a comparable glacier with shallow slope.
- A thick glacier flows faster than a comparable glacier that is thinner.

Distinction between Flow and Deformation Rate

- Deeper ice ***deforms*** faster (its shape changes faster)
- Deeper ice also carries the ice above it along with it
- Ice near the surface ***travels*** faster than deeper ice.

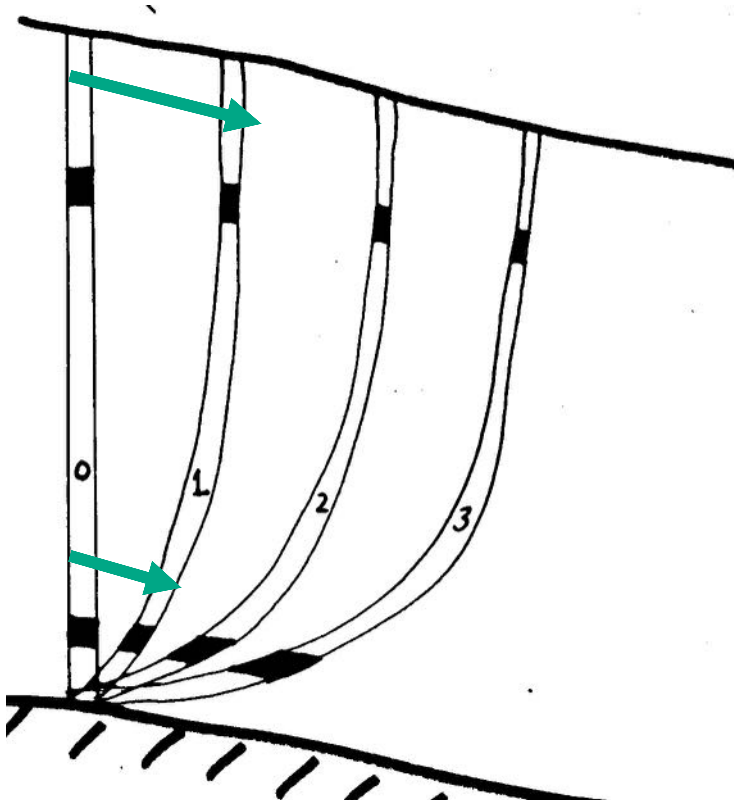


Vertical Section

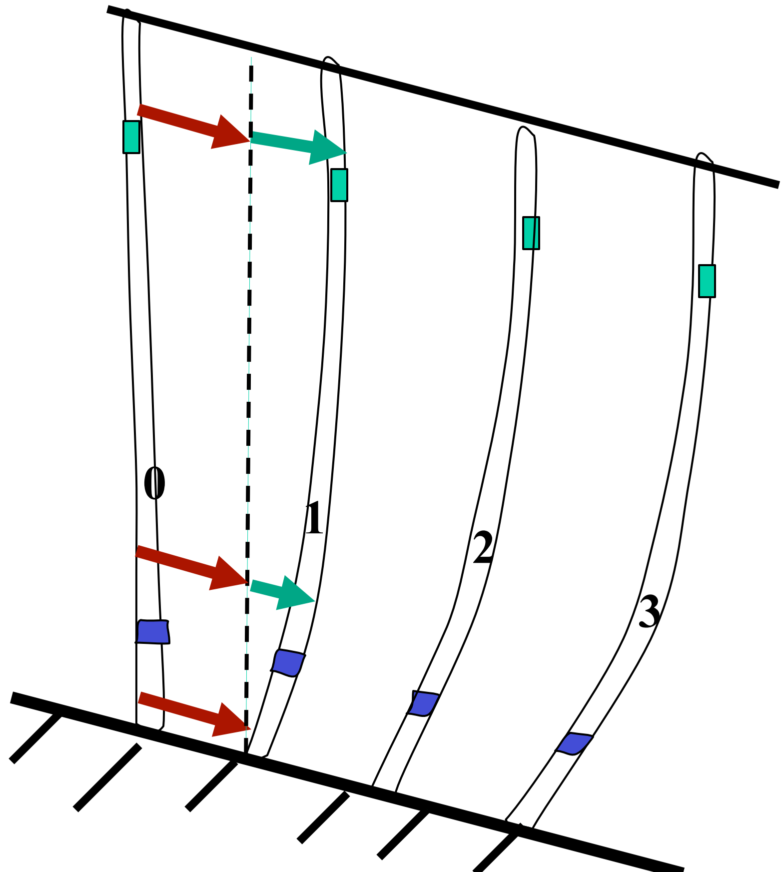
Deformation of a hole drilled in a glacier.

demo: (like a deck of cards on a slope.)

Distinction between viscous deformation and sliding



Deformation of a hole drilled in a glacier.



With sliding added as well

Glacier Sliding

Base must be wet for glacier to slide.

- Temperature must be at the melting point.

demo: cold vs "temperate” glacier on a slope

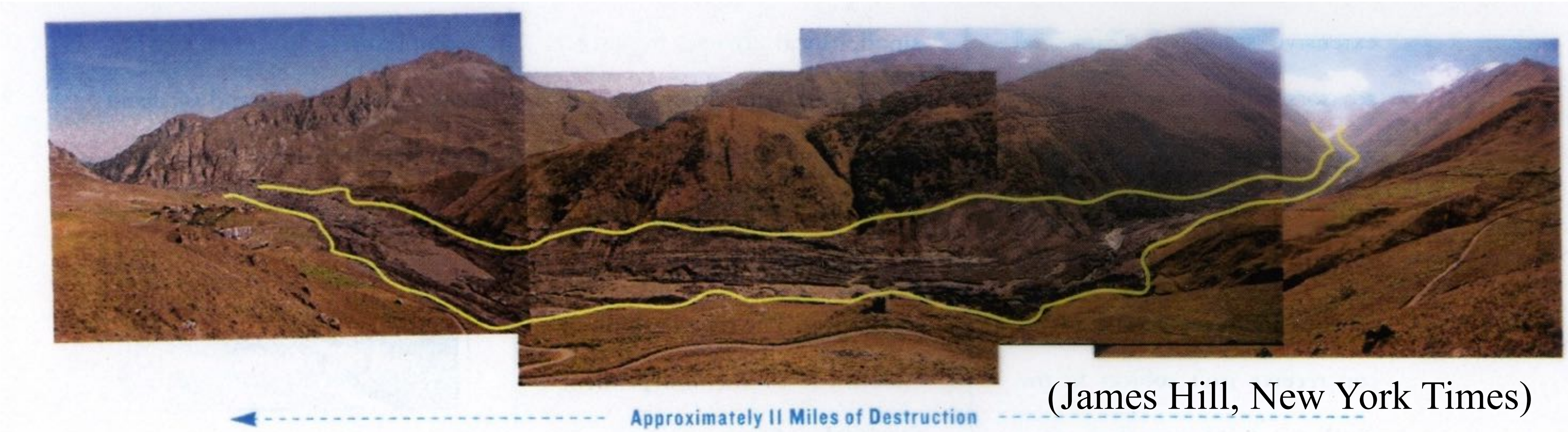
How does a wet slippery glacier "hang on" to the mountain-side?

Why does a slippery glacier stay on a mountainside?

If the bed is rough enough …

Demo – temperate ice on sandpaper

Why does a slippery glacier stay on a mountainside? Sometimes it doesn't - Ice Avalanche!

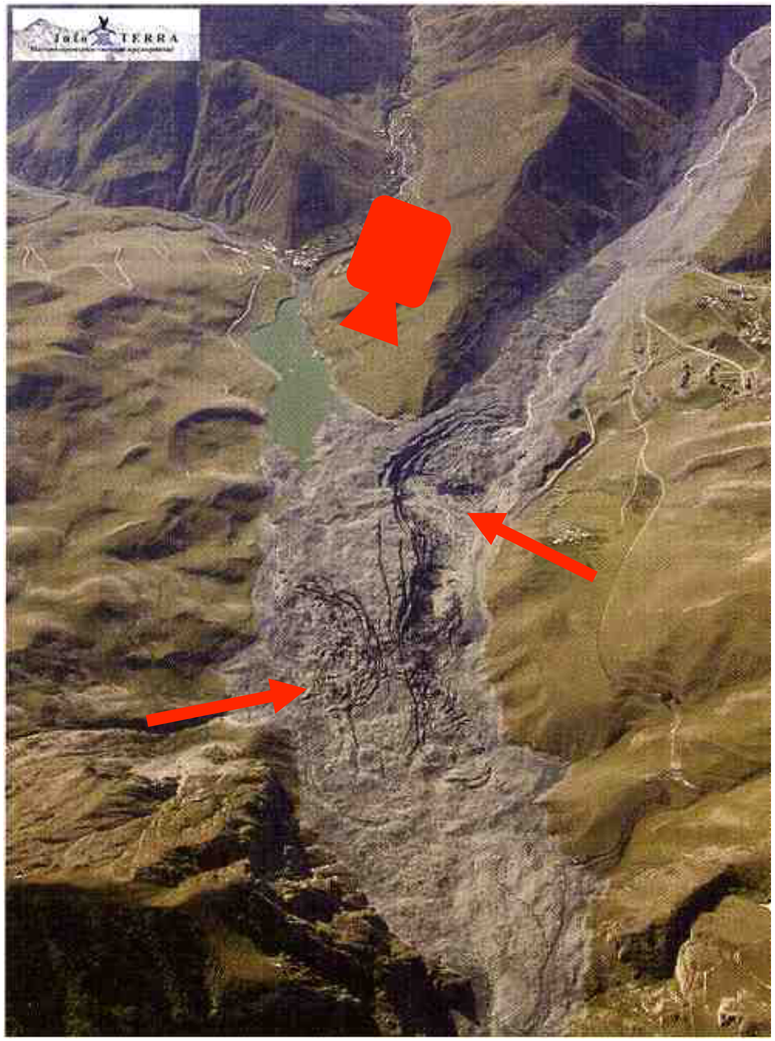


(James Hill, New York Times)

September 20, 2002, North Ossetia, (Russian Caucasus, near site of 2014 Winter Olympic Games at Sochi).

- 2×10^7 tonnes of rock and ice broke off Kazbek Massif and avalanched down ***Kolka Glacier***.
- ice, rock, and mud swept ~18 km through Karmadon Gorge at up to 180 km per hour.
- ~140 fatalities, including action-movie hero Sergei Bodrov Jr.
- village of Nizhny Karmadon destroyed.
- Similar avalanches occurred there in 1835 and 1902.

New Debris-dammed Lake



Ice/rock debris dam was melting out and collapsing 1 year later.

Haeberli et al. 2004. *J. Glaciol*. 50(171), 533.

Houses at Gornaia Saniba flooded by the dam

nature geoscience

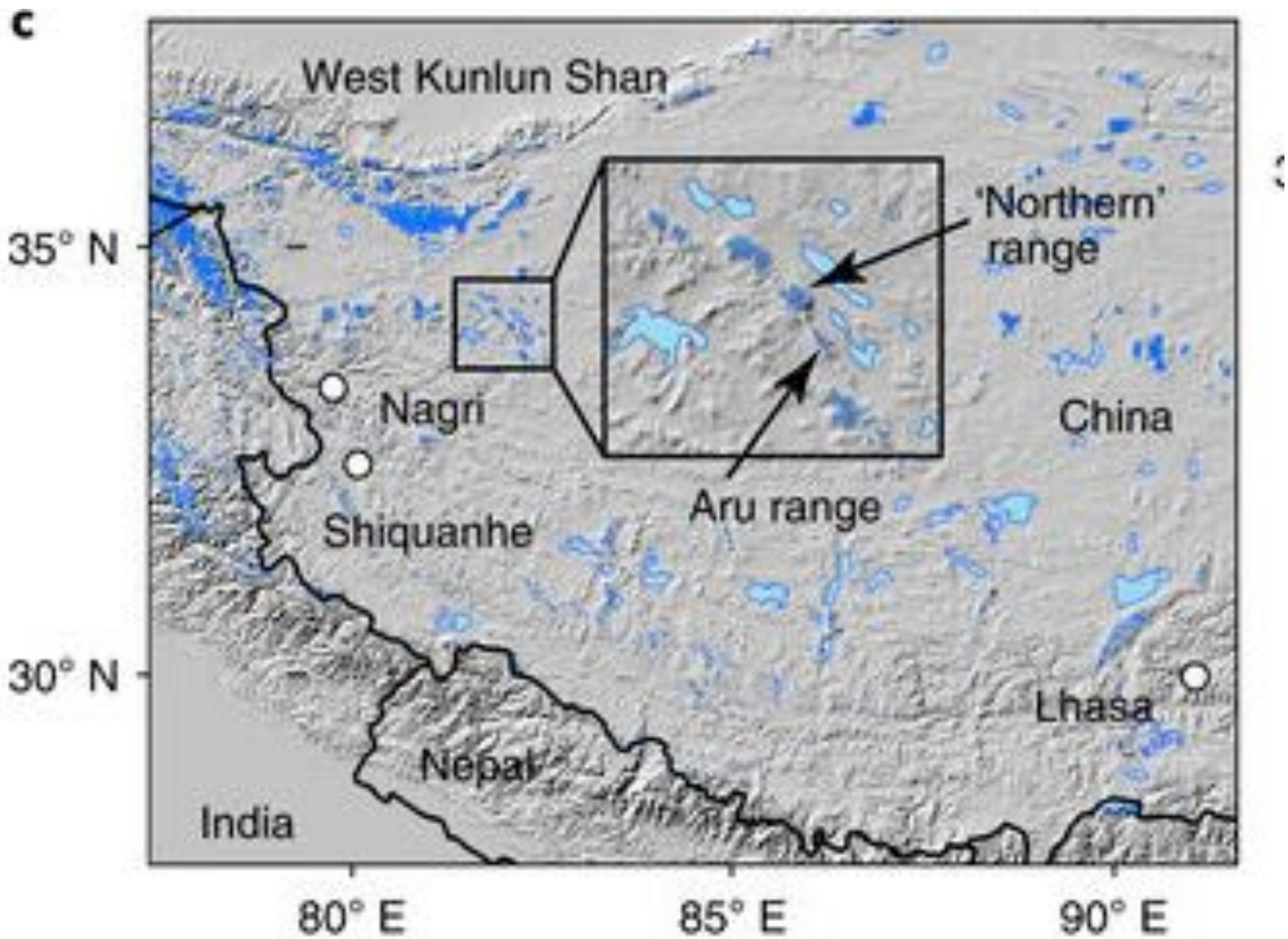
ARTICLES
https://doi.org/10.1038/s41561-017-0039-7

Massive collapse of two glaciers in western Tibet in 2016 after surge-like instability

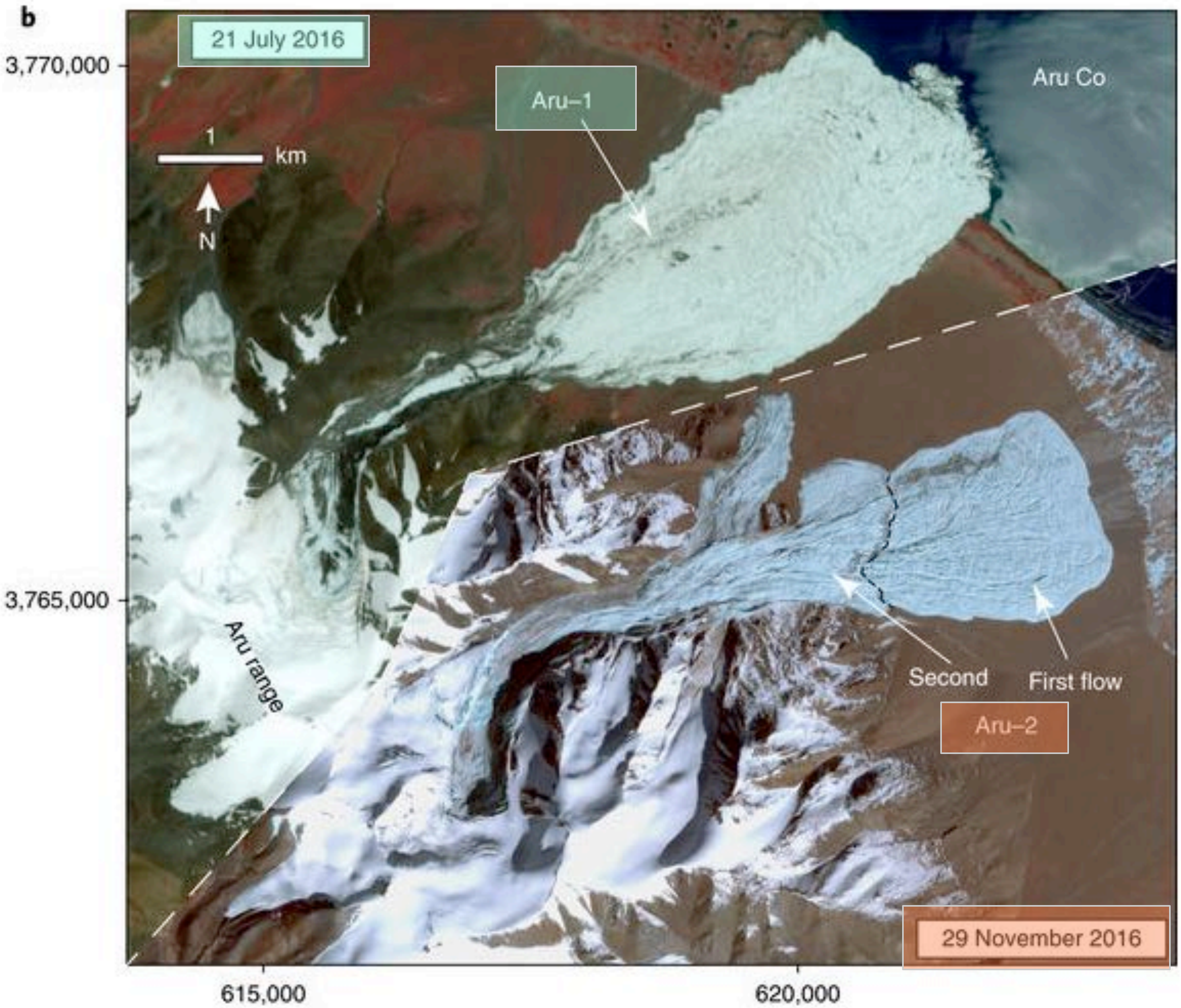
Andreas Kääb[1]*, Silvan Leinss[2], Adrien Gilbert[1], Yves Bühler[3], Simon Gascoin[4], Stephen G. Evans[5], Perry Bartelt[3], Etienne Berthier[6], Fanny Brun[6,7], Wei-An Chao[8], Daniel Farinotti[9,10], Florent Gimbert[7], Wanqin Guo[11], Christian Huggel[12], Jeffrey S. Kargel[13], Gregory J. Leonard[14], Lide Tian[15], Désirée Treichler[1] and Tandong Yao[15]

Surges and glacier avalanches are expressions of glacier instability, and among the most dramatic phenomena in the mountain cryosphere. Until now, the catastrophic collapse of a glacier, combining the large volume of surges and mobility of ice avalanches, has been reported only for the 2002 130 × 10⁶ m³ detachment of Kolka Glacier (Caucasus Mountains), which has been considered a globally singular event. Here, we report on the similar detachment of the entire lower parts of two adjacent glaciers in western Tibet in July and September 2016, leading to an unprecedented pair of giant low-angle ice avalanches with volumes of 68 ± 2 × 10⁶ m³ and 83 ± 2 × 10⁶ m³. On the basis of satellite remote sensing, numerical modelling and field investigations, we find that the twin collapses were caused by climate- and weather-driven external forcing, acting on specific polythermal and soft-bed glacier properties. These factors converged to produce surge-like enhancement of driving stresses and massively reduced basal friction connected to subglacial water and fine-grained bed lithology, to eventually exceed collapse thresholds in resisting forces of the tongues frozen to their bed. Our findings show that large catastrophic instabilities of low-angle glaciers can happen under rare circumstances without historical precedent.

Published on-line January 22, 2018.



Kääb et al. (2018). *Nature Geoscience.*



Kääb et al. (2018). *Nature Geoscience.*

Aru-2

The mega-avalanche, one of the largest ever documented worldwide, killed nine herders and hundreds of their animals.

What happened?

- Climate change increased snowfall at highest elevations.
- Accumulation area thickened.
- Bed thawed due to greater insulation.
- Bed was muddy silt.
- slippery!

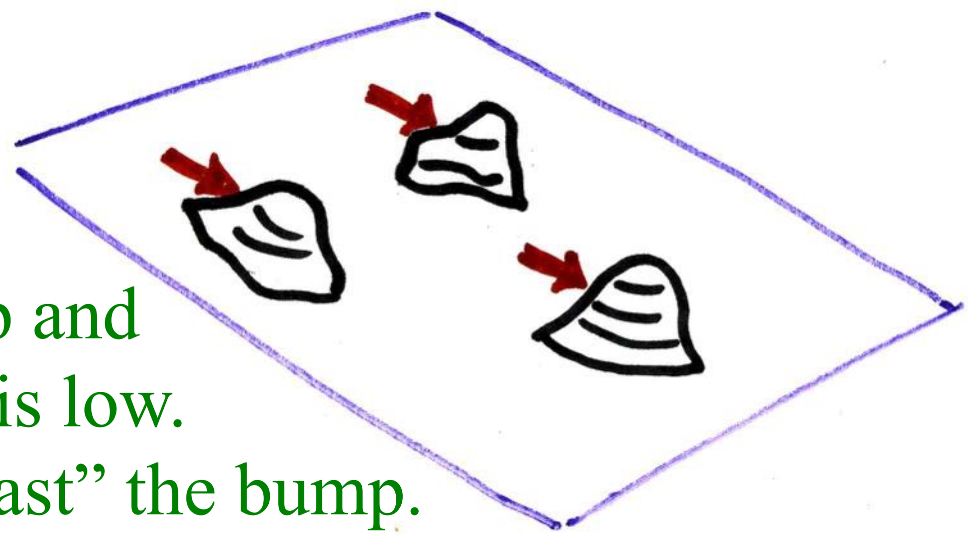
A possible group project?

Kääb et al. (2018). *Nature Geoscience.*

Sliding over a Hard Bed

Rock can be smooth and slippery.
Ice is held back by bumps in bedrock.

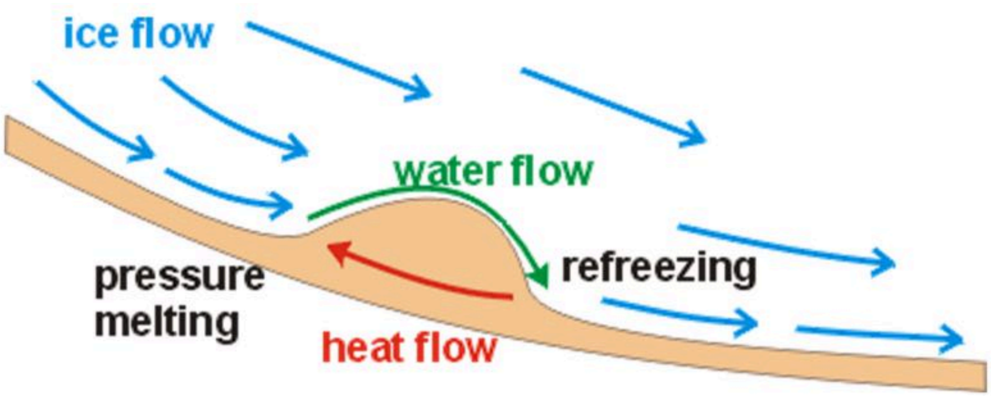
- Bumps act as "nails" up into the ice.
- Pressure is high on upstream faces of bumps that are holding back the ice.
- Ice can melt (pressure depresses freezing point).
- Water flows around bump and refreezes where pressure is low.
- Ice has effectively "slid past" the bump.

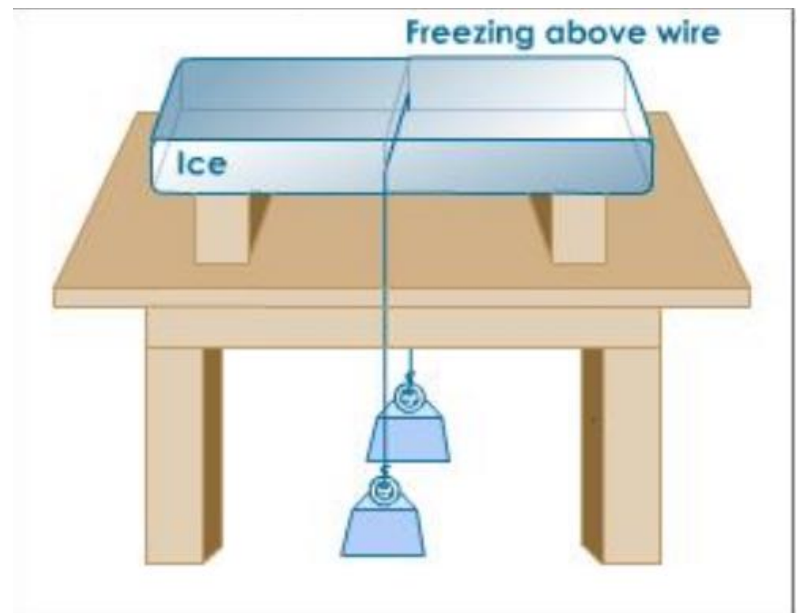


Regelation ("refreezing" in French)

- What is it?
- What happened in the demo?
- Why?

- Glacier sliding past small bumps





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The Shape Shifter

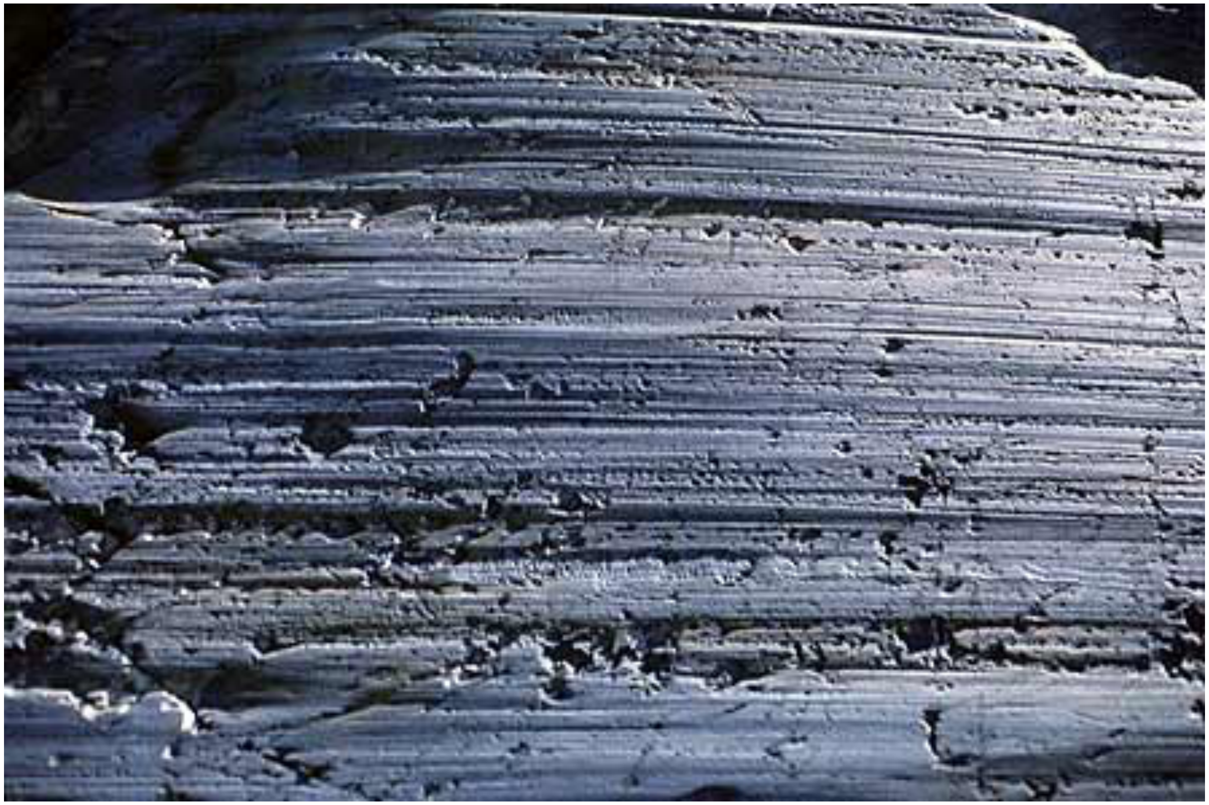
You put the squeeze on me?
Energized by my surroundings,
I cool, and transmogrify from my sturdy state
as I slip away.
The pressure off, I shed my fluid form,
Gratefully offering up my energy,
back to my cooperating world.
I am firm again and true,
and I have passed the squeeze unaltered.

(Anon.)

Friction from Sliding Clasts

Rock clasts are held in the ice as it moves along.
- Rocks in basal ice dig into bedrock, act as brakes.
- Grooves or striations show direction of ice motion.

Bedrock in front of Yale Glacier Alaska

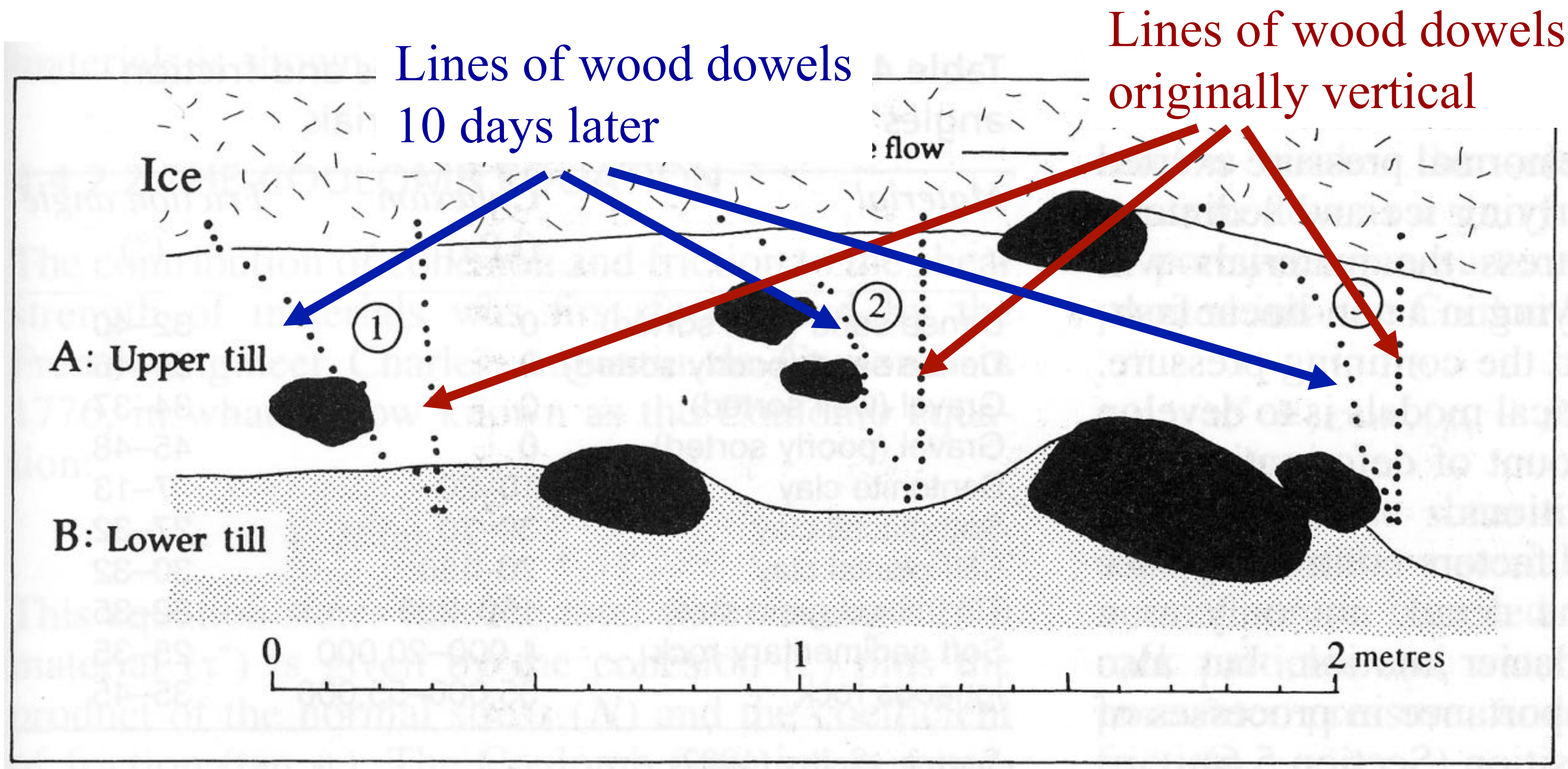


Tom Lowell's Glacier Image Database, University of Cincinnati

Soft Bed - Basal Drag

Subglacial sediment deforms as ice moves across it

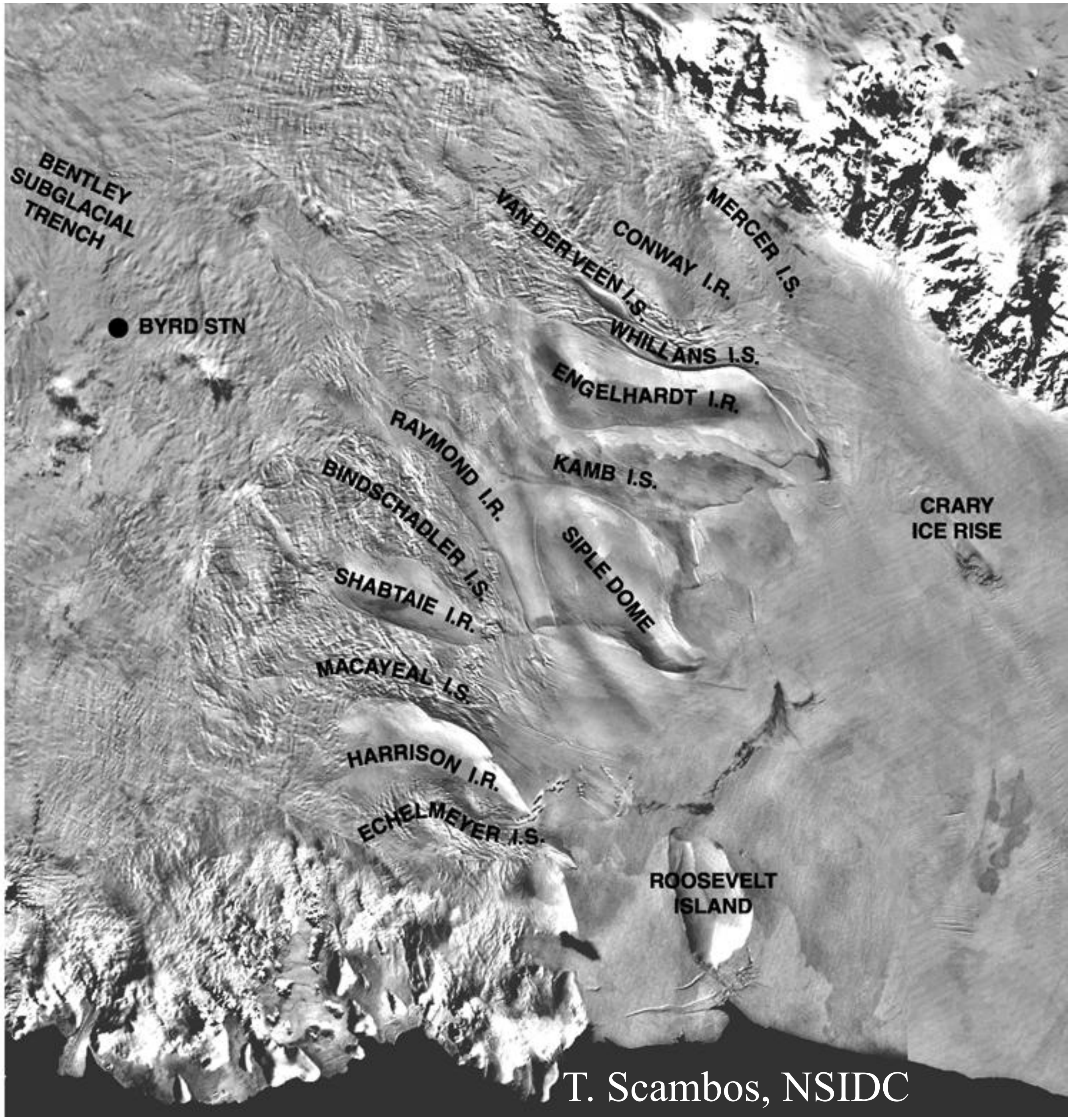
- Rock-on-rock friction inside the sediment (till) acts as brake, resisting ice motion.



Boulton and Hindmarsh (1987). Iceland

Soft Bed – West Antarctica

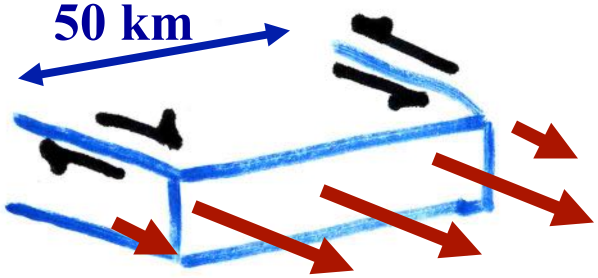
- Marine mud lubricates bed under Ice Streams
- Ice Ridges are frozen to bedrock



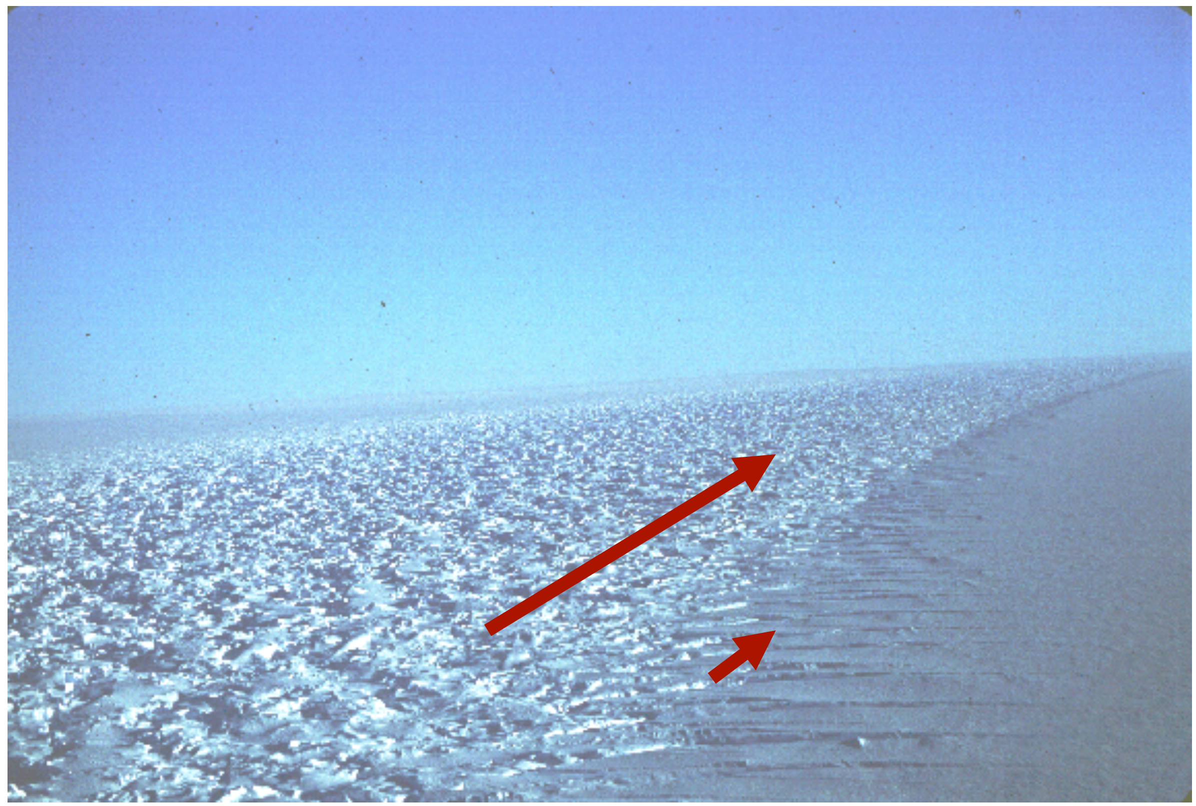
Soft Bed - Lateral Drag

Very slippery basal sediment under West Antarctic Ice Streams can't hold back the ice.

- Ice restrained almost entirely by drag from edges.



N. Nereson, UW



Sliding Speed

Sliding speed of glaciers increases if

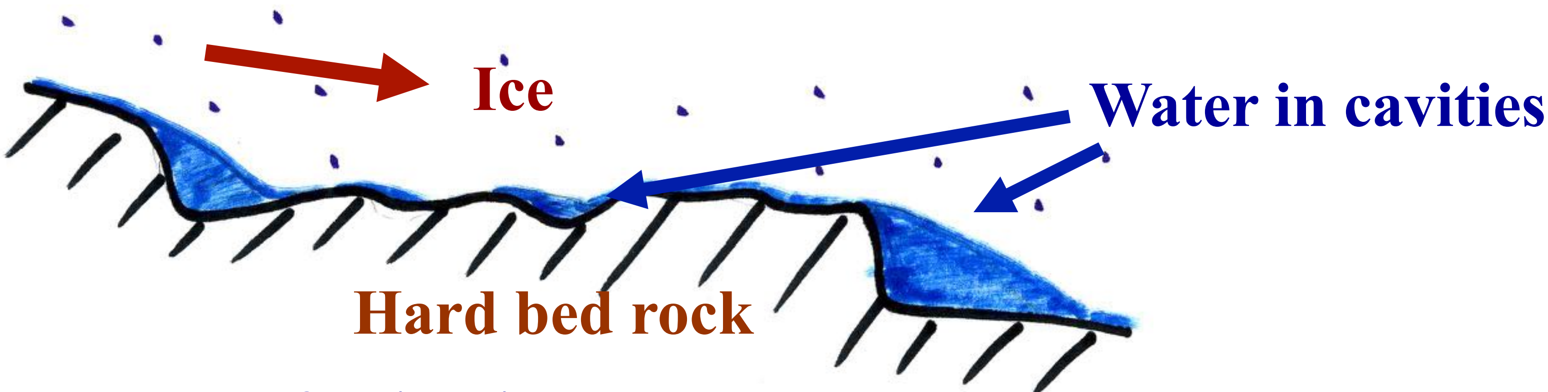
- Ice thickness increases
- Ice surface slope increases
- ***Water pressure at the bed increases***

Demo: change in force needed to make a block slide as water pressure increases

Sliding Speed and Basal Water Pressure

On a rocky bed:

- Higher pressure "floats" ice.
- Higher pressure reduces friction with the bedrock.
- If bed is "rough", high pressure also reduces contact area where sliding friction can occur.



On a "soft" bed:

- High water pressure softens basal mud.
- Softer mud deforms and flows faster.
- Carries glacier along with it faster.

Examples of Sliding Speeds

Where	**When**	**Sliding Speed**	**Deformation Speed (surface)**
Nisqually Glacier Mt Rainier	Summer/fall	70 m a^{-1}	15 m a^{-1}
Nisqually Glacier	Winter/spring	35 m a^{-1}	20 m a^{-1}
Blue Glacier (lower reach)	summer	10 m a^{-1}	40 m a^{-1}
Variegated Glacier	Surging	10,000 m a^{-1}	40 m a^{-1}
Jakobshavn Isbrae (Greenland)	All the time	8-12 km a^{-1}	5 km a^{-1}
Ice Stream Whillans (West Antarctica)	All the time	500 m a^{-1}	5 m a^{-1}

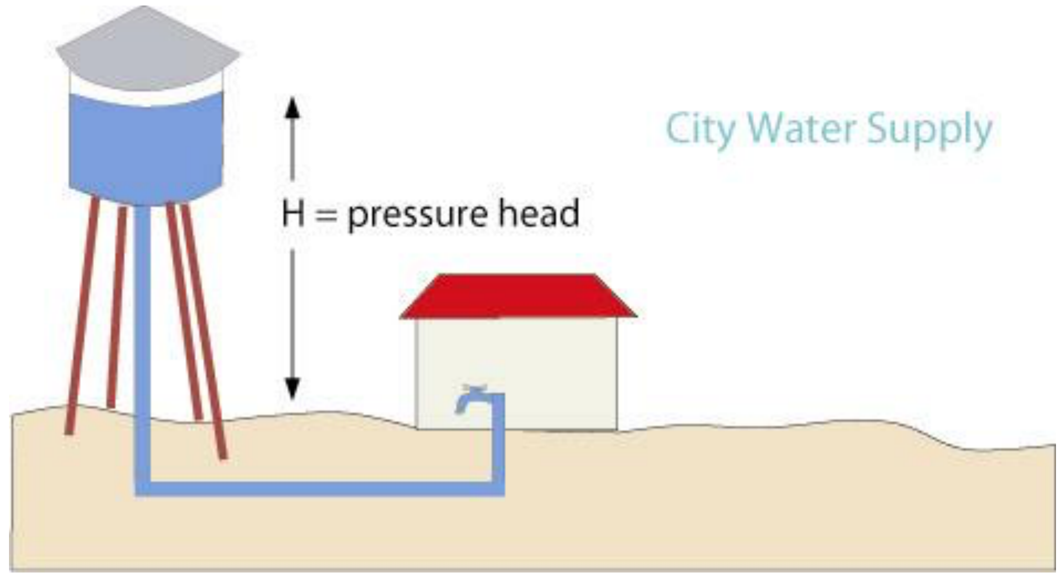
Rapid Changes in Speed

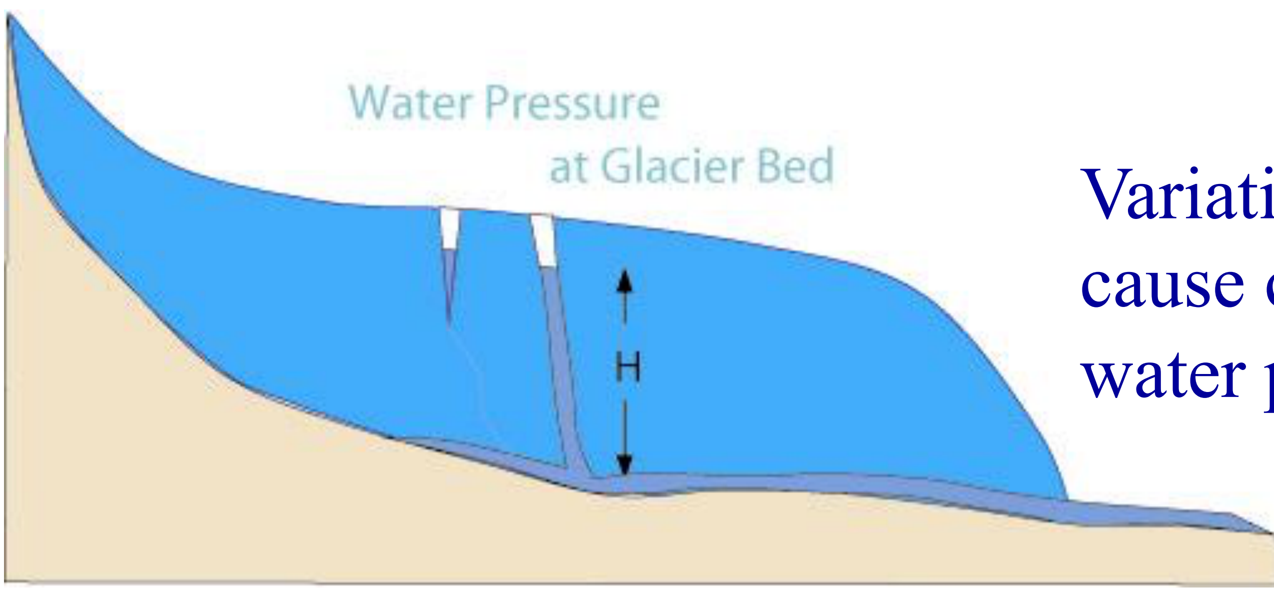
When a glacier changes its motion quickly (e.g. daily or weekly), the cause ***must*** be a change in the ***sliding speed***.

- The internal deformation (quasi-viscous flow) cannot be radically altered until the thickness, or slope, or temperature of the glacier change significantly.
- All of these take a much longer time to change.

Why does Water Pressure Change?

Height of water in water tower controls water pressure in faucets.





Variations in water level cause changes in basal water pressure.

Water Flow in Glaciers

Origin of water

- Melting of ice and snow at the surface
- Rain
- Frictional melting from ice sliding over bedrock.

Result

- Large supply of water on hot summer days and after rain storms.

Rivers on the Greenland Ice Sheet

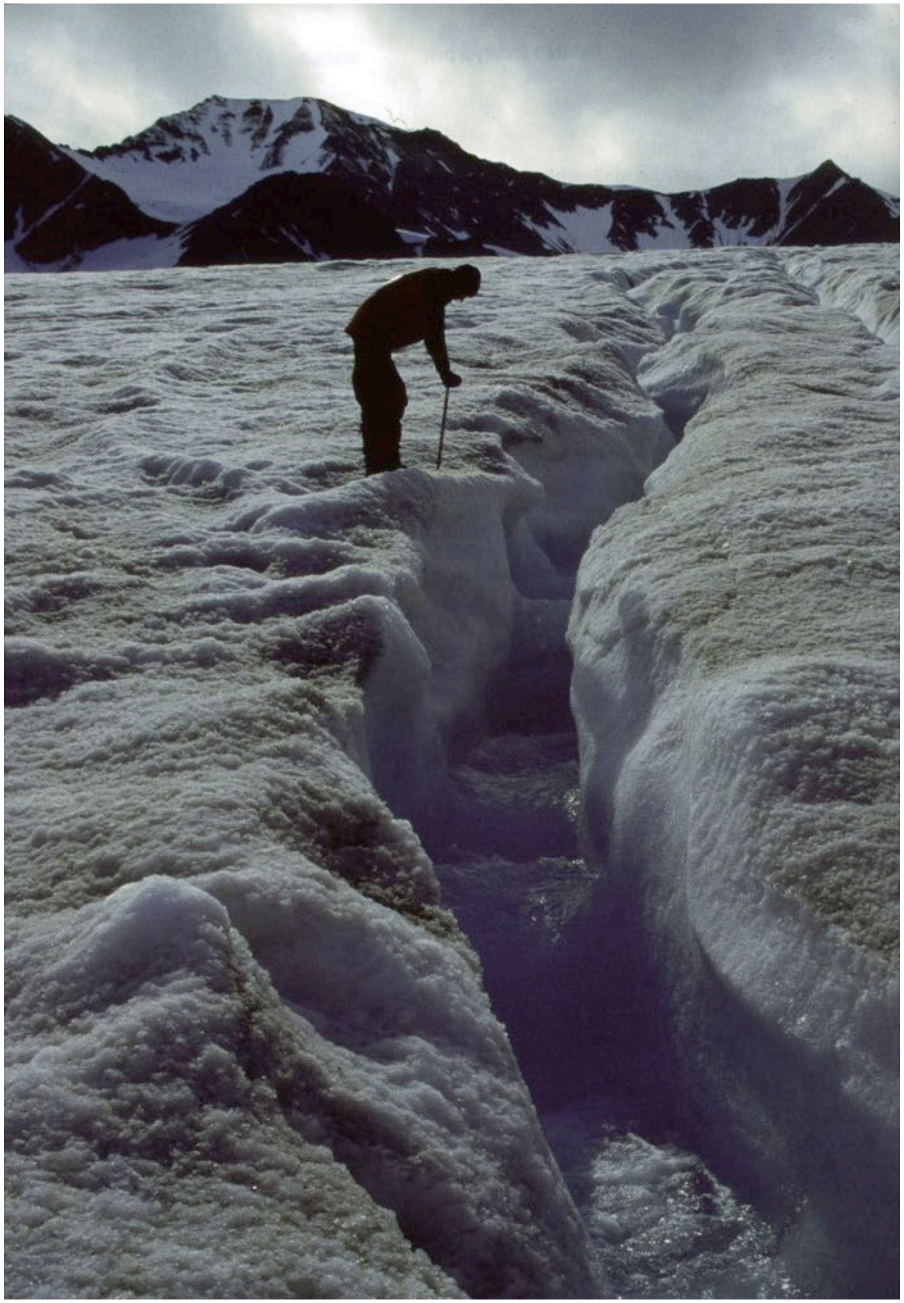
Vibeke Gletscher,
East Greenland

An opportunity to go rafting?

Probably not a good idea…

← ~300 m →

Hambrey and Alean, ***Glaciers***.



Austre Lovenbreen, Spitsbergen. Hambrey and Alean. ***Glaciers***.

Streams on Glaciers

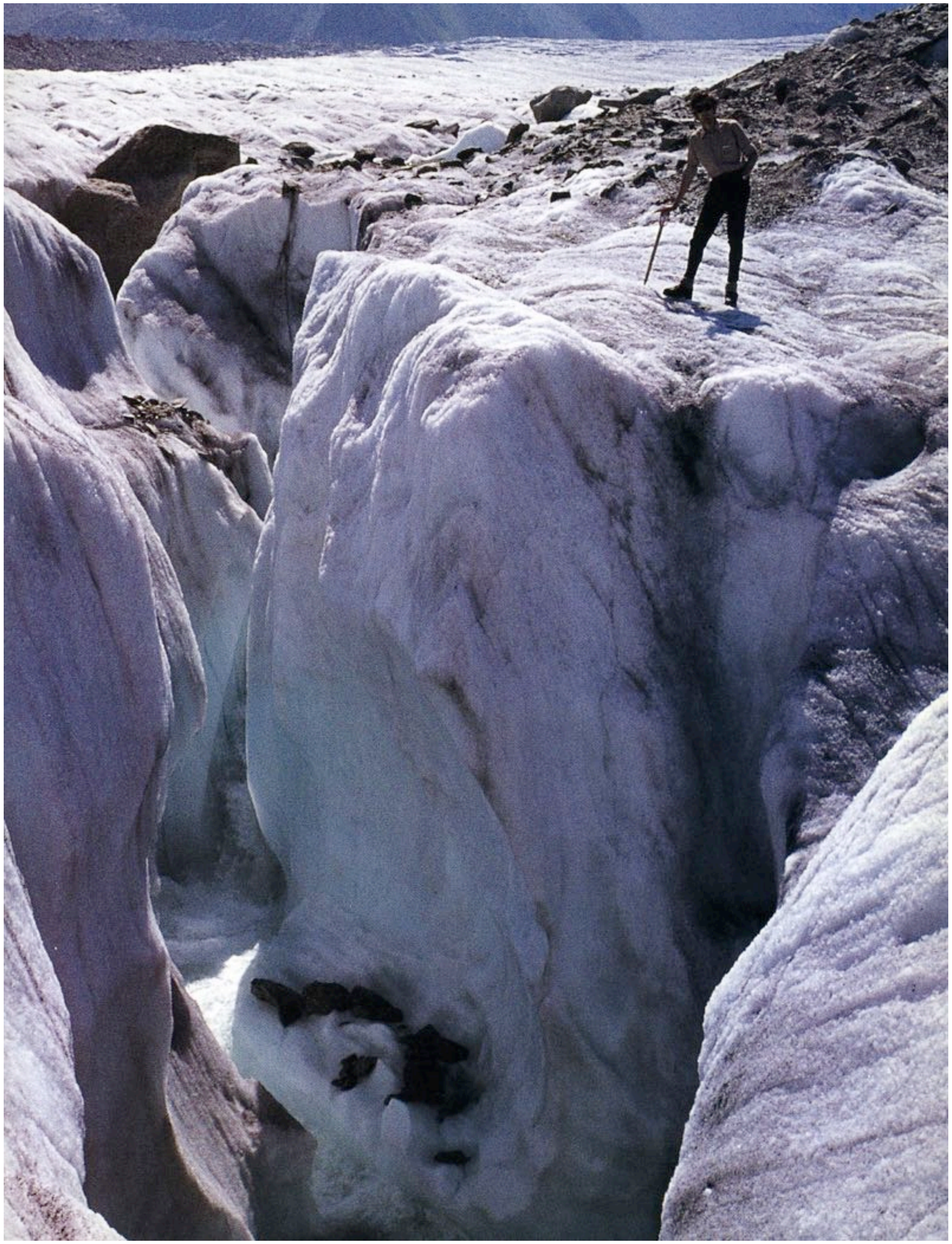
Water can melt channels into glacier ice.

- Water has lower albedo (darker) than ice, so water absorbs more sunlight than ice does.
- Water dissipates potential energy as it loses elevation.
- Water in contact with ice stays at $0^{o}C$.
- So what happens to that energy?

Moulins

Water will find a way somehow to move down into a glacier.

• a supraglacial stream will typically flow into a crevasse.



Mer de Glace, France
Hambrey and Alean. ***Glaciers***.

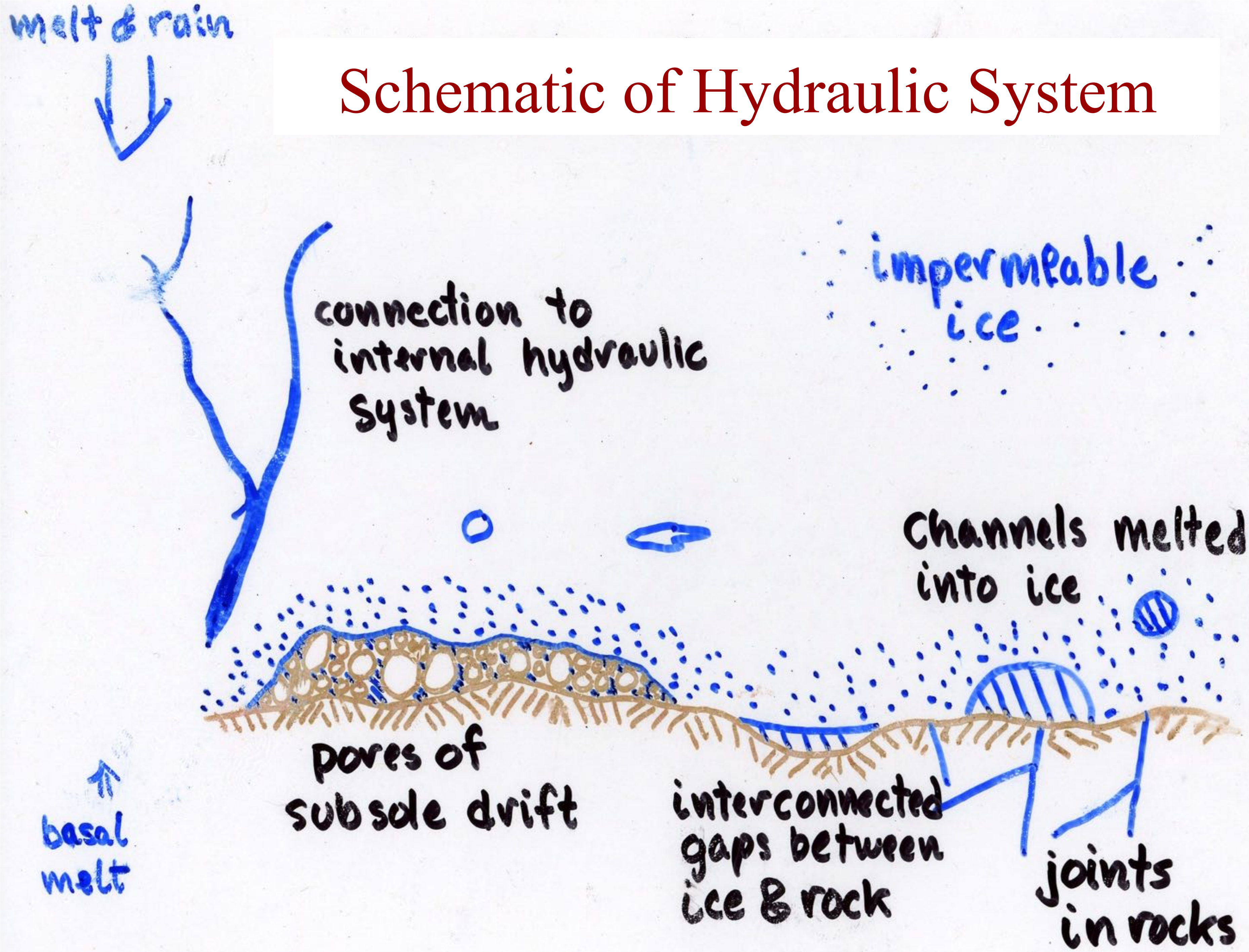
Tunnels

We can see the water coming out at a glacier terminus

- But where has it been?

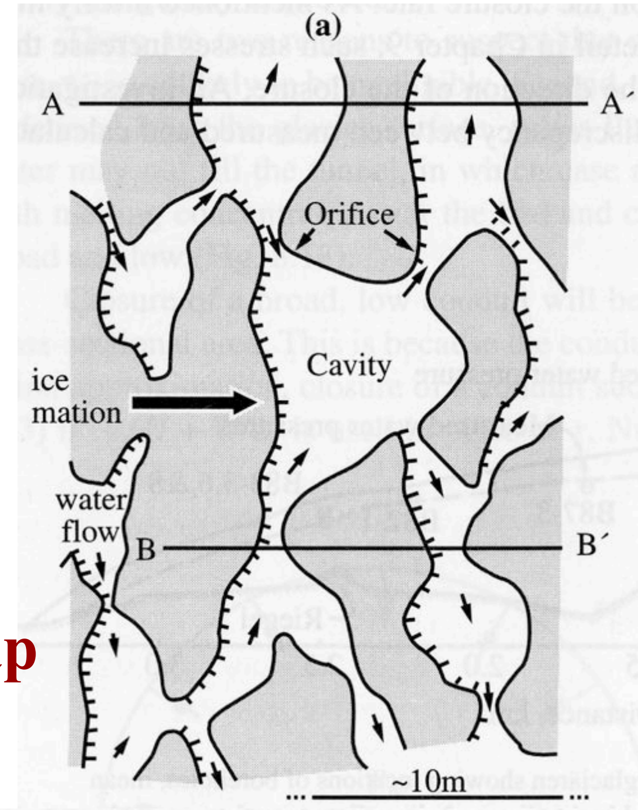
Fox Glacier, NZ.
Hambrey and Alean. ***Glaciers***.

Schematic of Hydraulic System



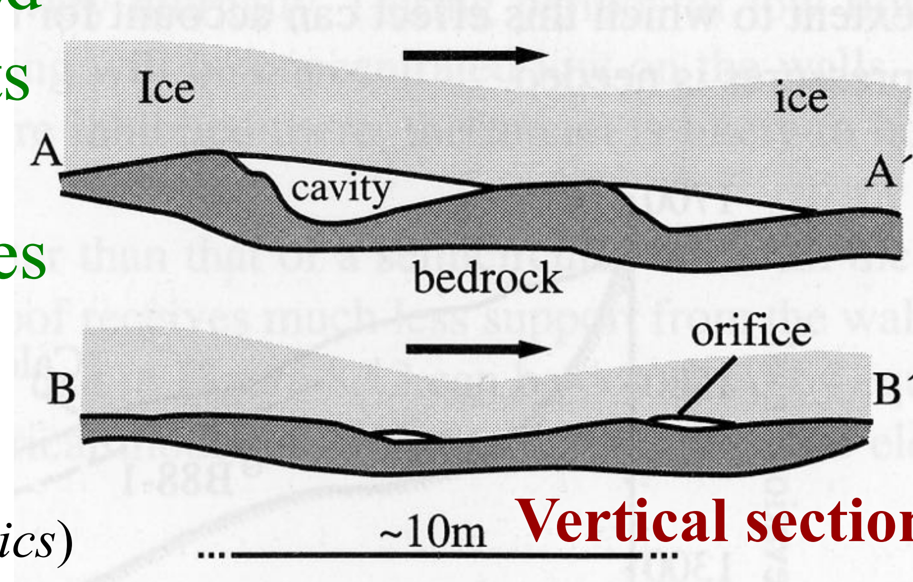
Linked Cavities

In absence of subglacial tunnels, water flows through a ***linked-cavity system*** of interconnected basal cavities and narrow passage-ways.



Map

- Drainage is inefficient.
- High water pressure is needed to carry even limited amounts of water.
- Water will collect in crevasses and cavities until high pressures are reached.



Vertical section

(Hooke, *Fundamentals of Glacier Mechanics*)

Linked Cavities in Central Park

Glaciated bedrock with ledges, cracks, and hollows

(http://www.swisseduc.ch/glaciers/)

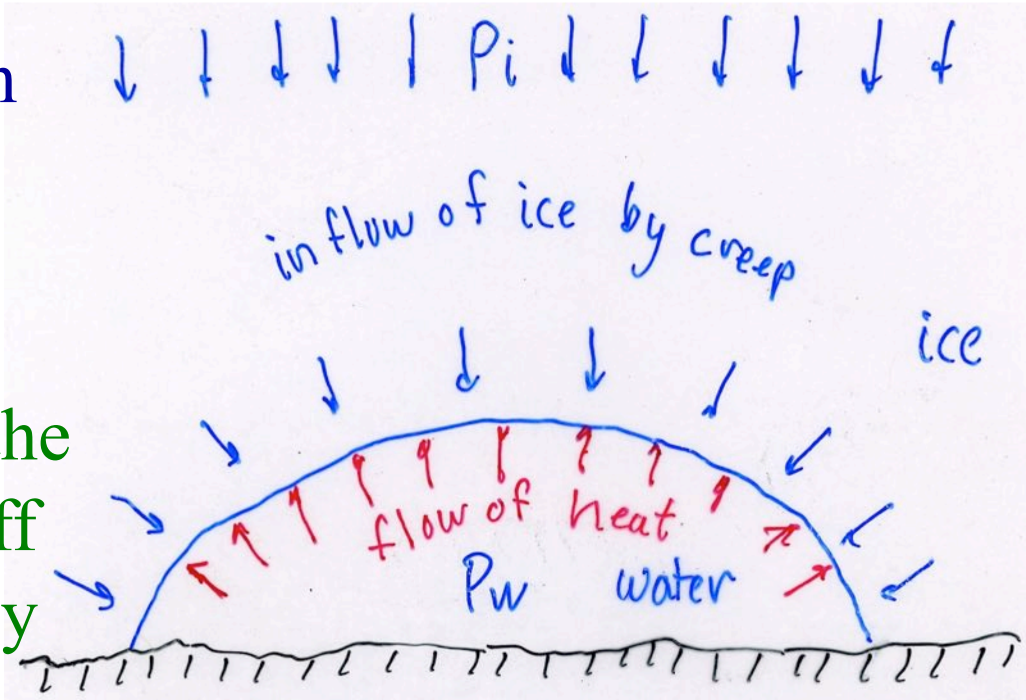
Tunnels

Arborescent networks of tunnels can carry large volumes of water at relatively low pressure compared to the pressure due to the weight of the overlying ice.

- Water flows from high pressure to low pressure.
- Water will flow from linked cavities into tunnels.

Ice also flows from high to low pressure.

- Ice also flows into the tunnels.
- Energy dissipated by the flowing water melts off the walls as fast as they can close in.



Seasonal Water Cycle

Early winter: little melt-water, low water pressure.
- Tunnels close, linked cavities survive.

Late winter: seepage, basal melt.
- water pressure rises slowly, sliding increases slowly.

Spring: high melt-water flux enters linked cavities.
- Water pressure rises, sliding increases slowly.

Early summer: too much water overloads cavities.
- Sliding hits its peak.
- Surface rises, cavities join, tunnels start to form.

Late summer: water flows in low-pressure tunnels.
- Basal water drains, sliding slows down.

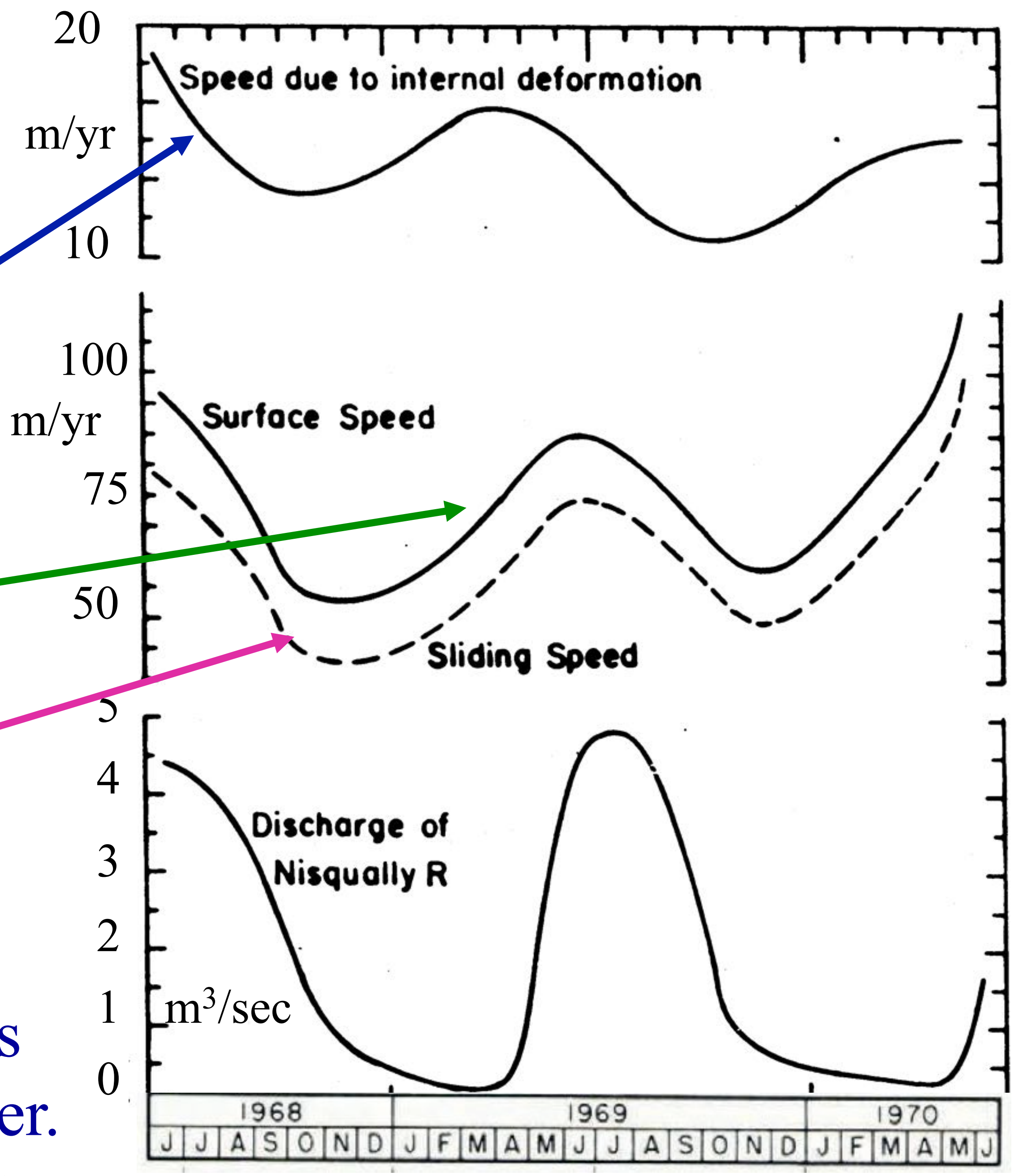
Flow of Nisqually Glacier

Speed due to viscous flow (deforming ice).
- Calculated from ice thickness and slope.

Surface speed
- Measured

Sliding speed
- Calculated as their difference.

Nisqually River comes from under the glacier.



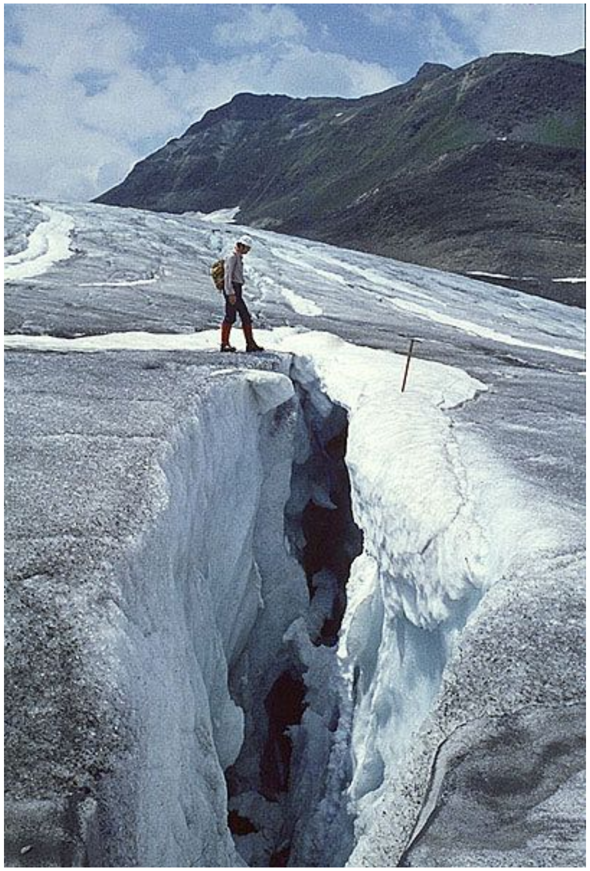
(Hodge, S., 1974. *J.Glaciol.*)

Brittle Behavior in Glaciers

Crevasses can form in the upper "skin" (about 30 meters, or 100 ft) of flowing glacier ice, when the ice tries to *stretch* rapidly.

- At greater depths, the ice continually flows back in to close up the cracks.
- Crevasses almost always form at right angles to the direction of the maximum stretching.

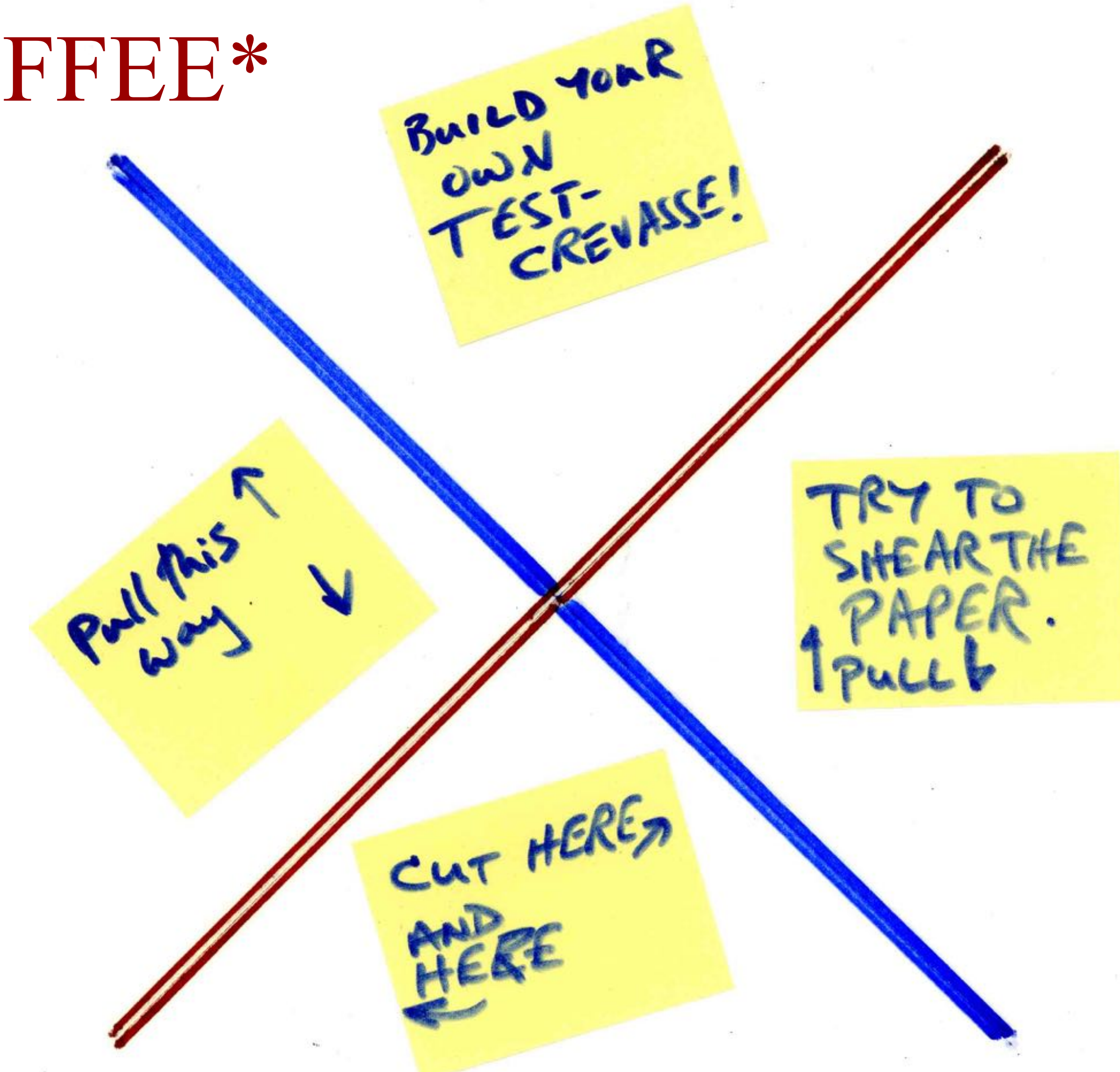
Demo: silly putty



Hambrey and Alean, 2005. *Glaciers.*

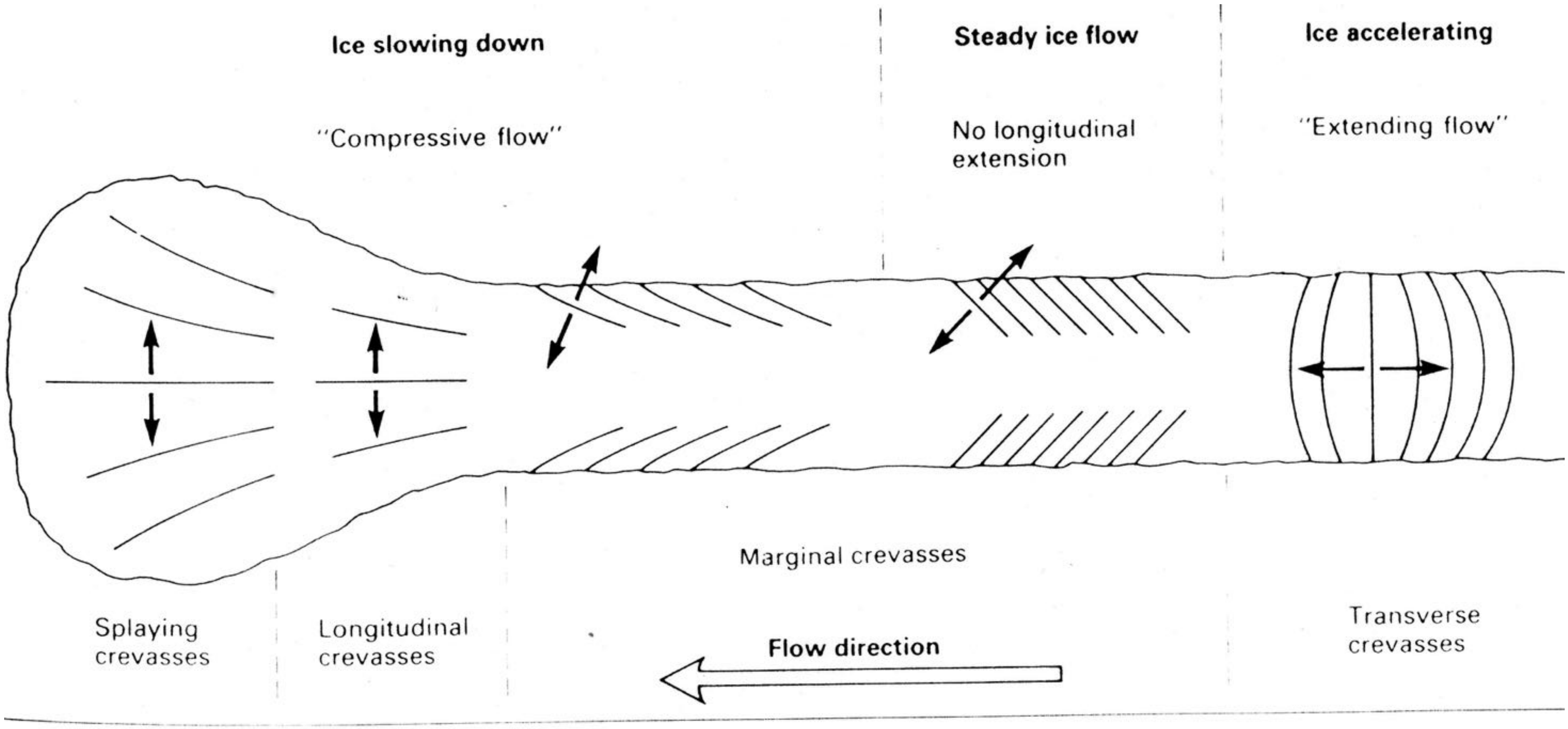
HELP!COFFEE*

Hawley
Extremely
Lightweight
Portable **!**
Crevasse
Orientation
Freehand
Failure
Estimation
Equipment



[*Designed by former ESS 203 TA Bob Hawley]

Where Crevasses tend to Form



The Curious Scientist
Questions on flow, deformation, and crevasses…

Google doc for Break-out rooms:
https://docs.google.com/document/d/
1LrpQNIJMsxJodqhTyrgpEuNamWgQIw7vGhQO7uvZ5co/edit

Hambrey and Alean, 2005. *Glaciers*.

Crevasse on Griesgletscher Switzerland

- Why might this crevasse have formed?

- Since this is summer, you can see it easily.
- In winter it might be hidden by a thin snow bridge (falling through is bad for your health!).

Crevasses on Fox Glacier, New Zealand

Crevasses on Arctic Piedmont Glaciers

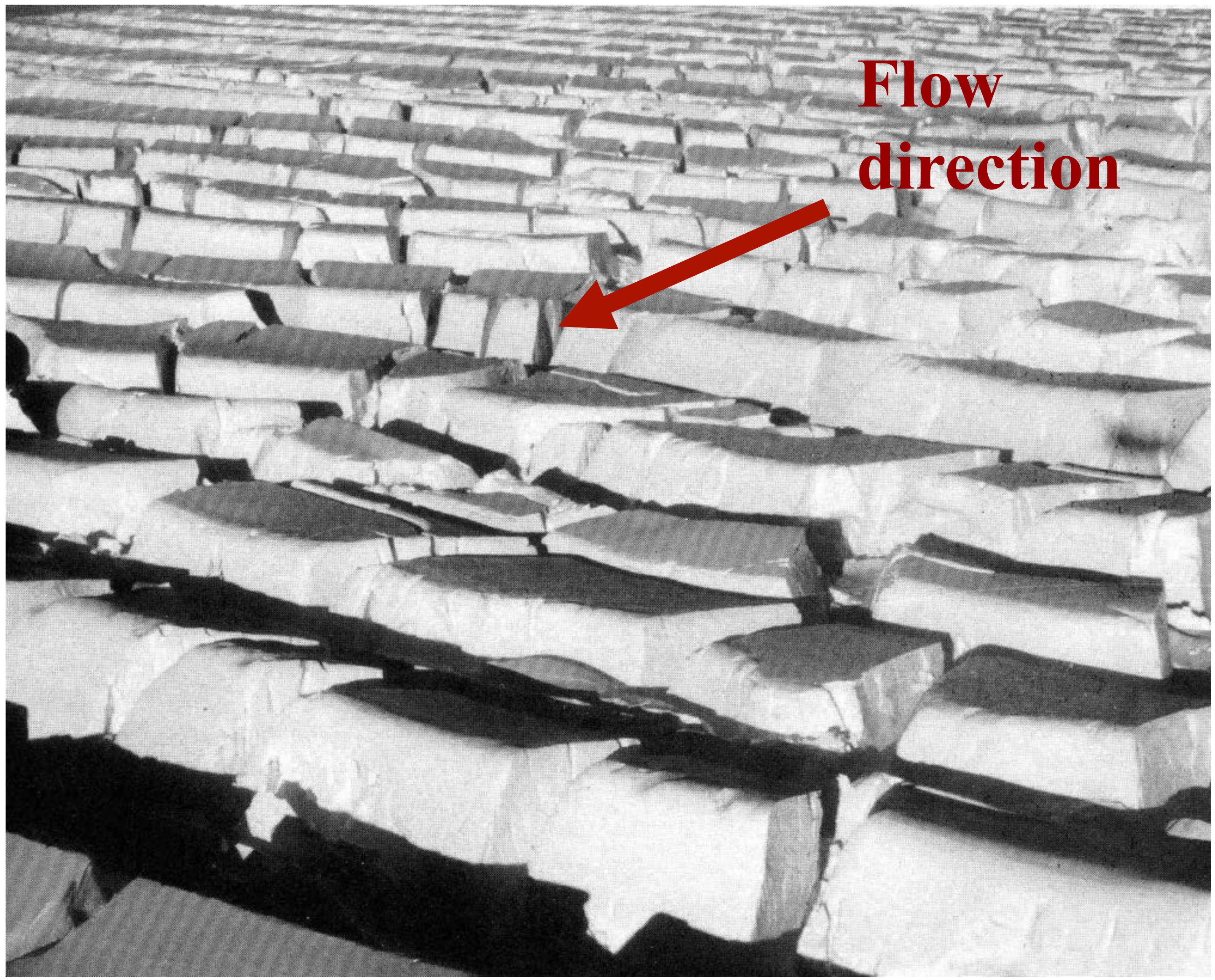
- Why did these crevasses form?

http://www.swisseduc.ch/glaciers/

Crevasses on an Antarctic Outlet Glacier

Ice accelerated into a valley through the Transantarctic Mountains, then slowed down and spread sideways.

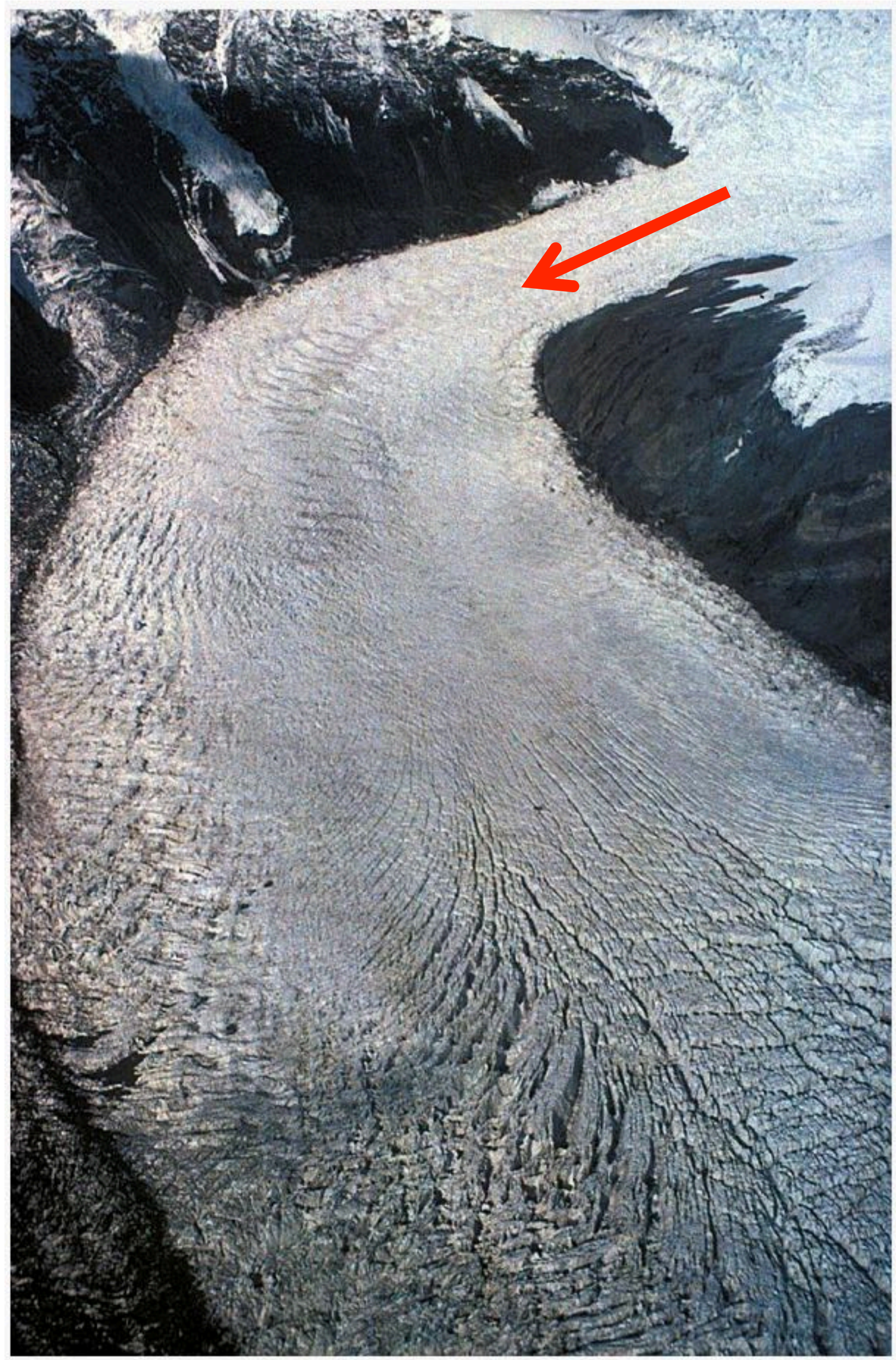
- When did each set of crevasses form?



R.P. Sharp. 1988. *Living Ice*

1. Alaskan Glaciers

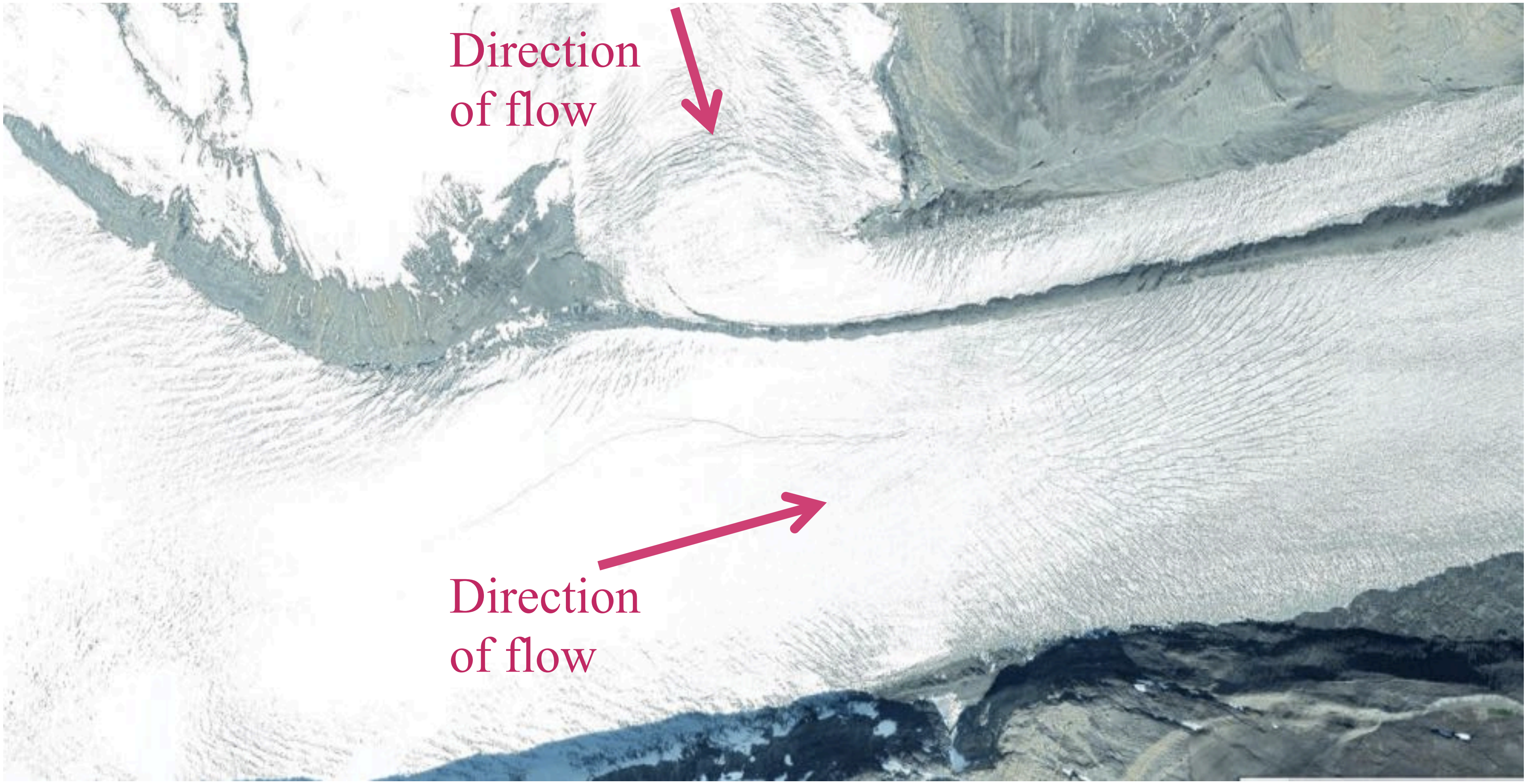
- Locate examples of all 3 types of crevasses (transverse, marginal, and splay) and explain why they formed.



http://www.antarcticglaciers.org/modern-glaciers/structural-glaciology/splaying-crevasse/

2. Crevasses on Saskatchewan Glacier

- Locate examples of all 3 types of crevasses (transverse, marginal, and splay) and explain why they formed.



Google Earth