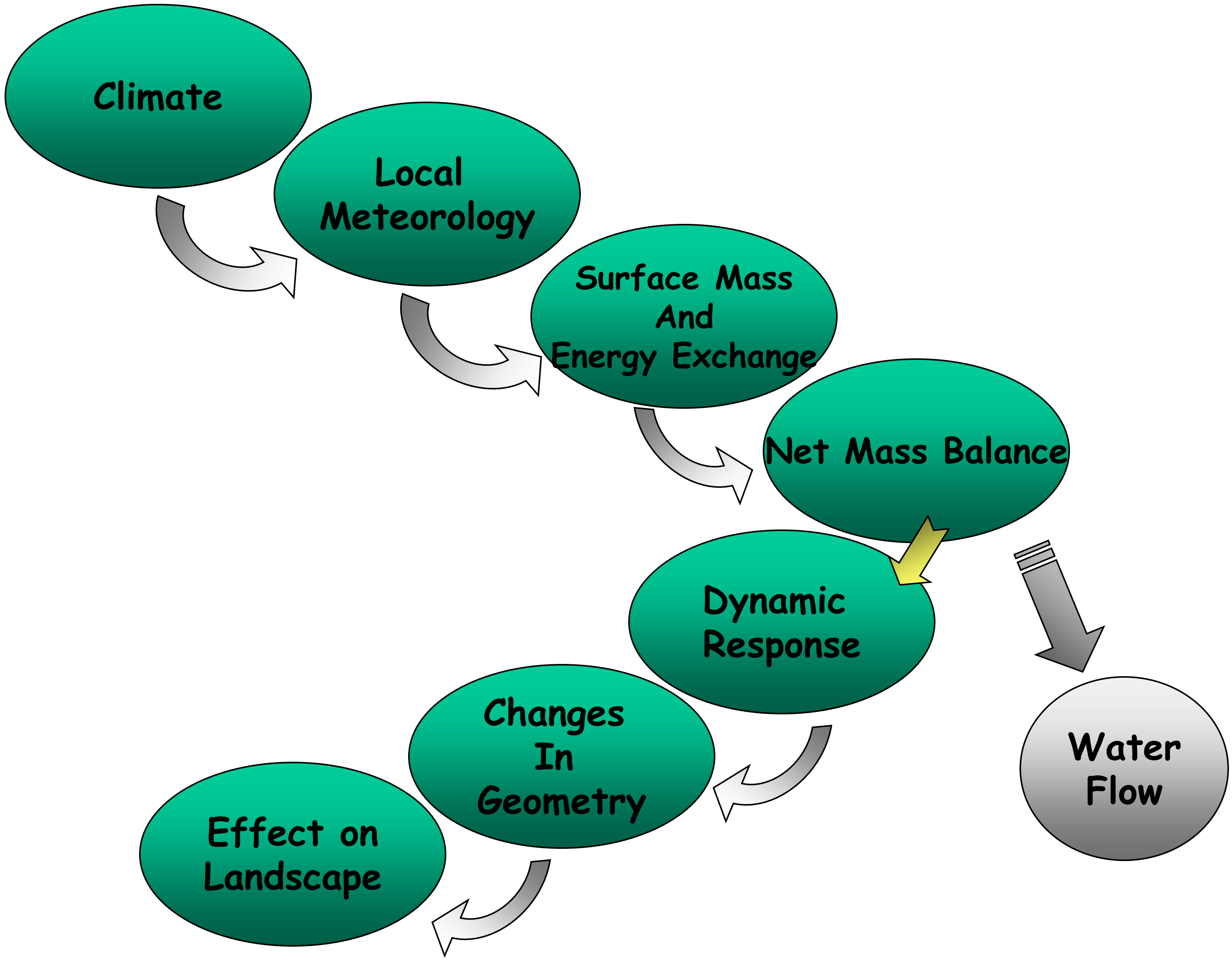
Glacier Hydrology

Why should you care?

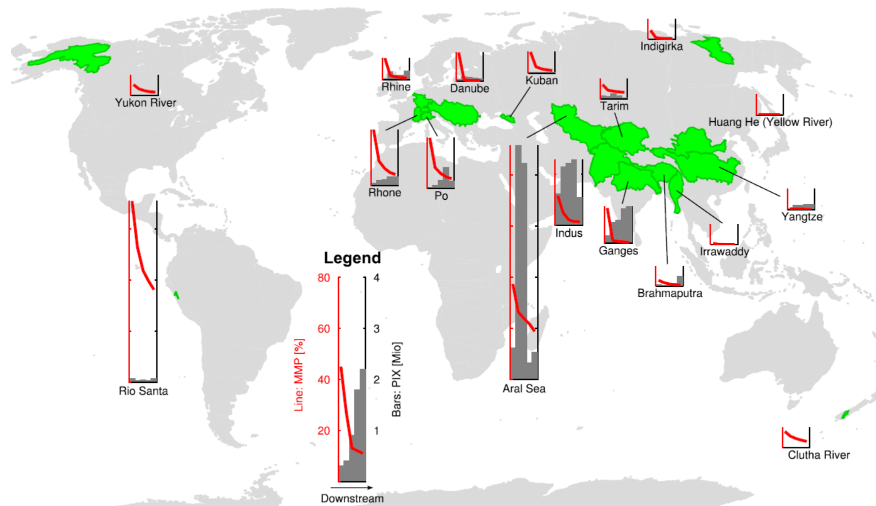

Climate
Local Meteorology
Surface Mass And Energy Exchange
Net Mass Balance
Dynamic Response
Changes In Geometry
Effect on Landscape
Water Flow

Practical Matters:
Glaciers in the Hydrological System

1. Glacier-fed rivers provide much of the water supply in some parts of the world.

Antisana Mountain, Equador

Dean Jacobsen

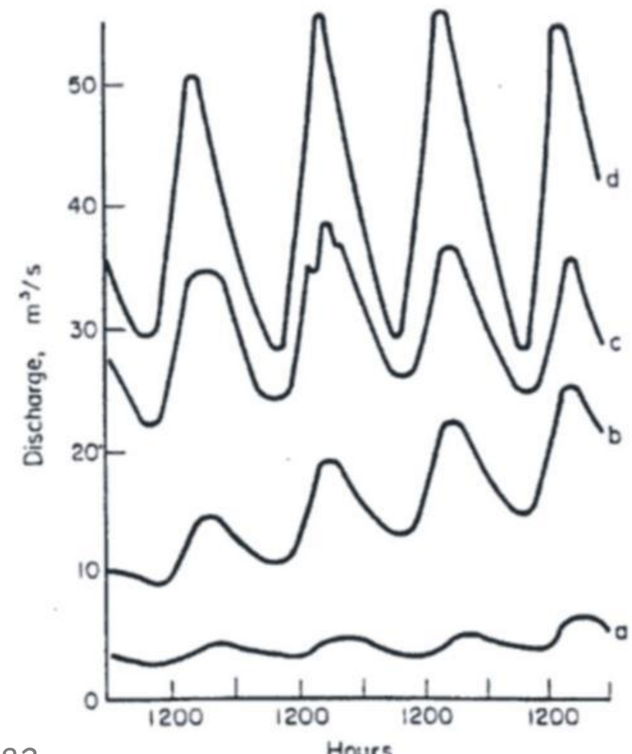


Kaser et al., 2010

Practical Matters:
Glaciers in the Hydrological System

2a. Run-off characteristics (daily and seasonal) differ from other types of stream flow.

Vatnajökull   Annes Hjemmeside



Behrens, 1982

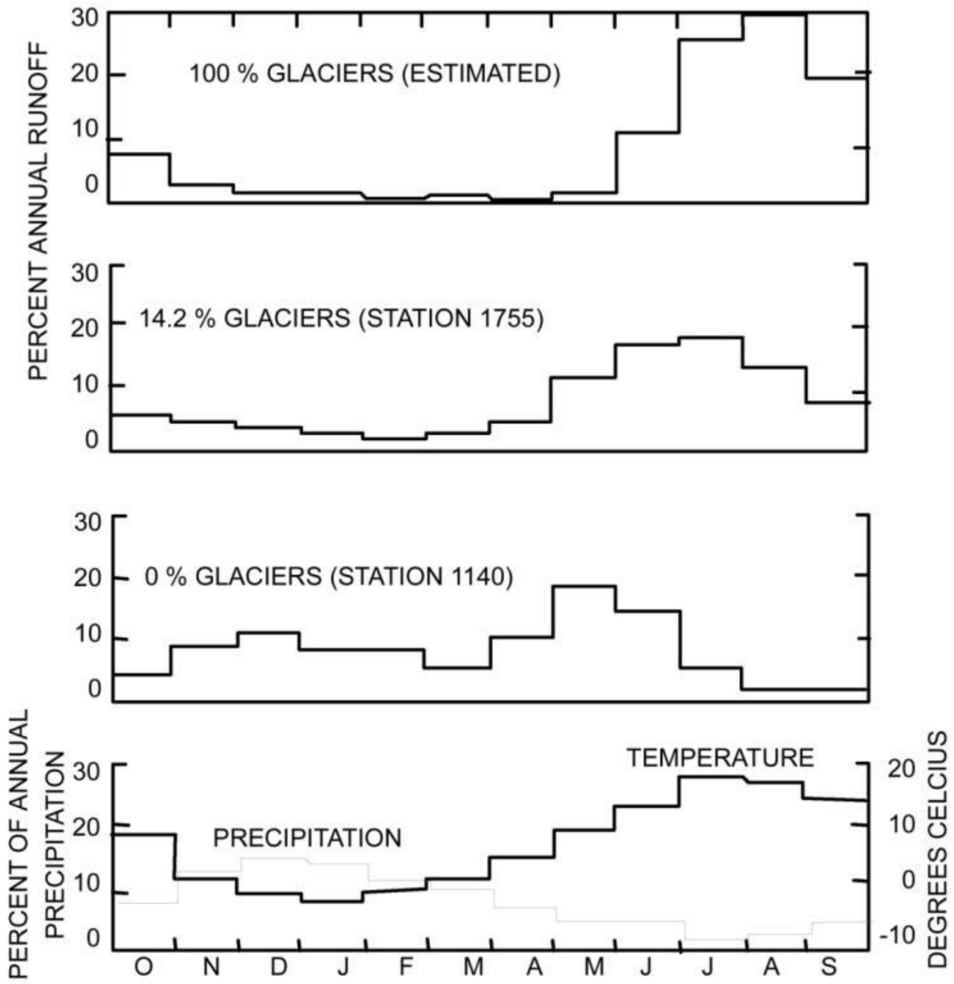
mid- summer

spring

Practical Matters:
Glaciers in the Hydrological System

2b. Contribution to regional runoff

Klawatti Glacier Thunder Creek Basin



Practical Matters:
Glaciers in the Hydrological System

3. Run-off locally used for hydroelectric power generation.

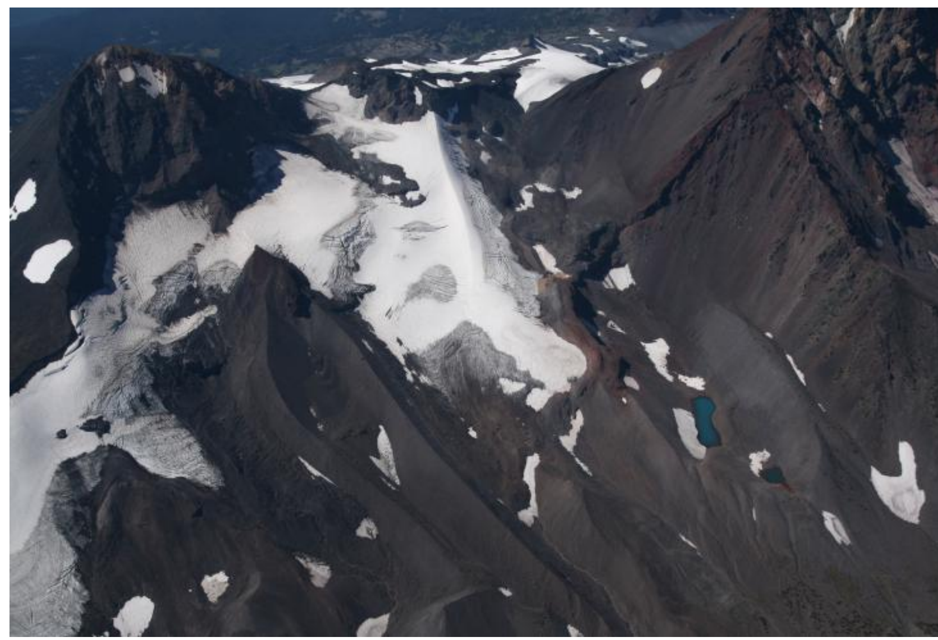
Oberarrgletscher, Switzerland
http://www.swisseduc.ch/glaciers/index-en.html

- Switzerland
- Norway

Practical Matters:
Glaciers in the Hydrological System

4. Flood hazards in alpine areas from moraine-dammed and ice-dammed lakes.

Hidden Lake, Kennicott Glacier — Austin Post



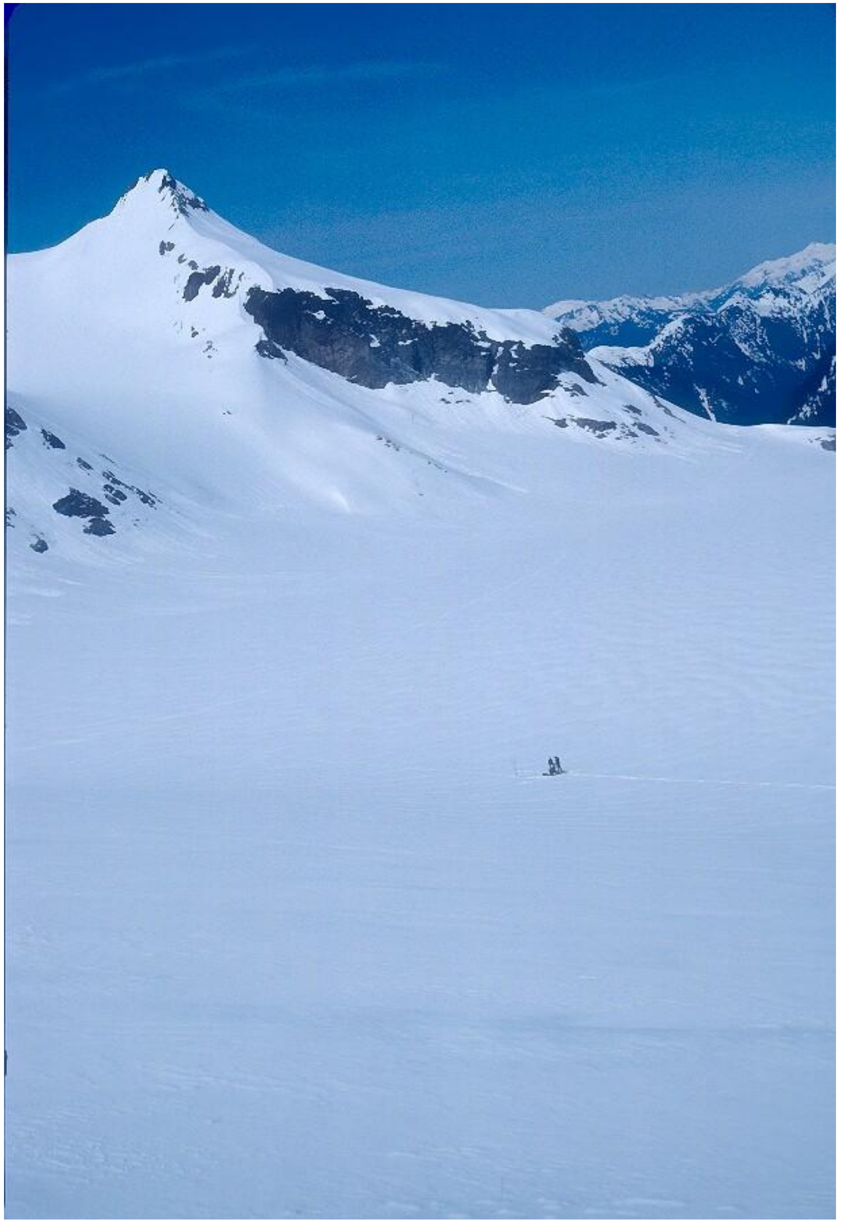
Thayer Glacier, North Sister, Oregon — John Scurlock

Practical Matters:
Glaciers in the Hydrological System

4. Flood hazards in alpine areas from moraine-dammed and ice-dammed lakes.

What can we learn from observation?

In the accumulation zone



Ablation Zone

Ablation Zone

In front of the glacier

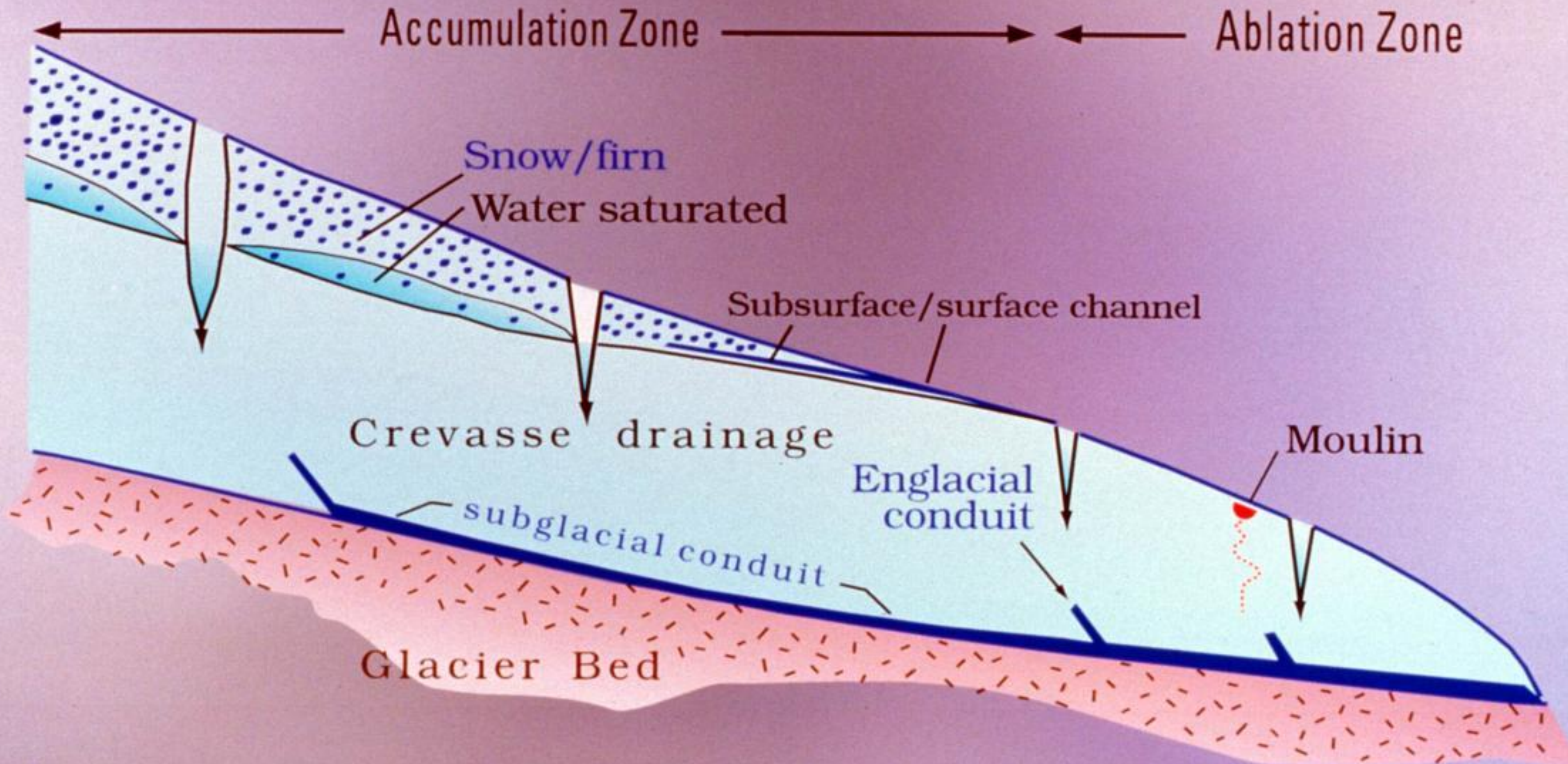
Emmons Glacier John Scurlock

Annes Hjemmeside

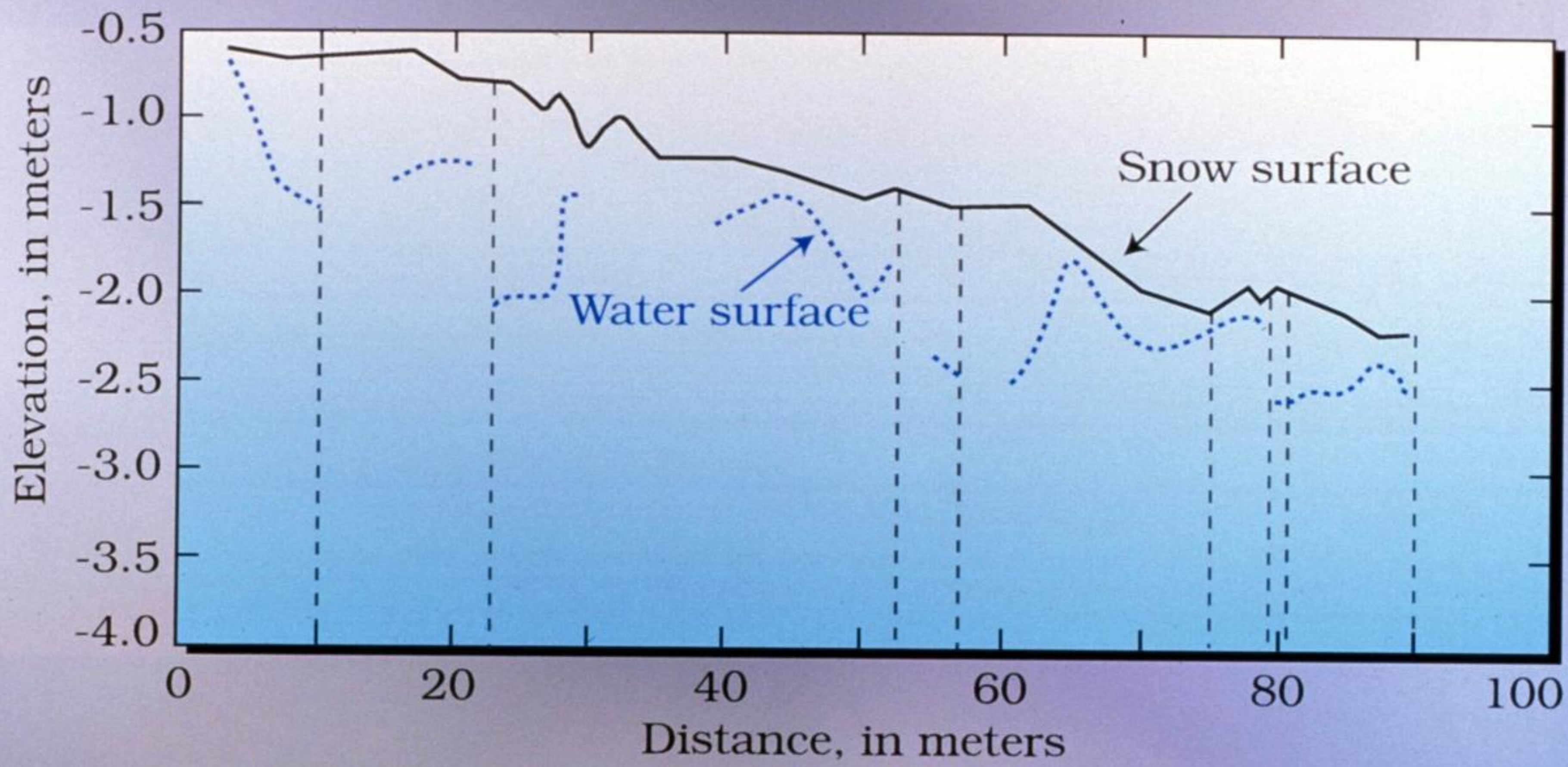
Vatnajökull

Subglacial Conduit

Hydrologic Cross Section of a Temperate Glacier

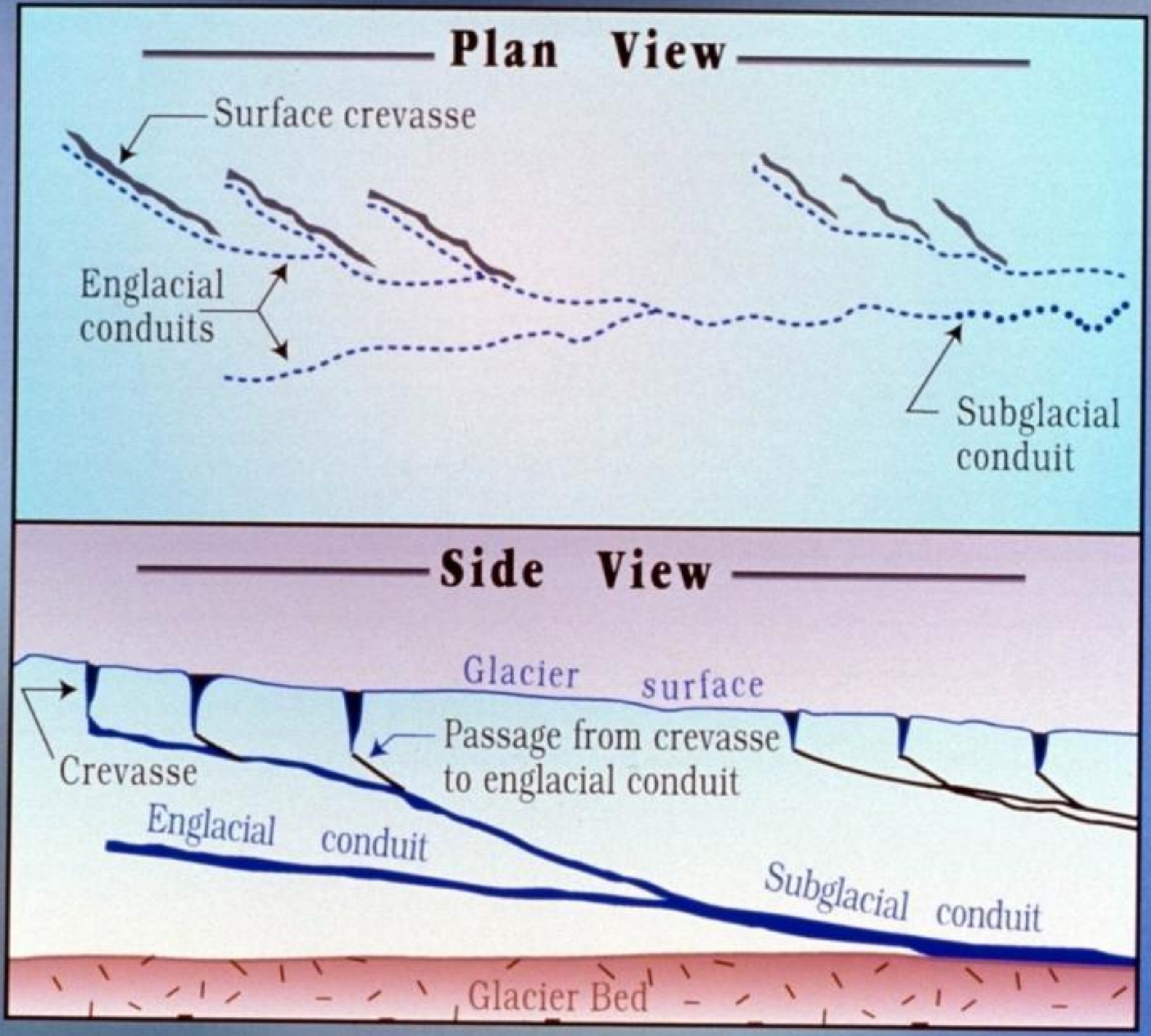


Firn water table……in addition to percoulation



Firn water table

Englacial Passageways



Englacial Passageways

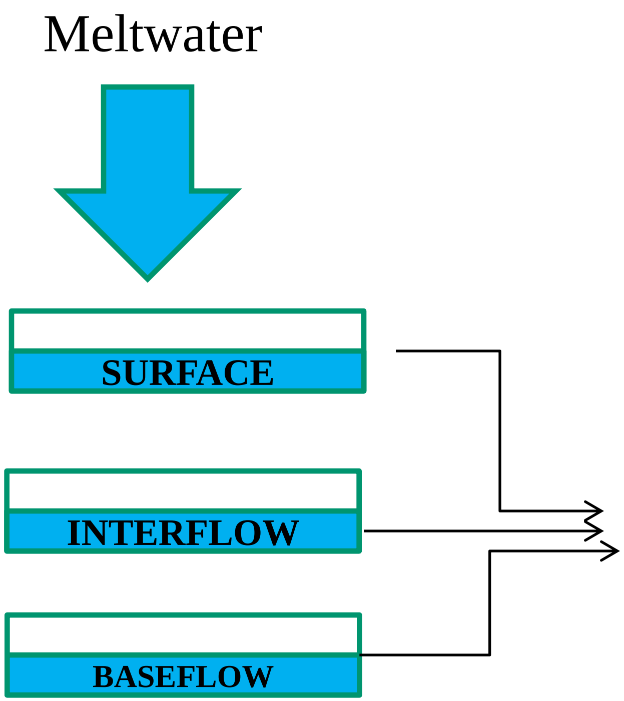
How do we learn about water flow through glaciers?

- Field studies of active glaciers
- Theoretical analysis
- Inferences from geomorphology

Field study of active glaciers

- Mass balance
- Stream monitoring (incl. hydrochemistry)
- Dye tracing
- Borehole-based studies
- Radio-echo sounding

Mass Balance



HYDROLOGICAL PROCESSES
Hydrol. Process. **17**, 297–311 (2003)
Published online in Wiley InterScience (www.interscience.wiley.com). DOI: 10.1002/hyp.1125

A comparative study in modelling runoff and its components in two mountainous catchments

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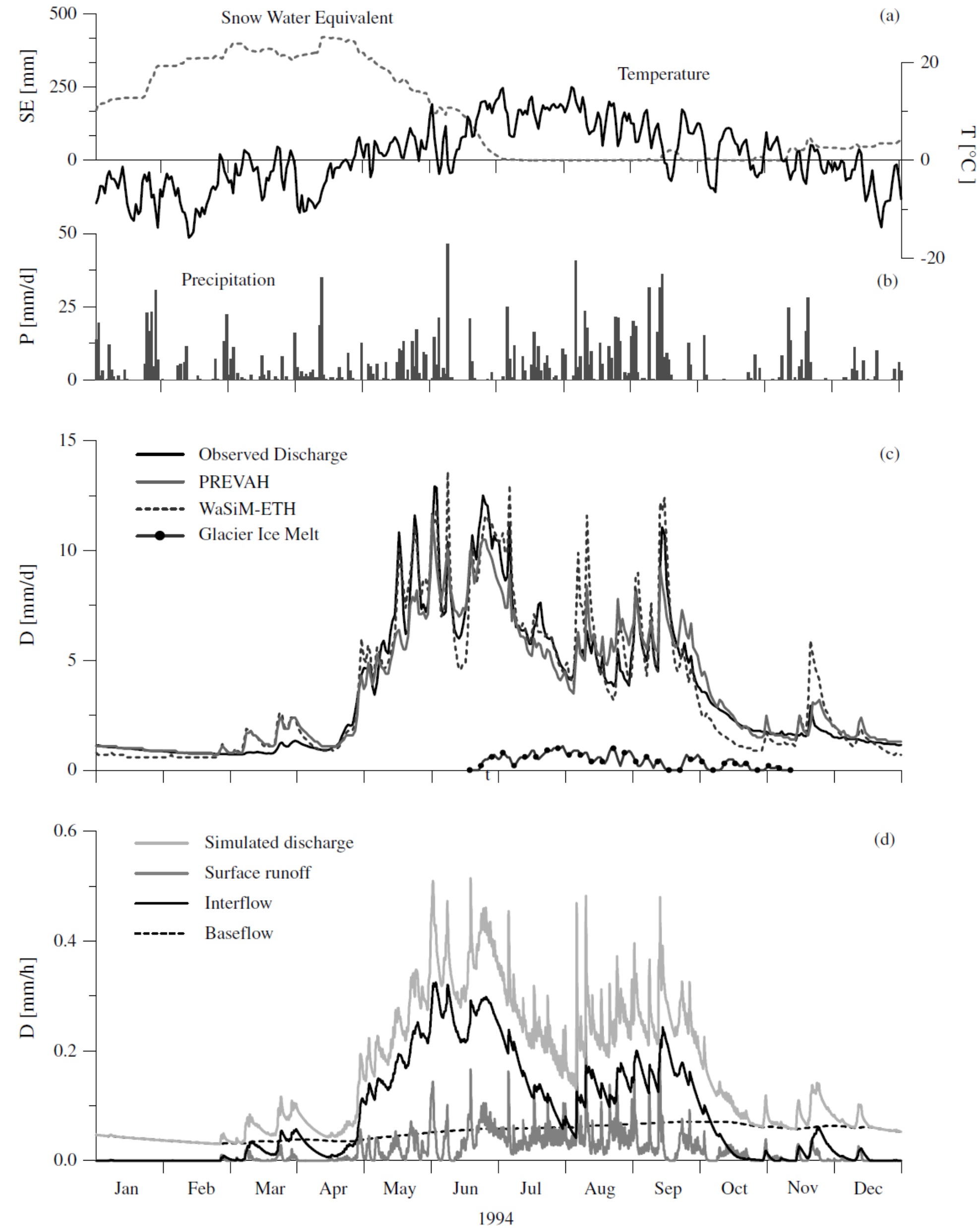
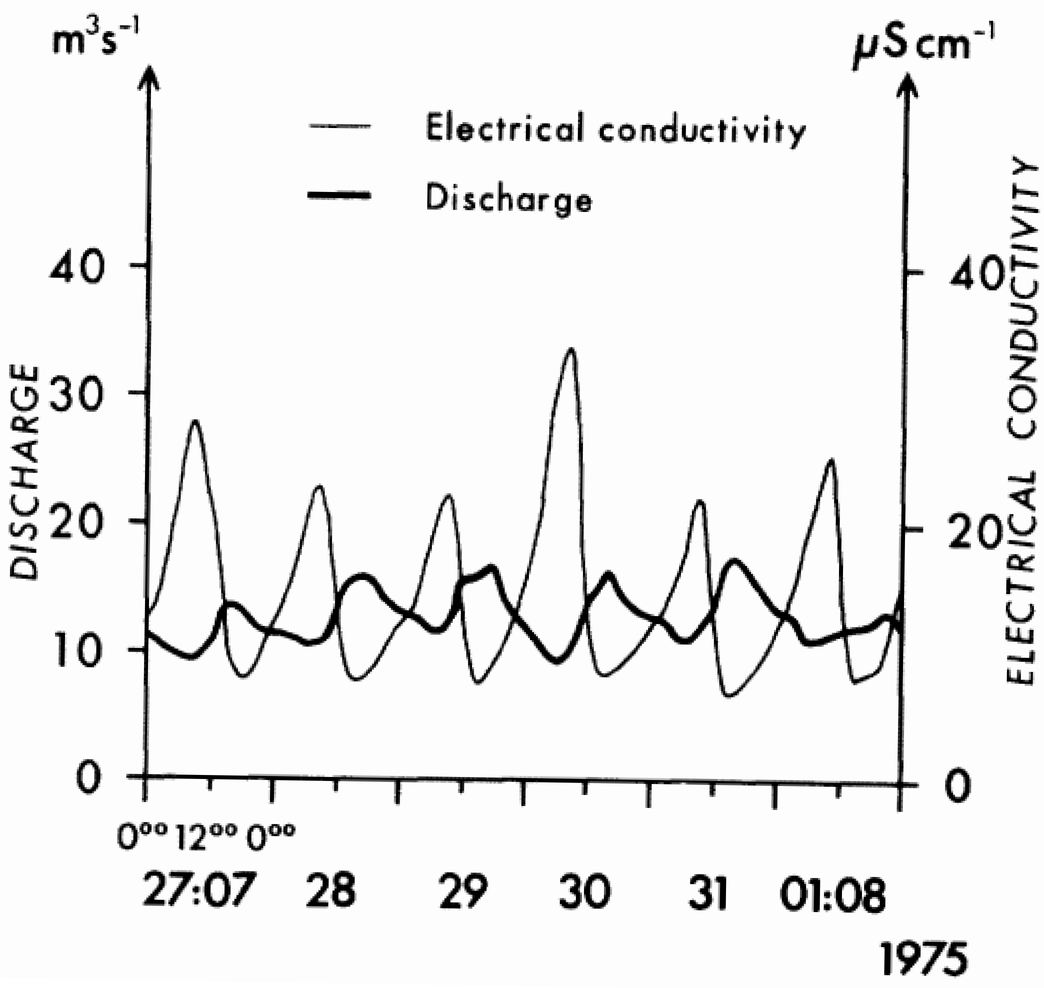
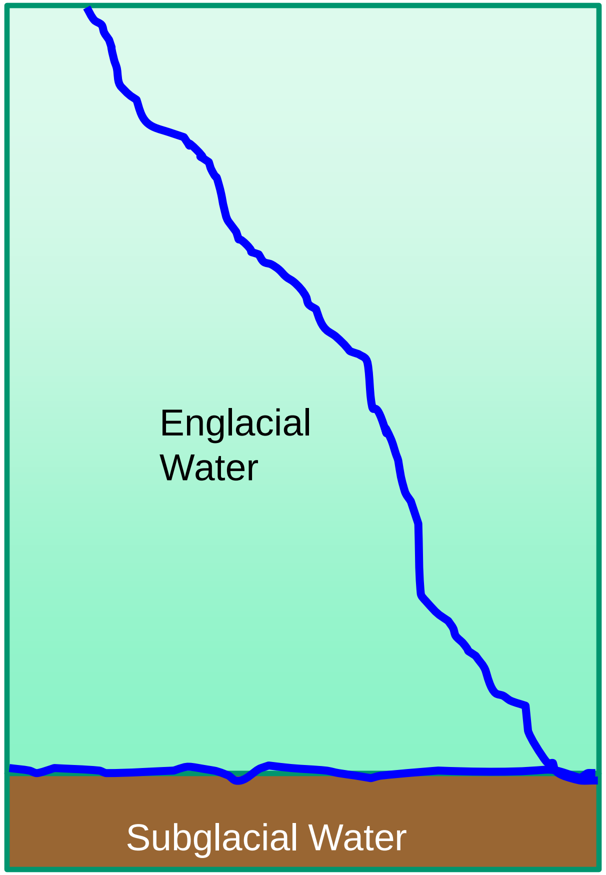


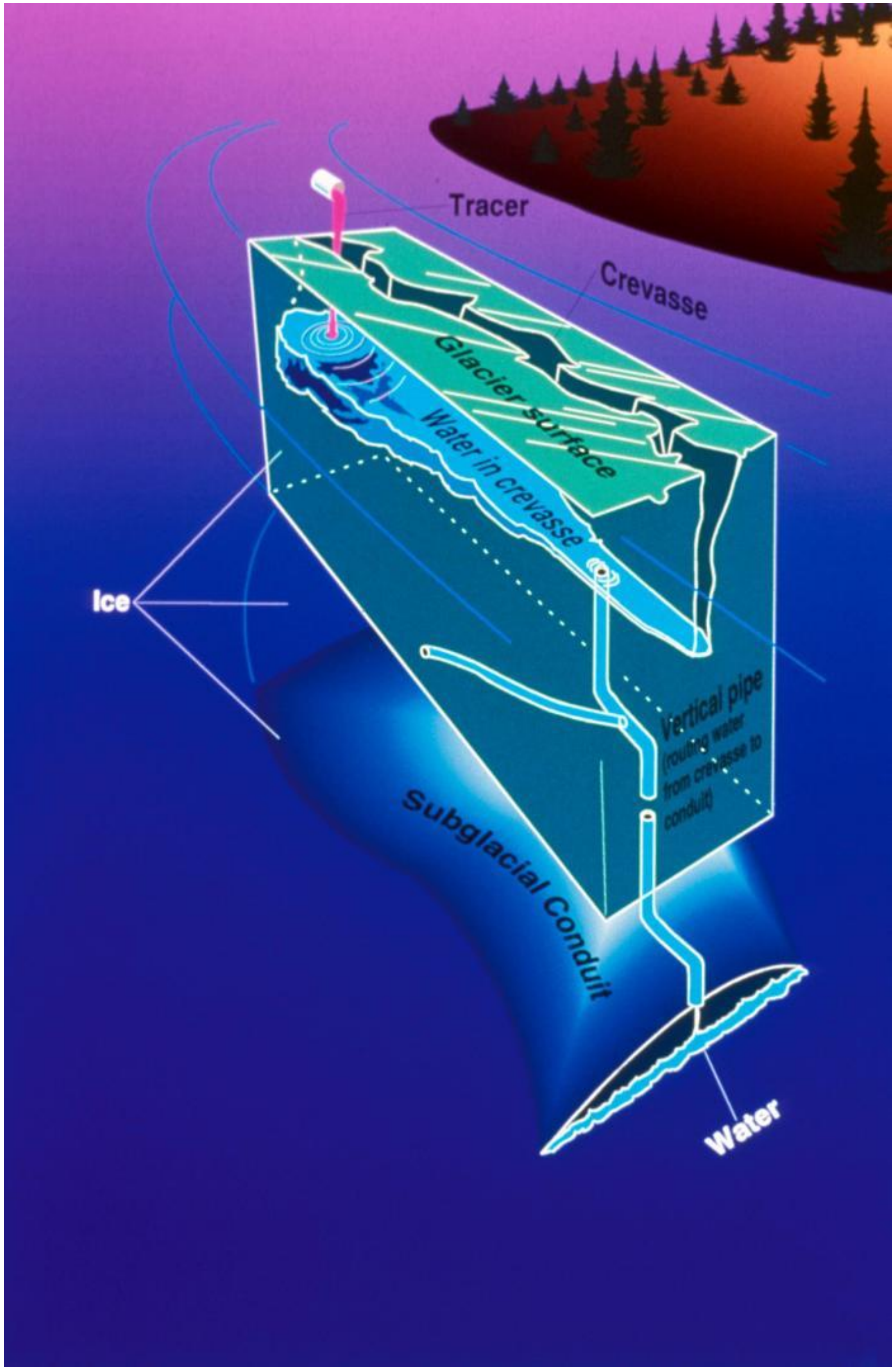
Figure 8. Dischmabach, hydrometeorological values for 1994: (a) daily average air temperature T and simulated snow water equivalent (SE); (b) daily precipitation rates P; (c) comparison between the observation and the simulation of daily discharges; the simulated contribution of glacier ice melt to the total runoff is specified separately; (d) hourly values of the runoff components as simulated by PREVAH

Stream Monitoring – including hydrochemistry

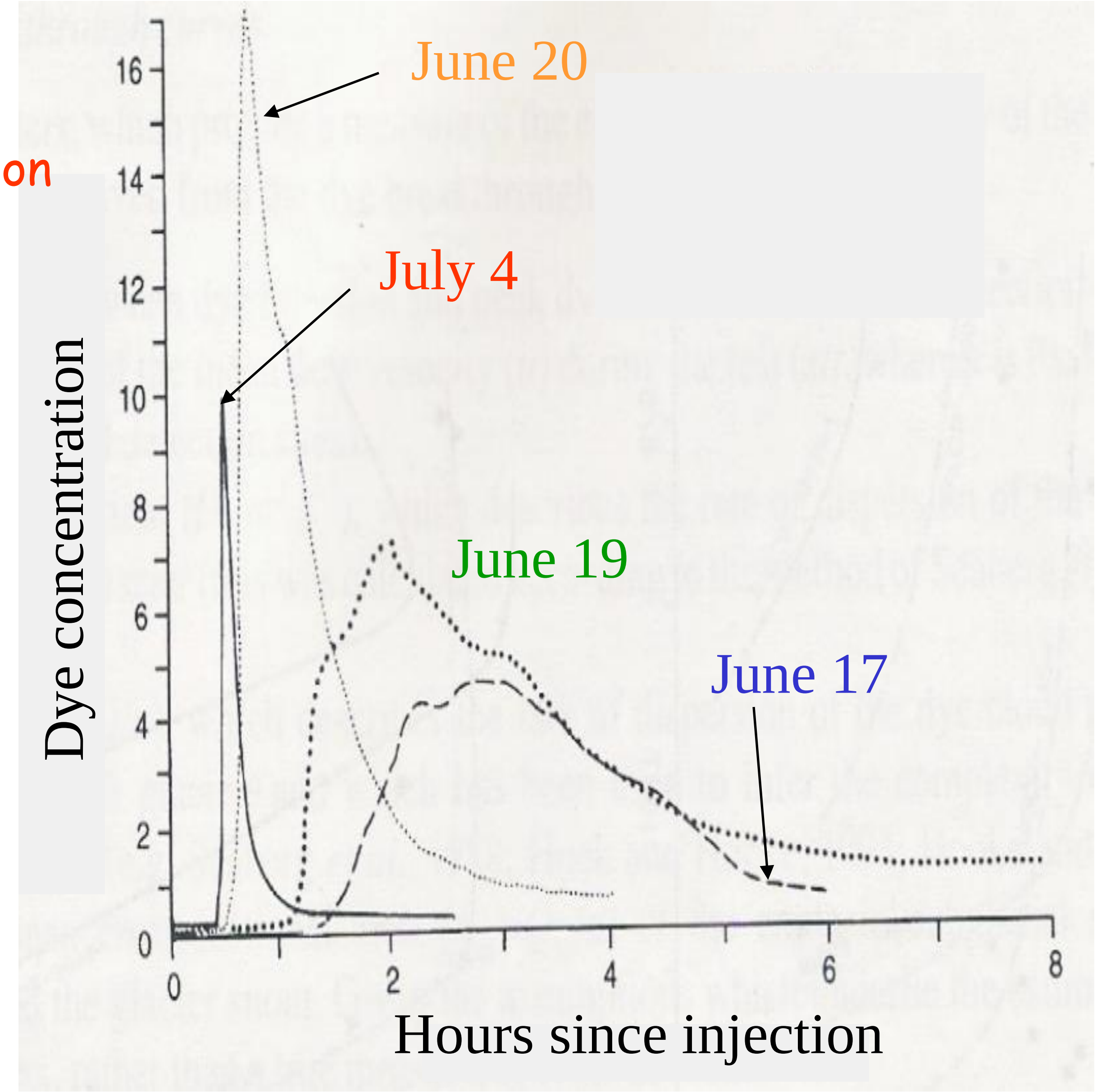




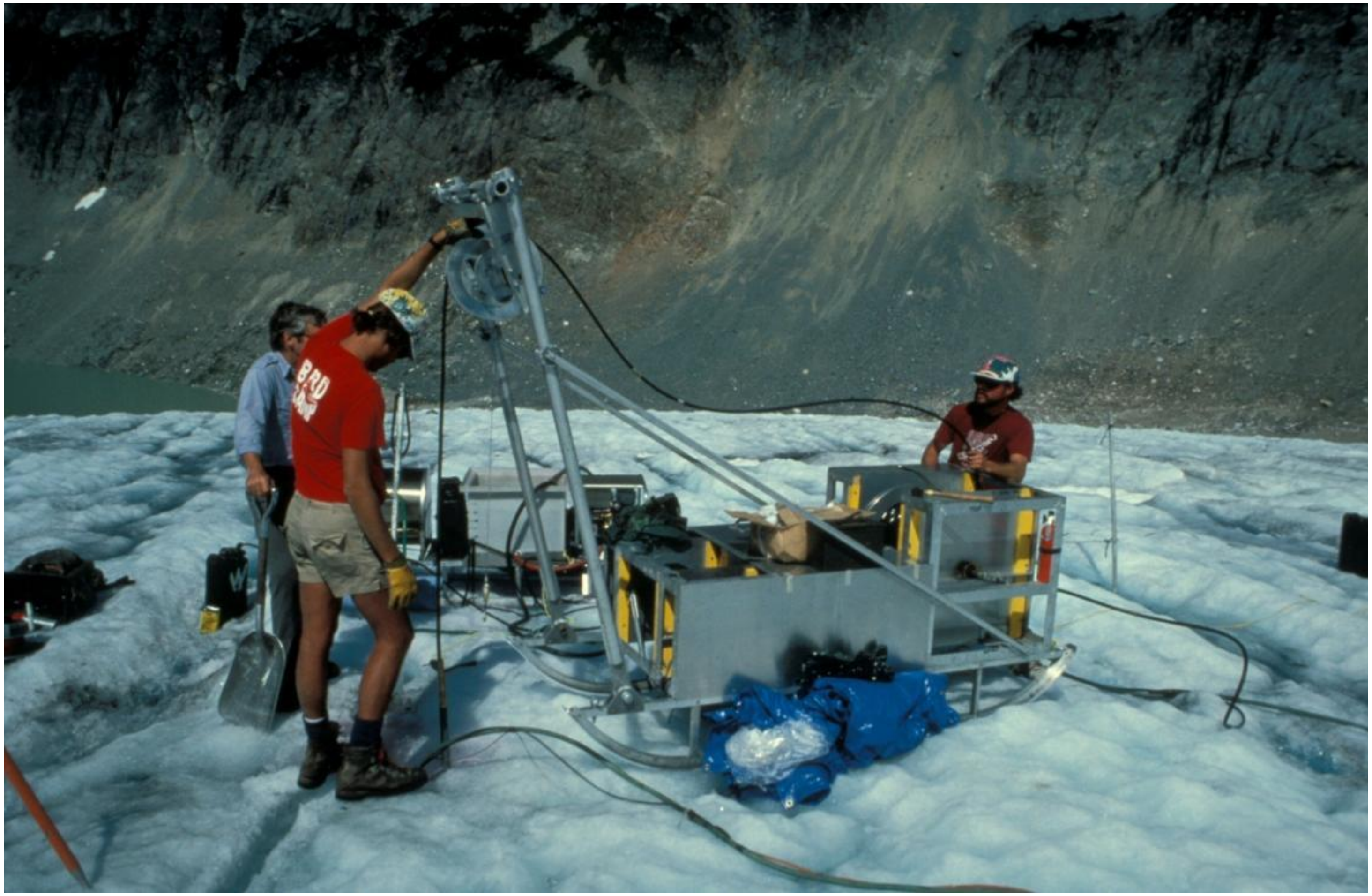
Dye tracing

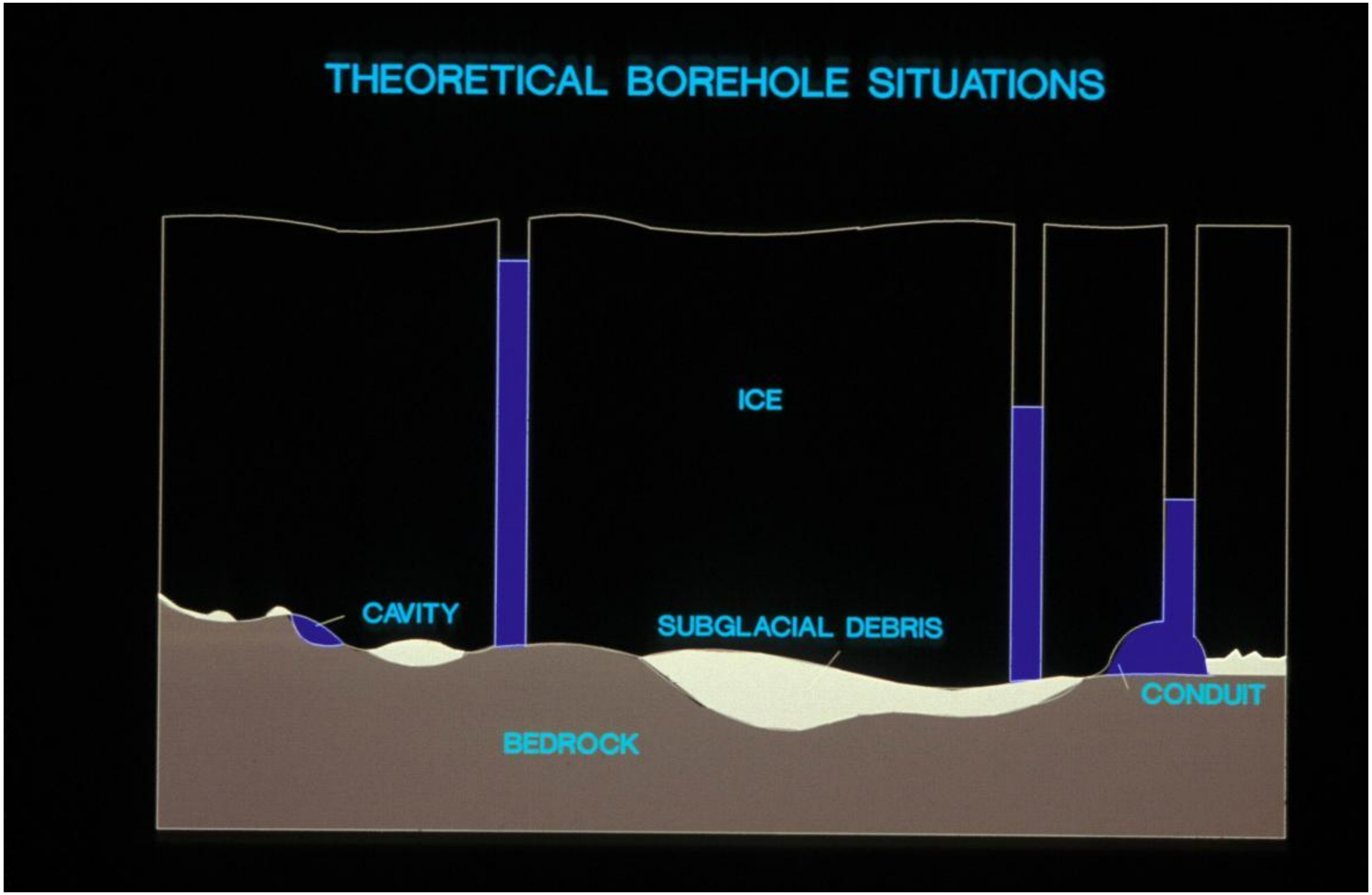

Tracer
Crevasse
Glacier surface
Water in crevasse
Ice
Vertical pipe
(routing water from crevasse to conduit)
Subglacial Conduit
Water

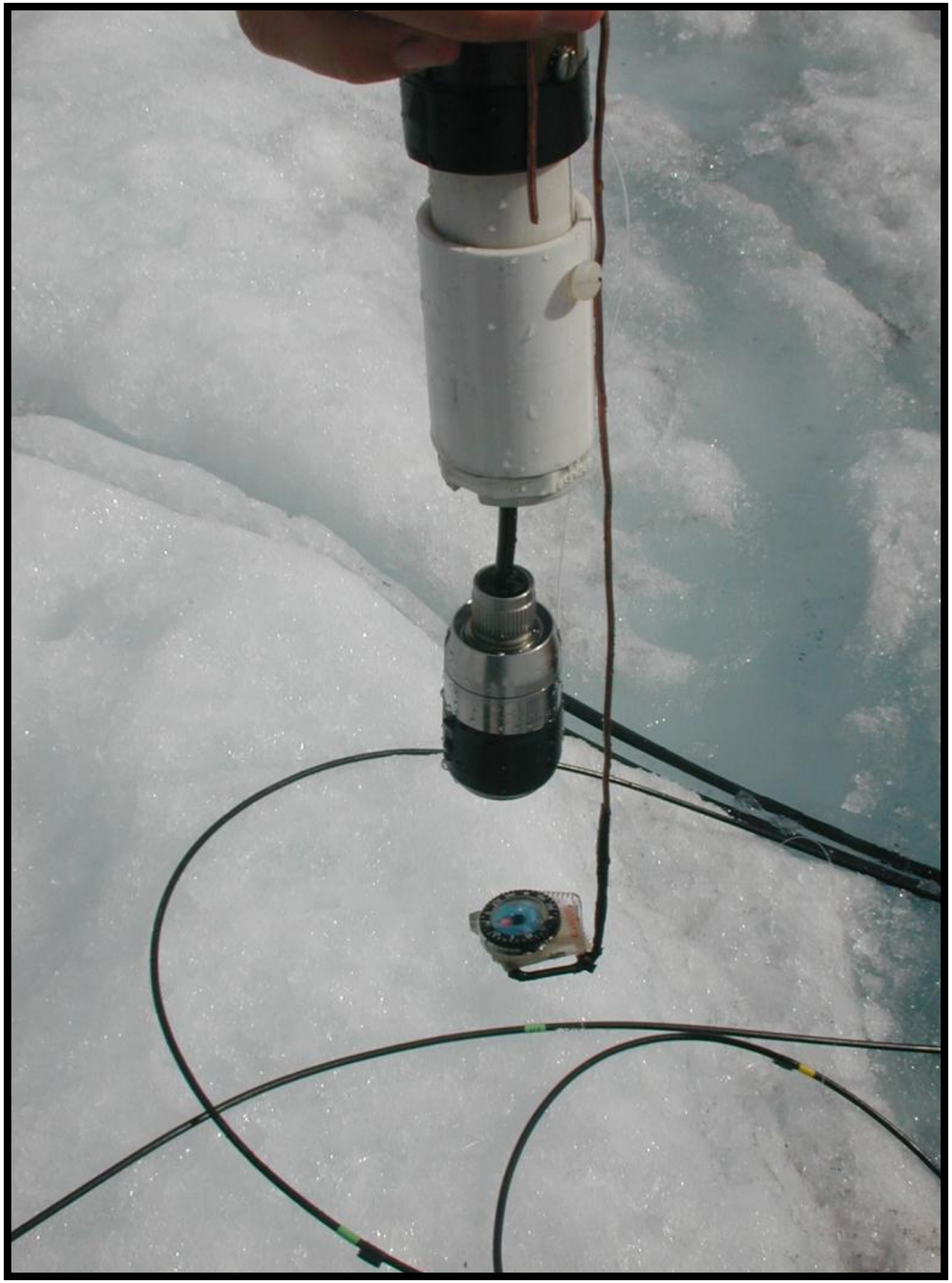
Character of the dye return curve commonly changes as the melt season progresses.



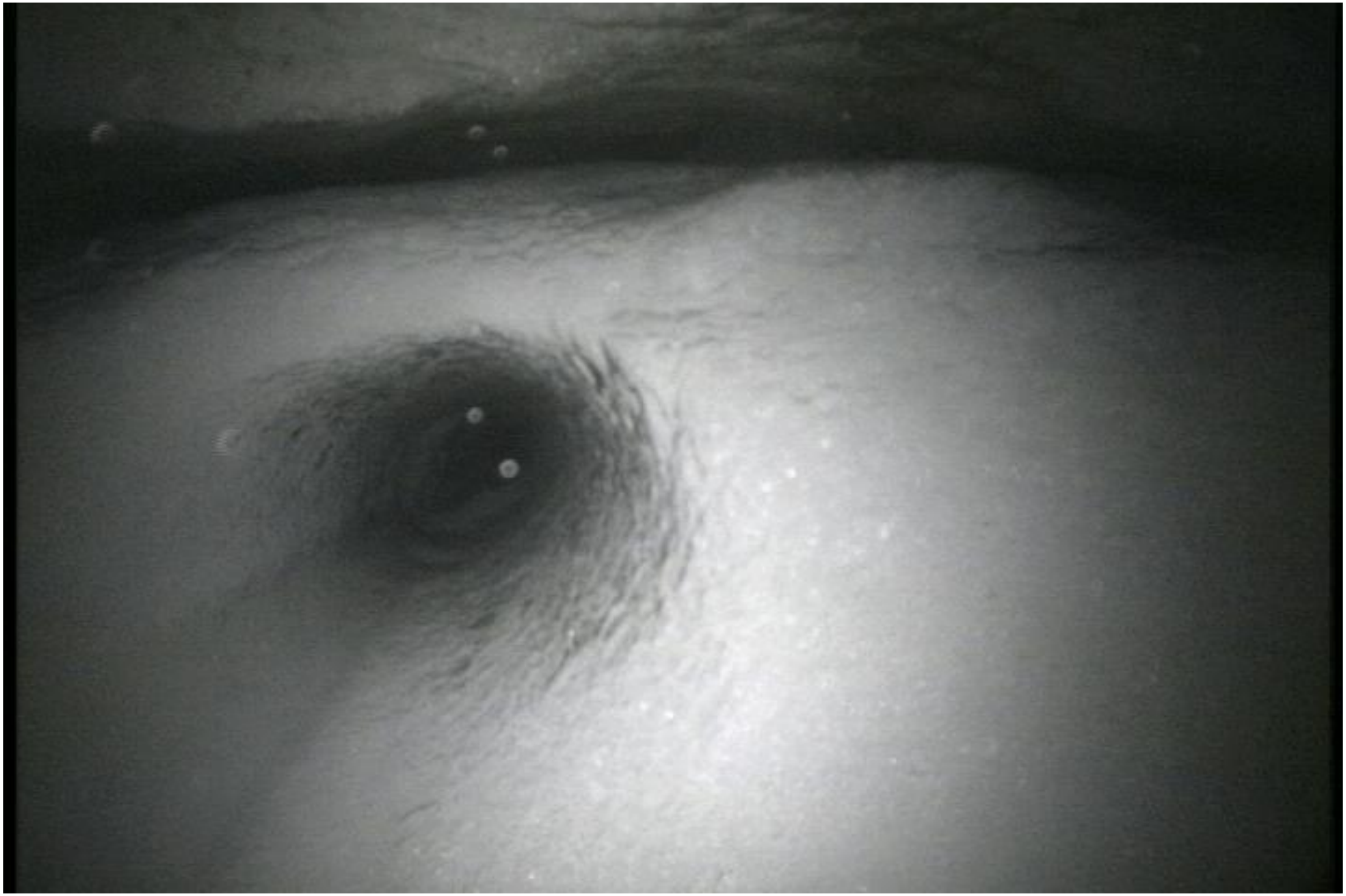
Boreholes

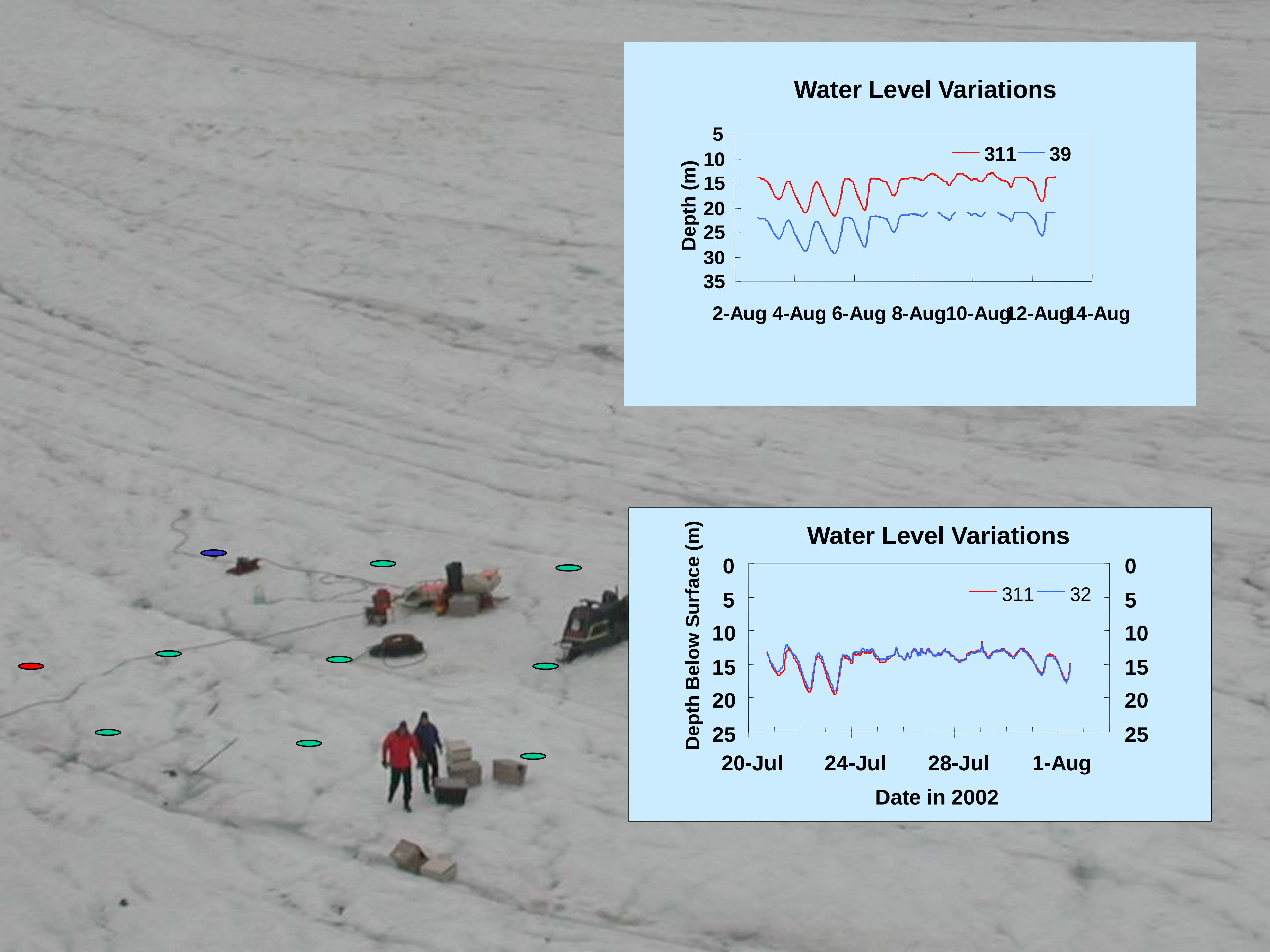



THEORETICAL BOREHOLE SITUATIONS
ICE
CAVITY
SUBGLACIAL DEBRIS
BEDROCK
CONDUIT

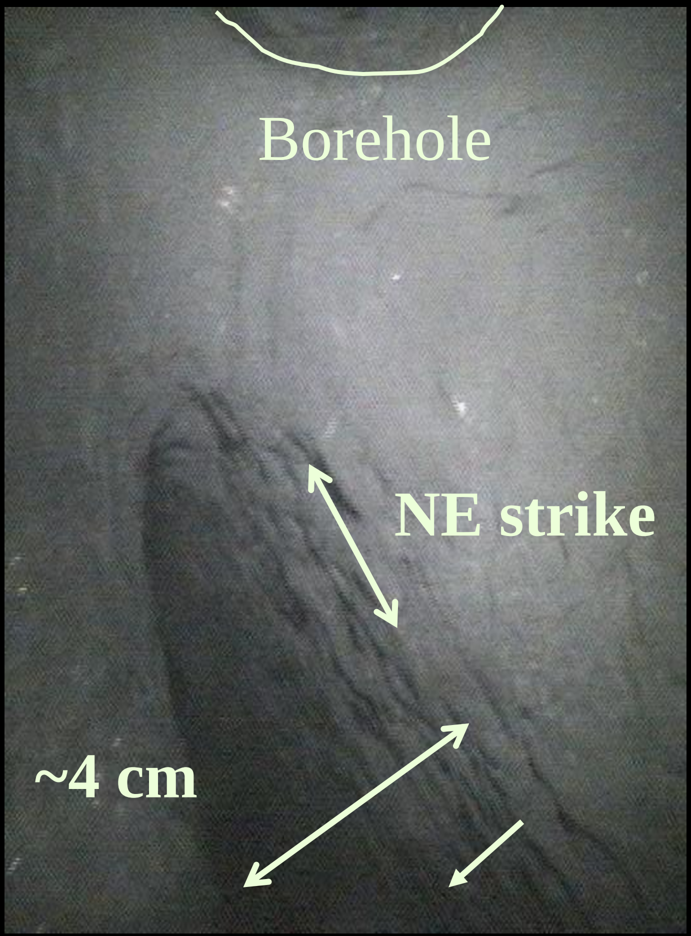


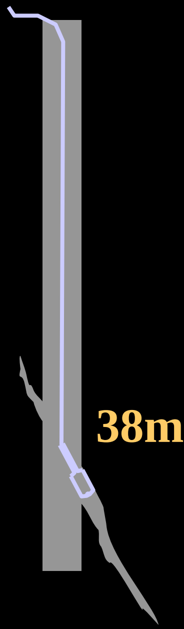
Fracture and Borehole

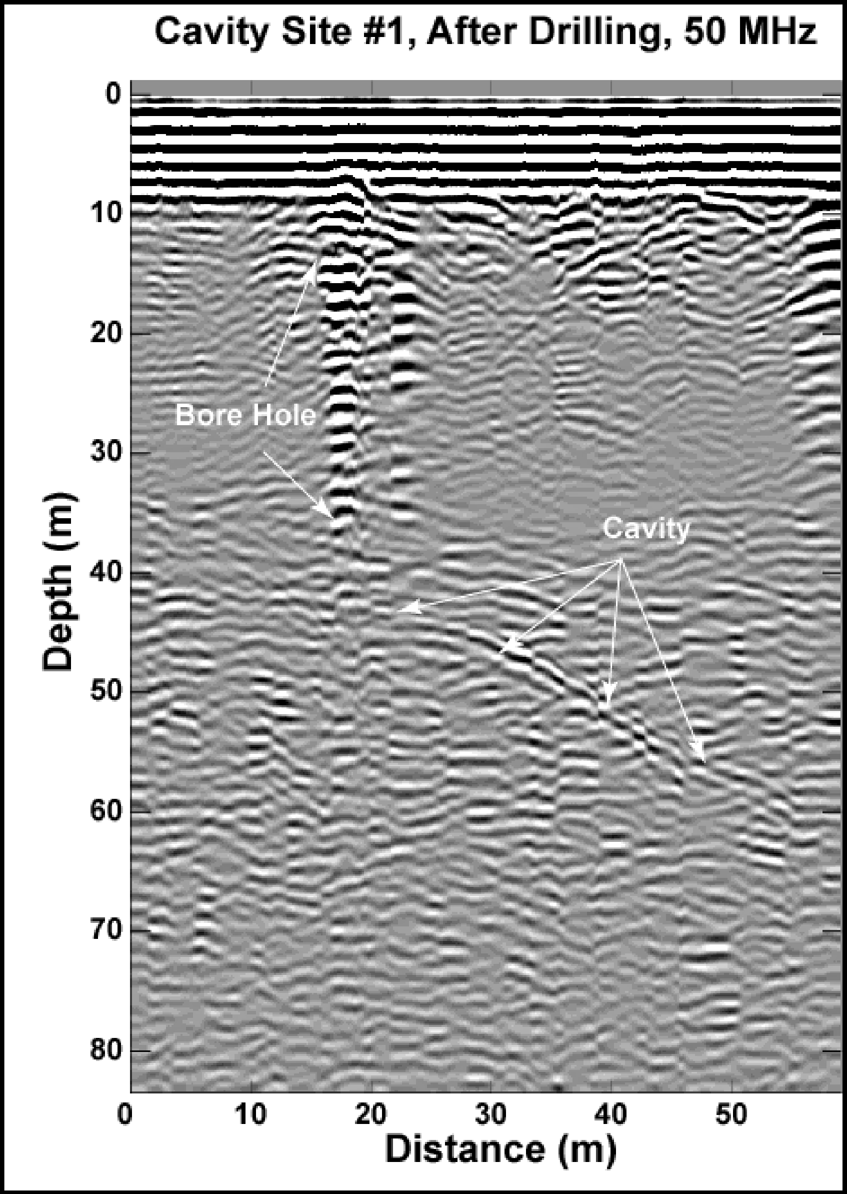



Water Level Variations
Depth (m)
5
10
15
20
25
30
35
311
39
2-Aug 4-Aug 6-Aug 8-Aug 10-Aug 12-Aug 14-Aug
Water Level Variations
Depth Below Surface (m)
0
5
10
15
20
25
311
32
20-Jul
24-Jul
28-Jul
1-Aug
Date in 2002

BH 311







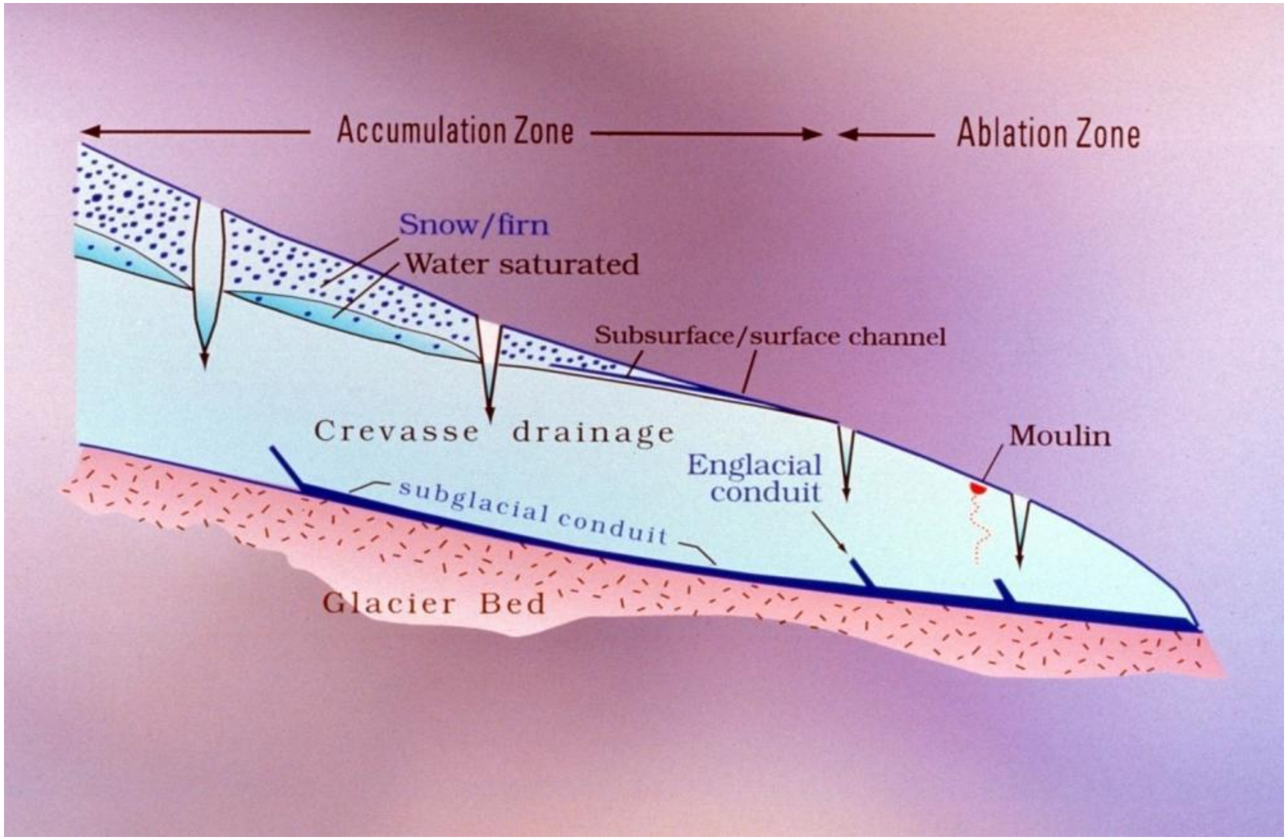
Drainage
Feature

Theoretical framework for glacier hydrology

- Field observations provide some constraints
- Thermodynamics, mechanics of materials provide additional constraints

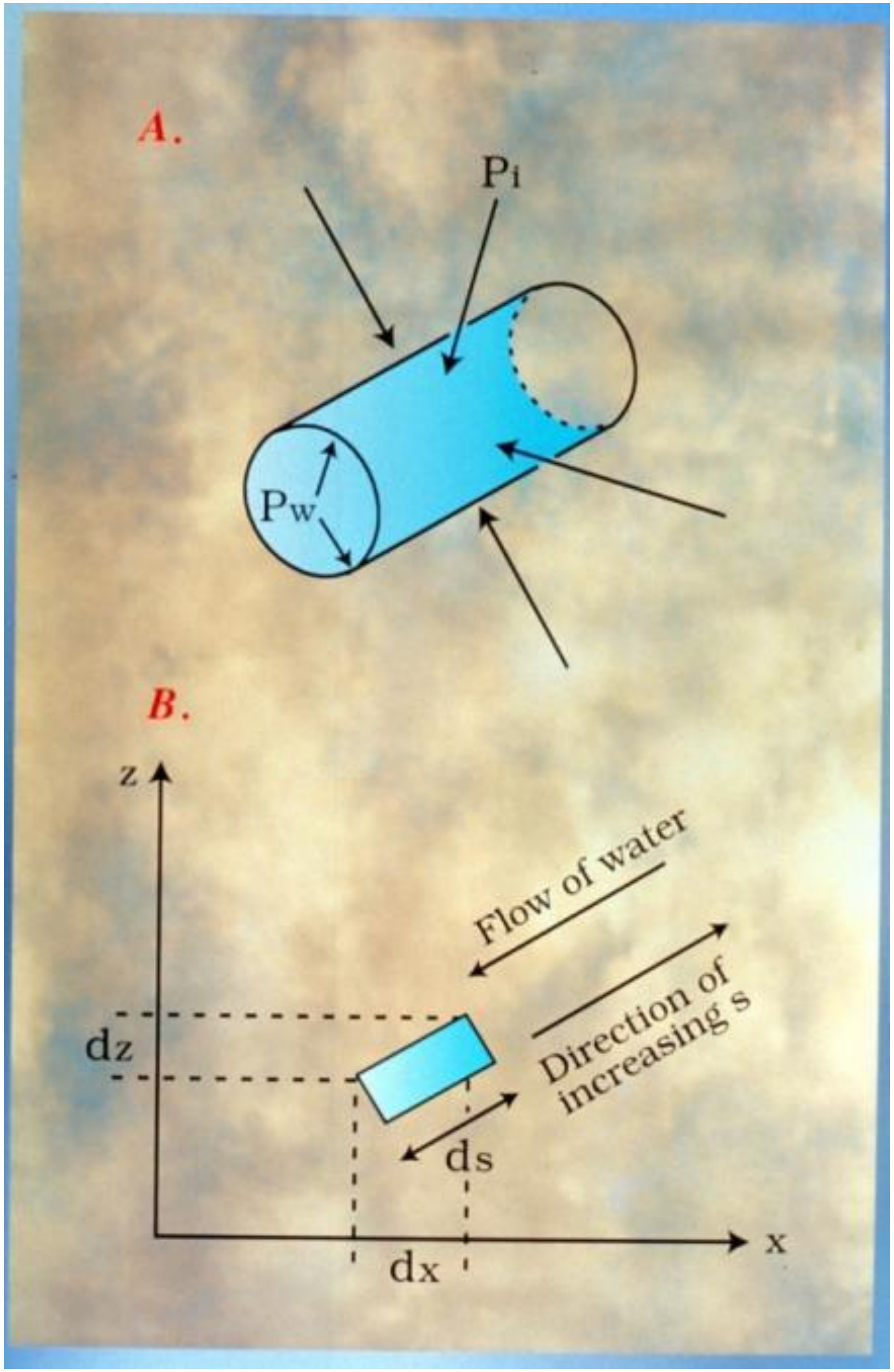
Cross section through glacier

Water is conveyed from glacier surface to bed and then discharged from the glacier.



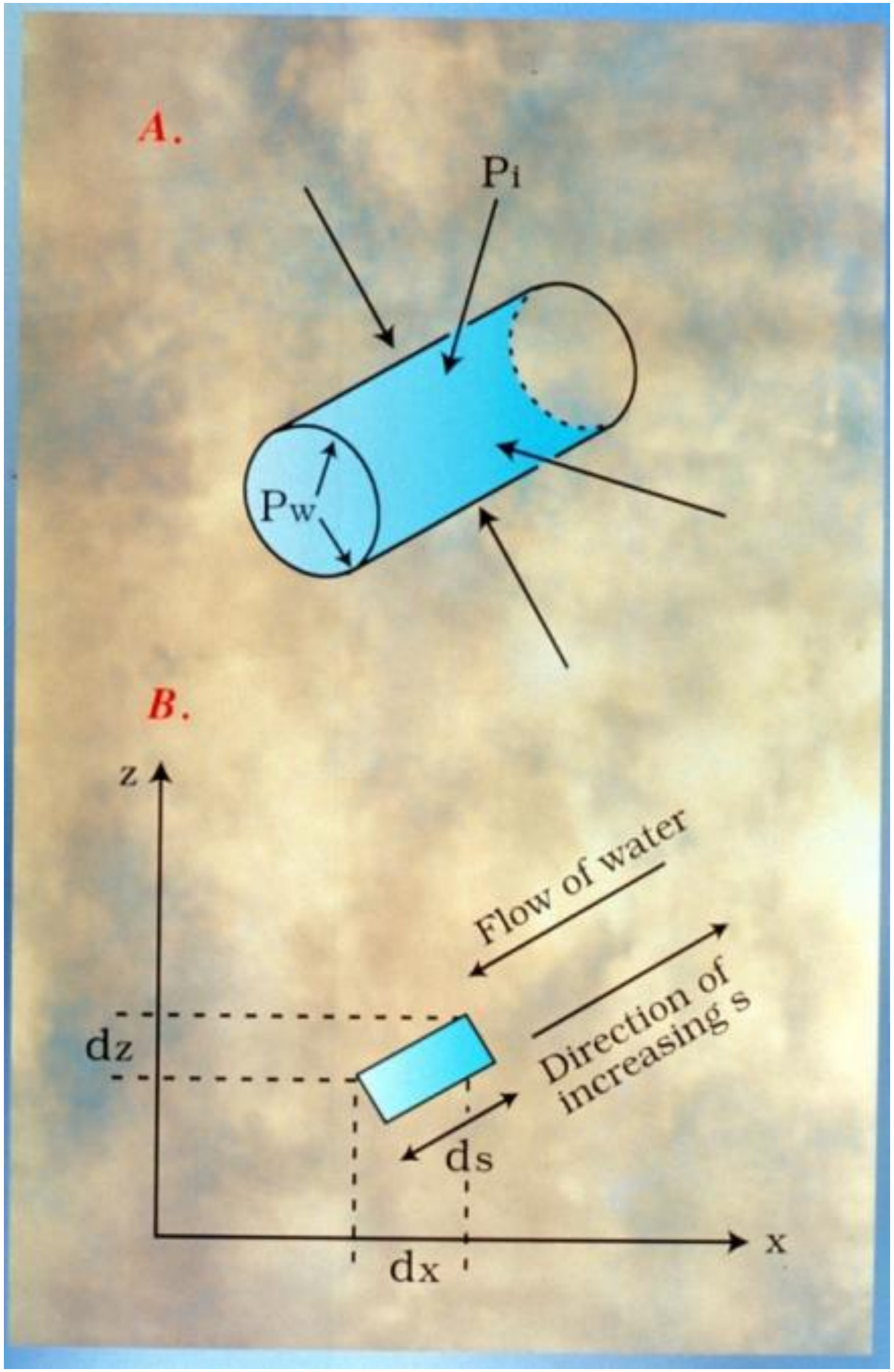
Channel enclosed by ice (R channels)

Channels in ice are *self-formed* and reflect a balance between melting of the walls (by energy dissipated in the flowing water) and creep of ice into the channel.



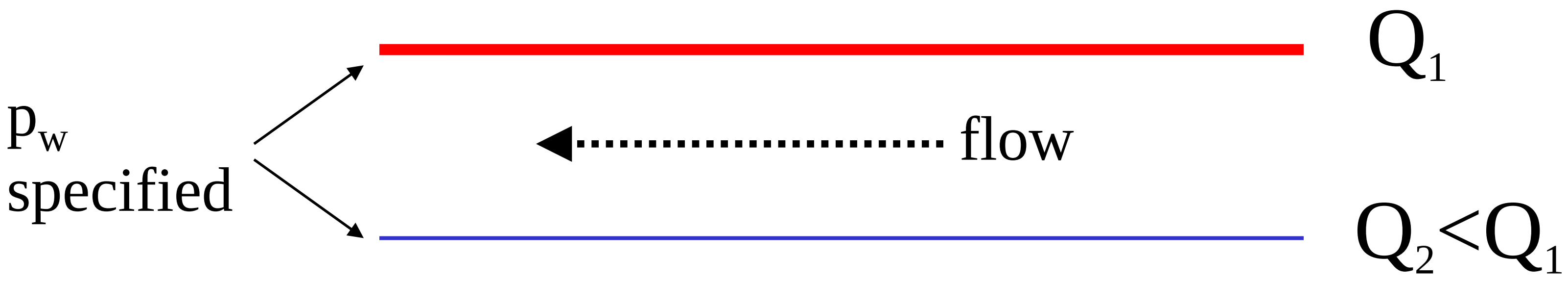
Channel enclosed by ice (R channels)

- Rate of change of channel cross-sectional area reflects difference between melting and creep closure.
- Water flow is impeded by friction.
- Energy dissipated by friction goes into melting.
- Water temperature stays at the pressure – melting point.

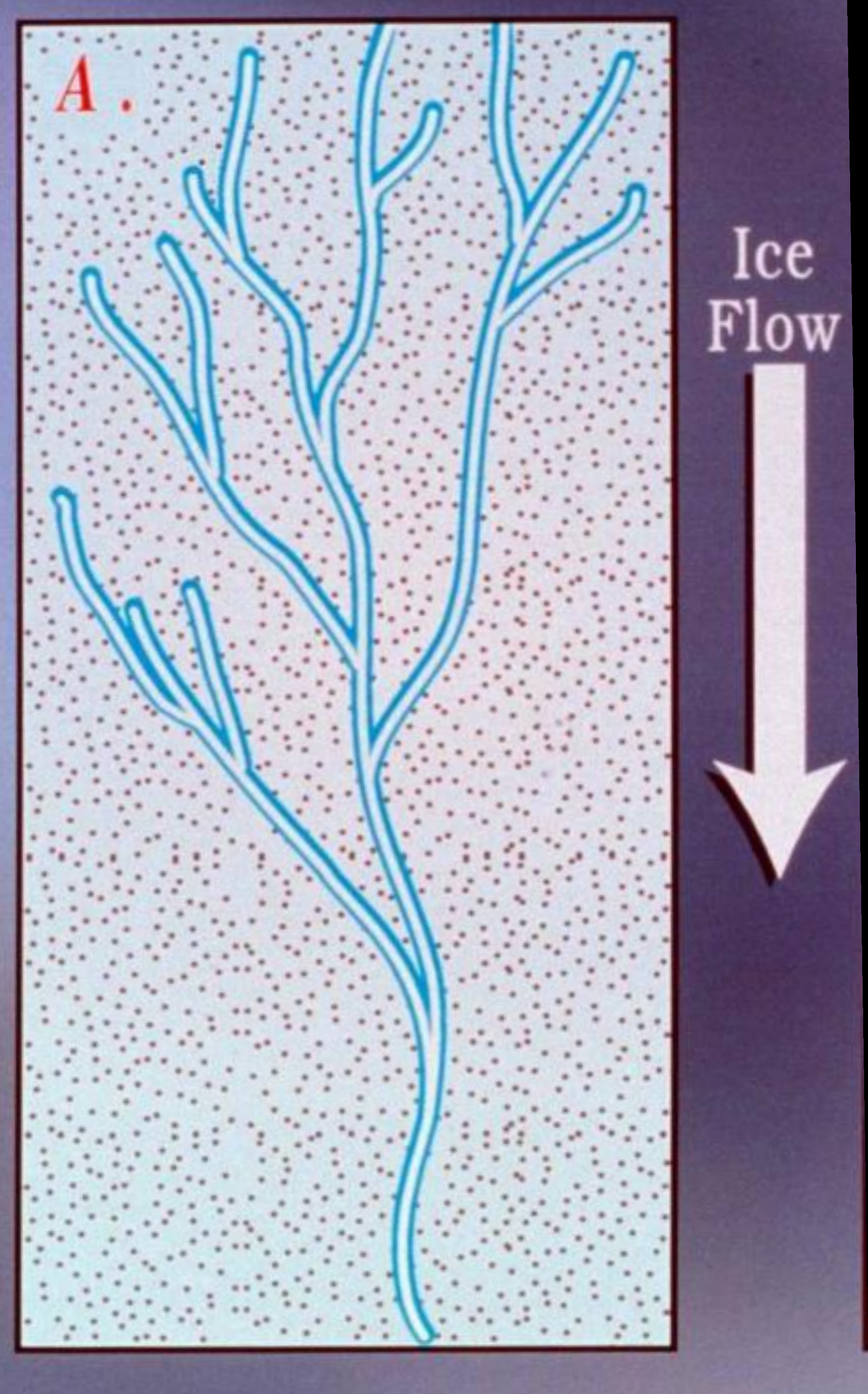


Steady state R channel

$$\frac{dp_w}{dx} = \frac{C\,(p_i - p_w)^{24/11}}{Q^{2/11}}$$



In steady state, flow should become concentrated into large channels, which are at lower pressure.

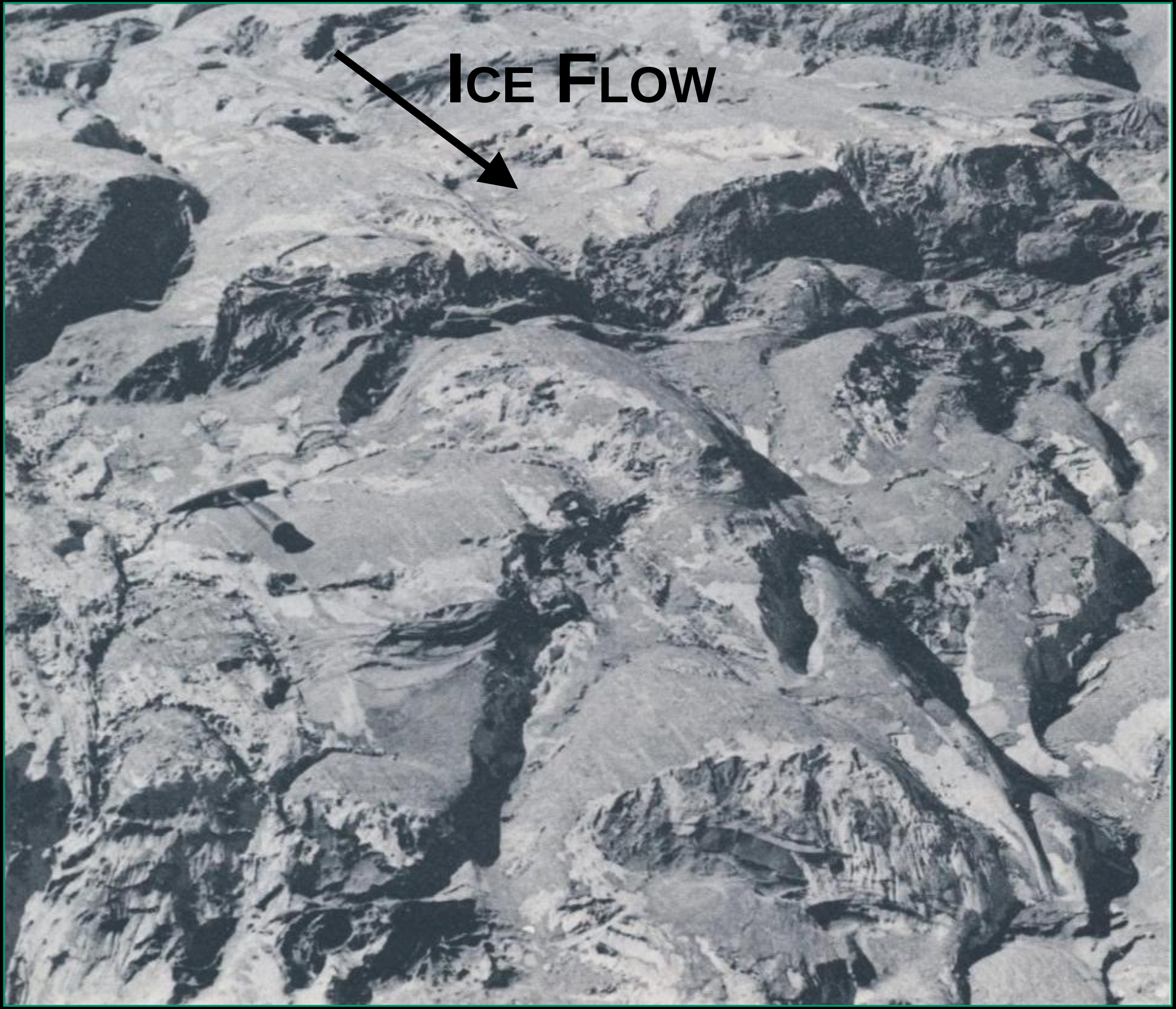


Arborescent

R- channels

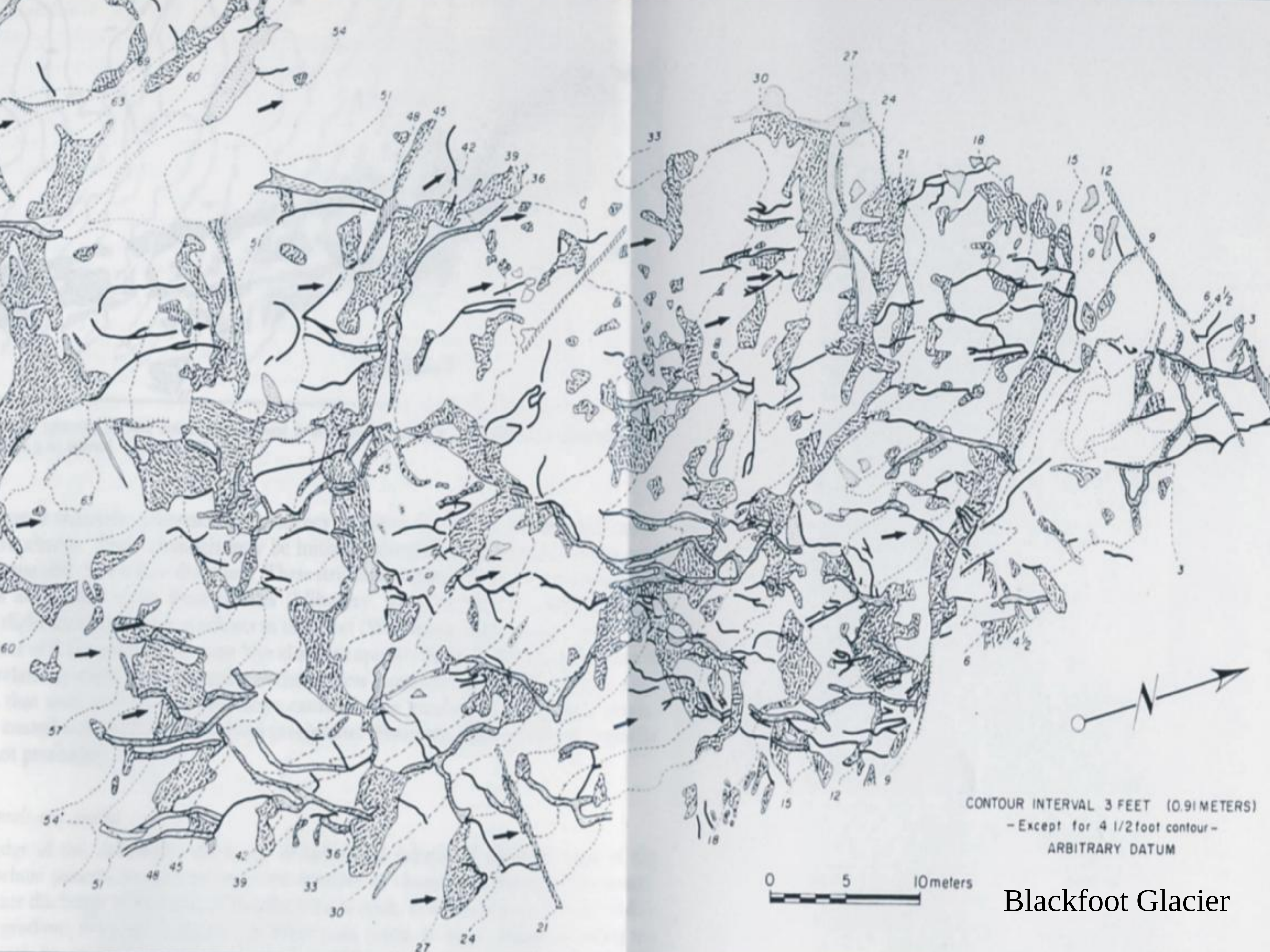
Insight from geomorphology

Features exposed on recently deglaciated carbonate bedrock provide insights into geometry of subglacial drainage network.



GLACIER DE FERPECLE, VALAIS, SWITZERLAND

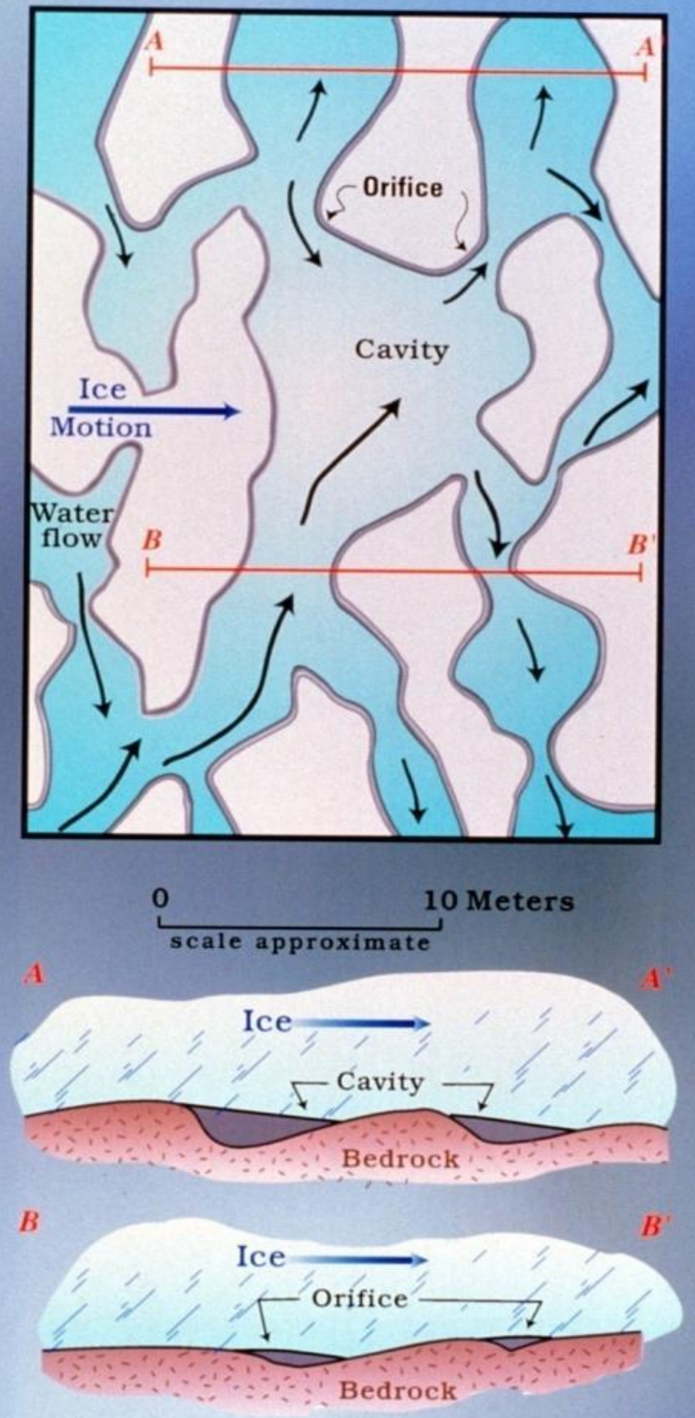
Robert Bingham



Blackfoot Glacier

Cavity network

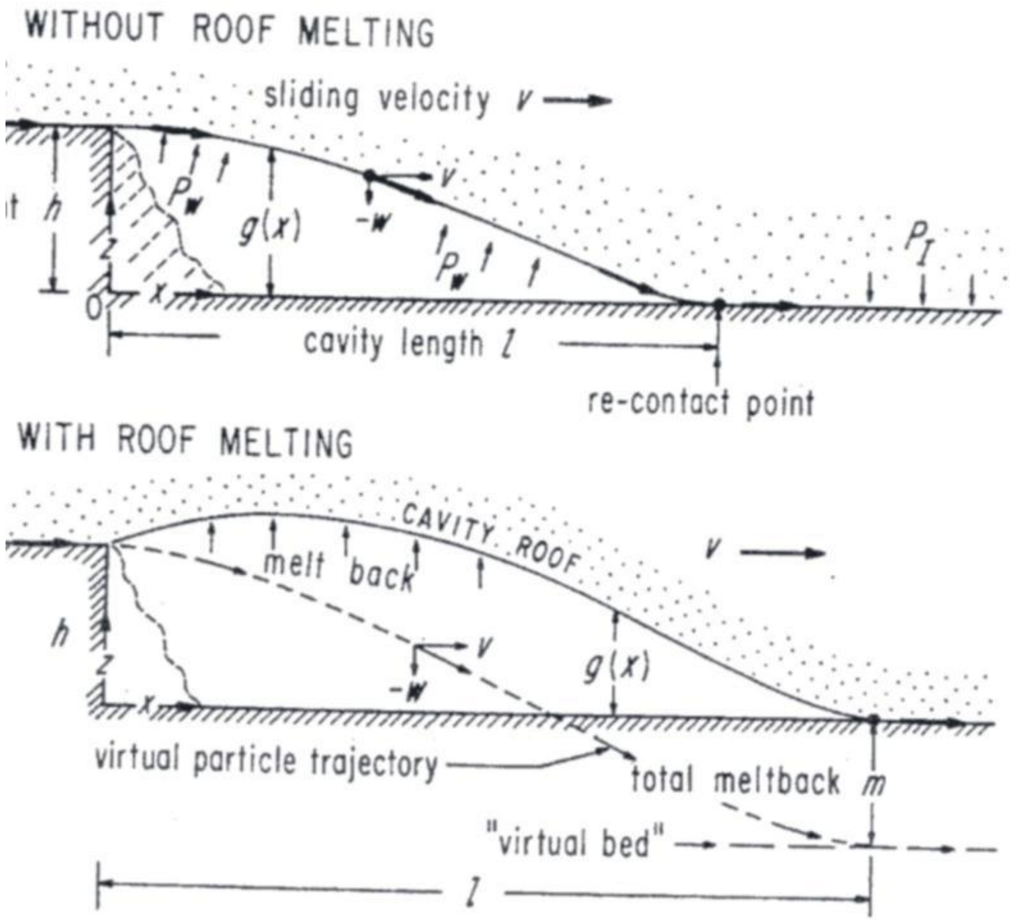
A cavity network has very different hydraulic properties than an arborescent channel network.



Cavity hydraulics

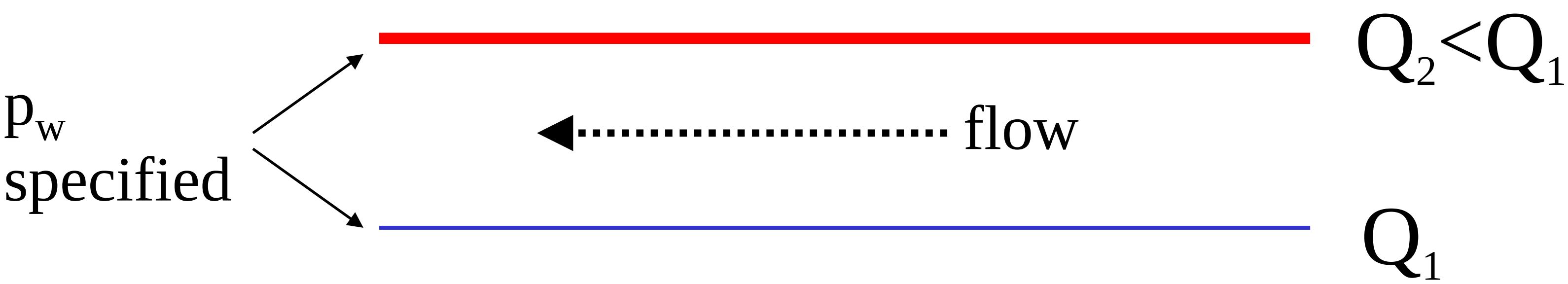
Cavity formation is controlled by,

- sliding speed
- bed roughness
- water pressure



Cavity-network hydraulics

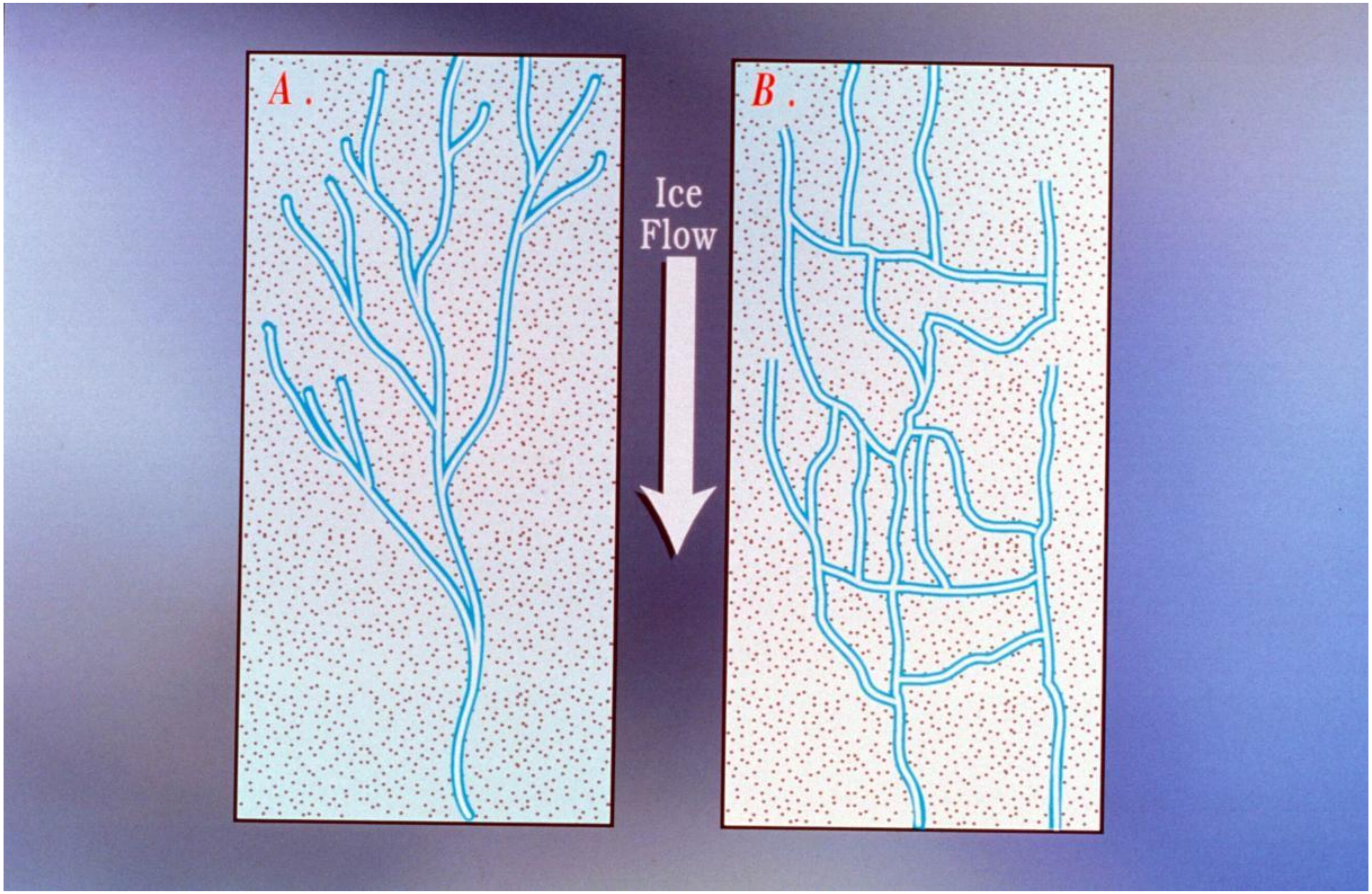
$$\frac{dp_w}{dx} = C\,\frac{Q^2(p_i - p_w)}{h^{\frac{13}{3}}\,u}$$

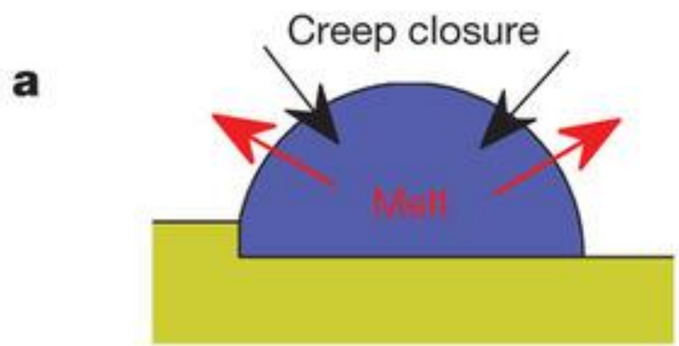


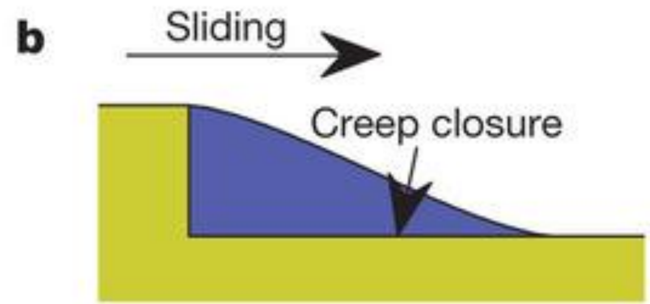
In steady state, flow should become concentrated into larger cavities, which are at higher pressure.

Arborescent nonarborescent

R- channels Cavities

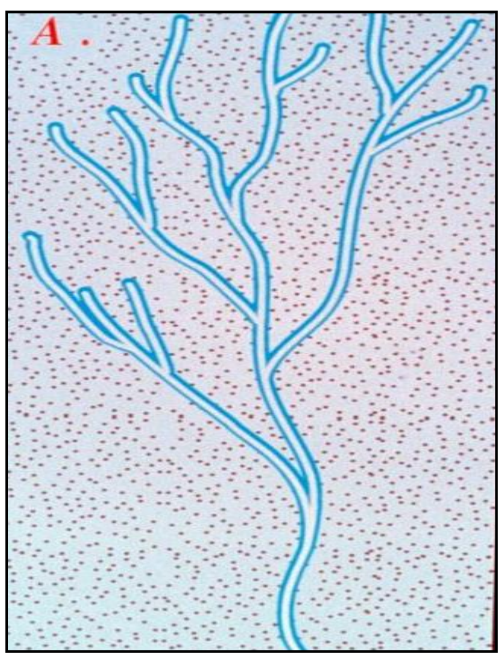


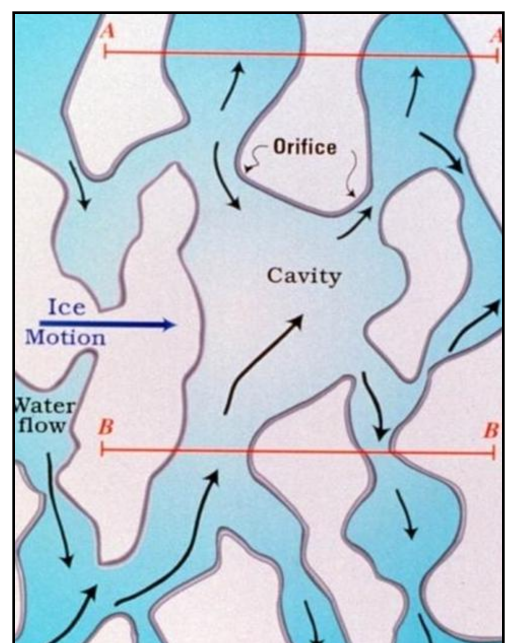




$$\frac{dp_w}{dx} = \frac{C\,(p_i - p_w)^{24/11}}{Q^{2/11}}$$

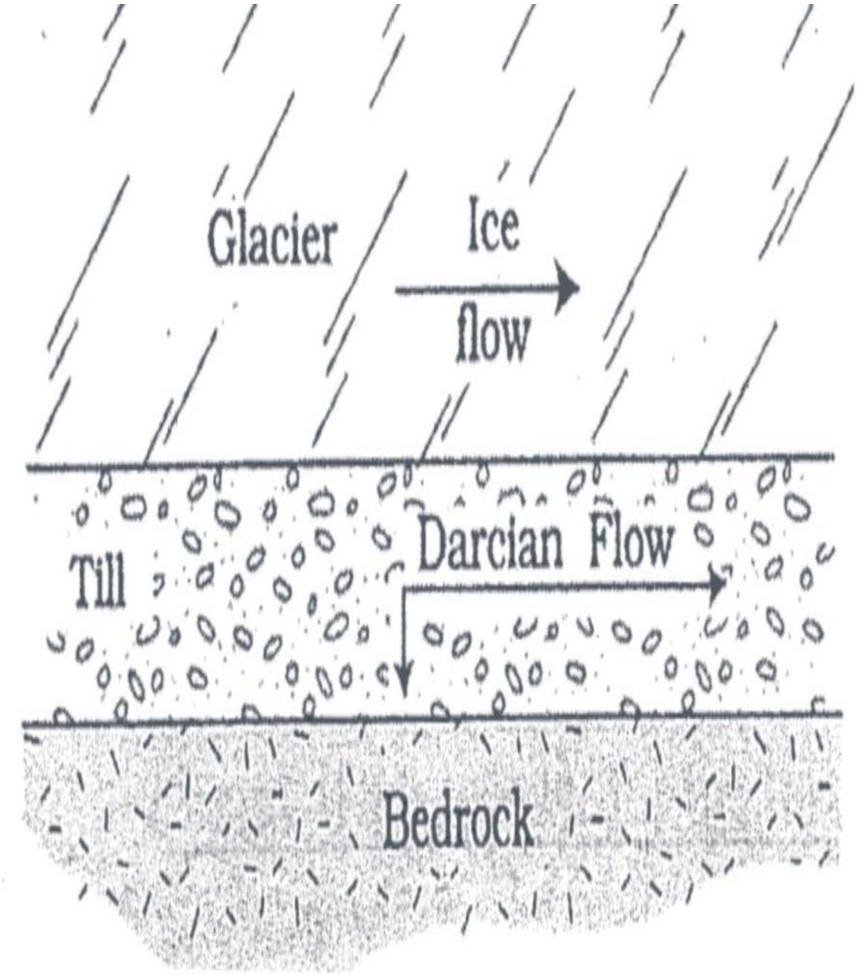
$$\frac{dp_w}{dx} = C\,\frac{Q^2(p_i - p_w)}{h^{\frac{13}{3}}\,u}$$

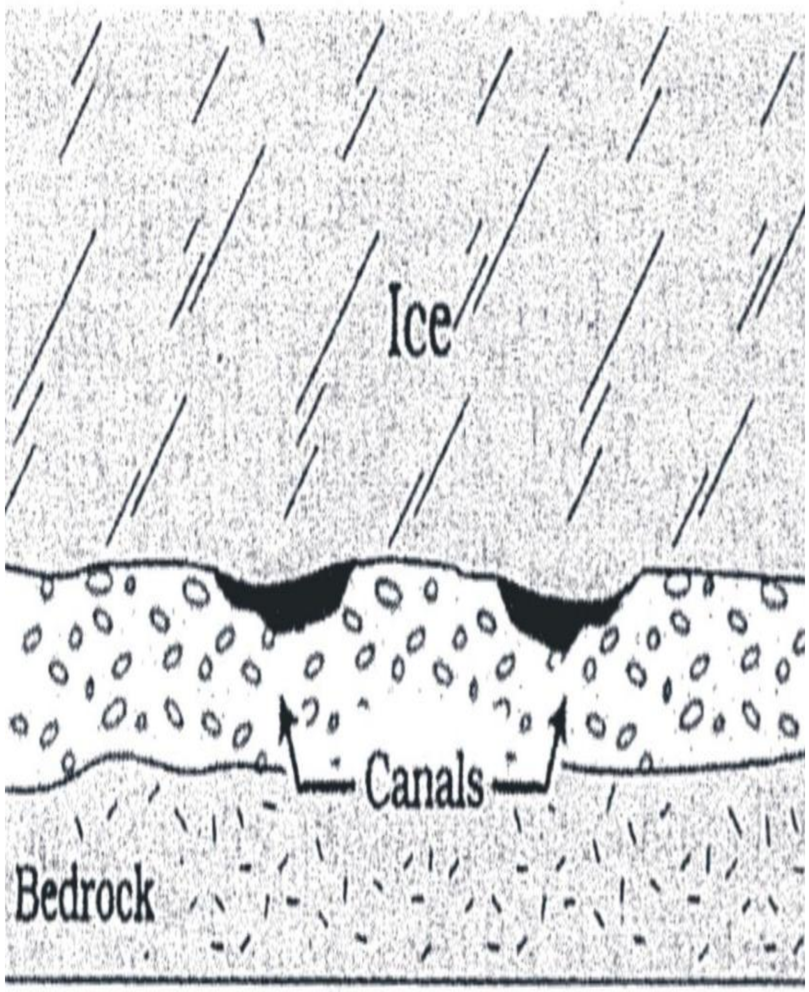




Role of till at the bed

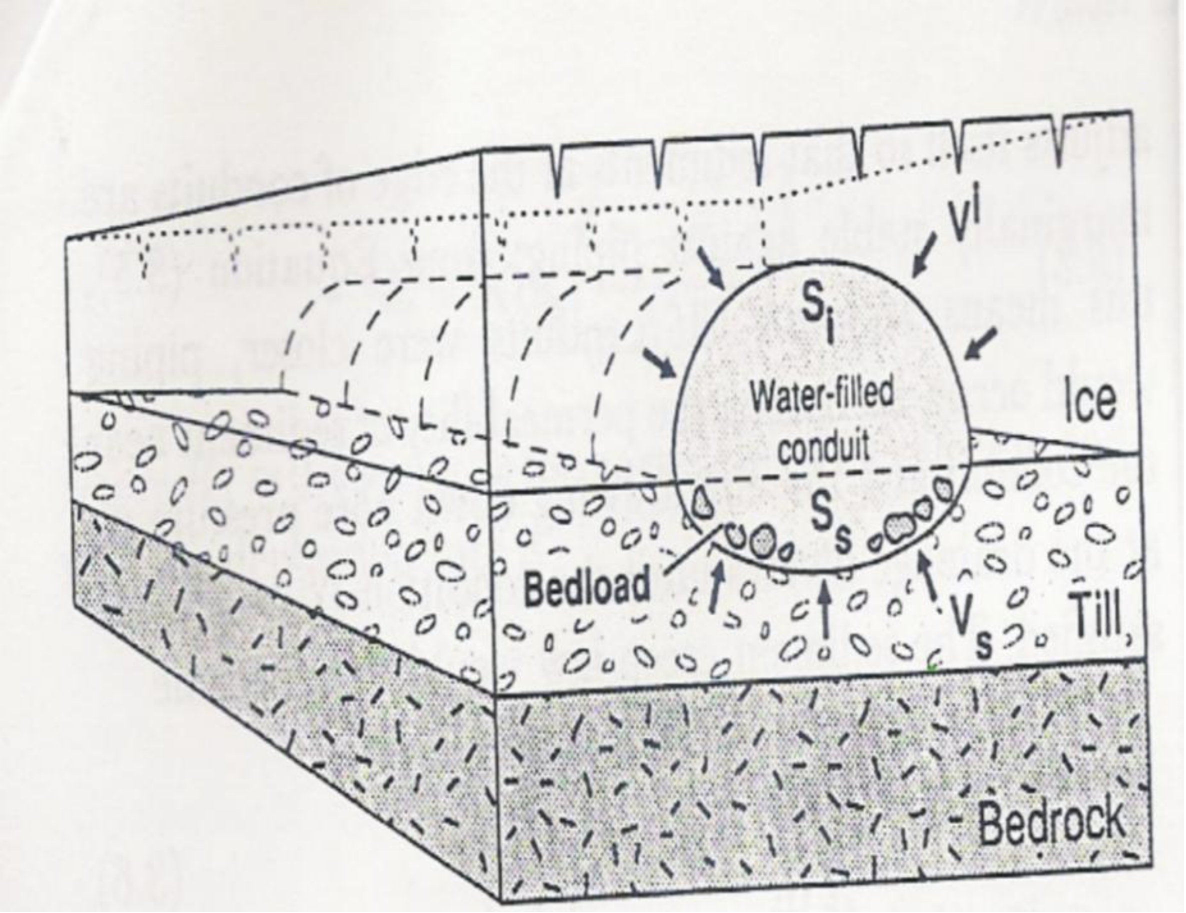
Suppose bed is primarily sediment (till)….





Till canal—physics

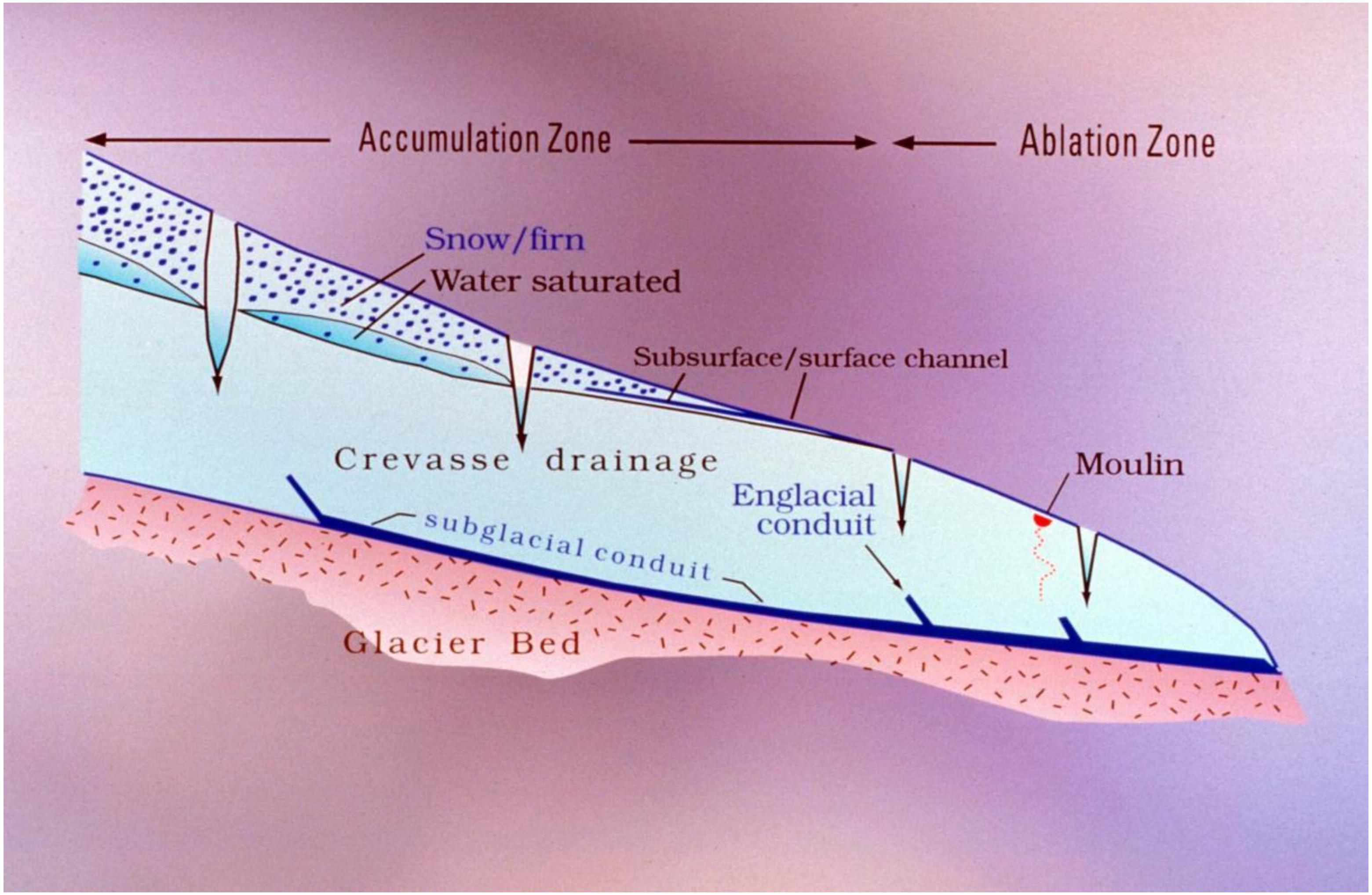
Ice and sediment tend to flow in to fill channel. Water flow enlarges conduit by melting and also transports sediment.



Seasonal
Drainage system evolution

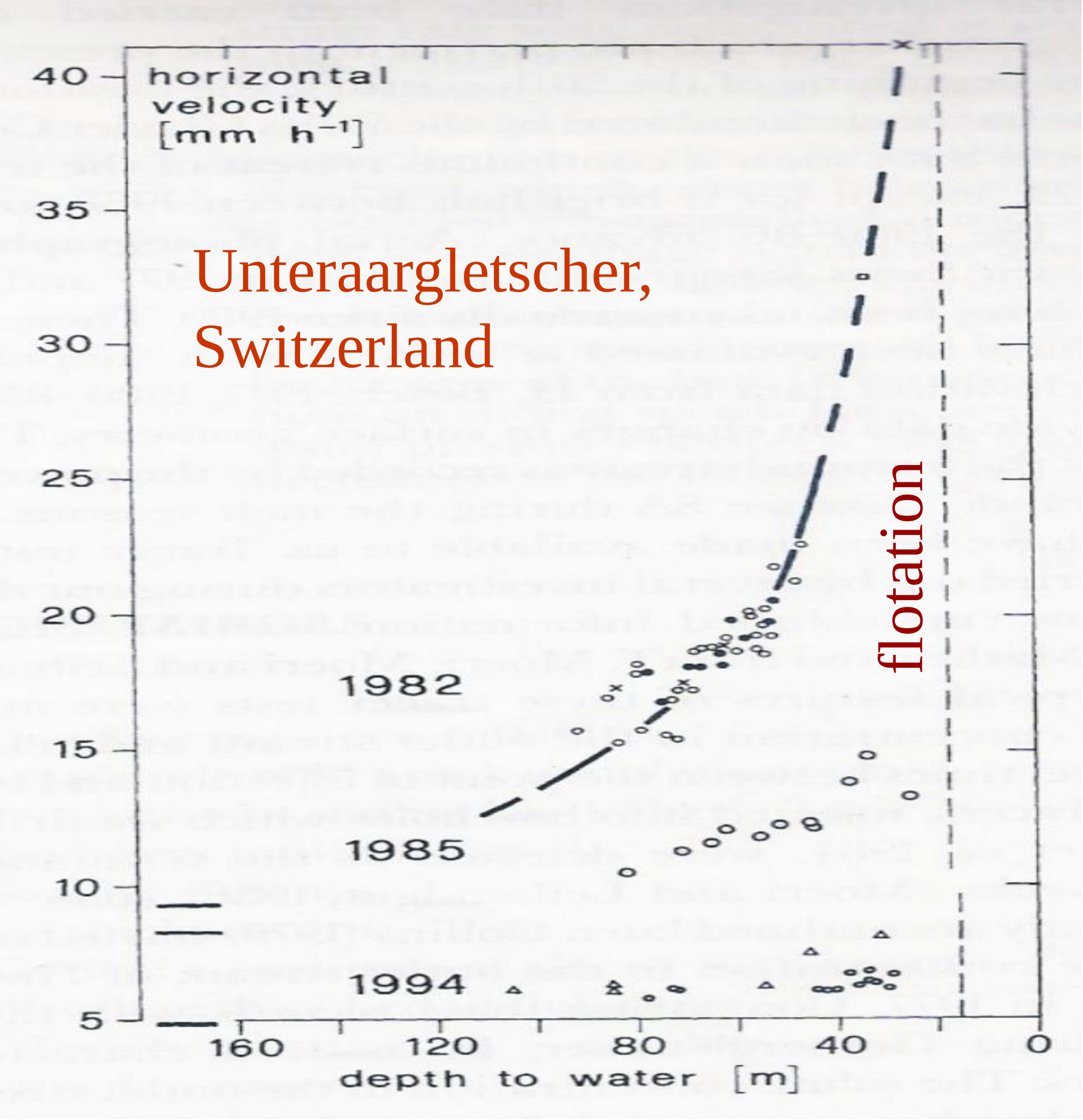
- Basal drainage system tend to collapse during winter
- Early in melt season—cavity dominate
- Rapid increase in water flux to bed destabilizes linked cavity network and promotes R channel formation

Summary of Glacier Hydrology



Water and glacier sliding

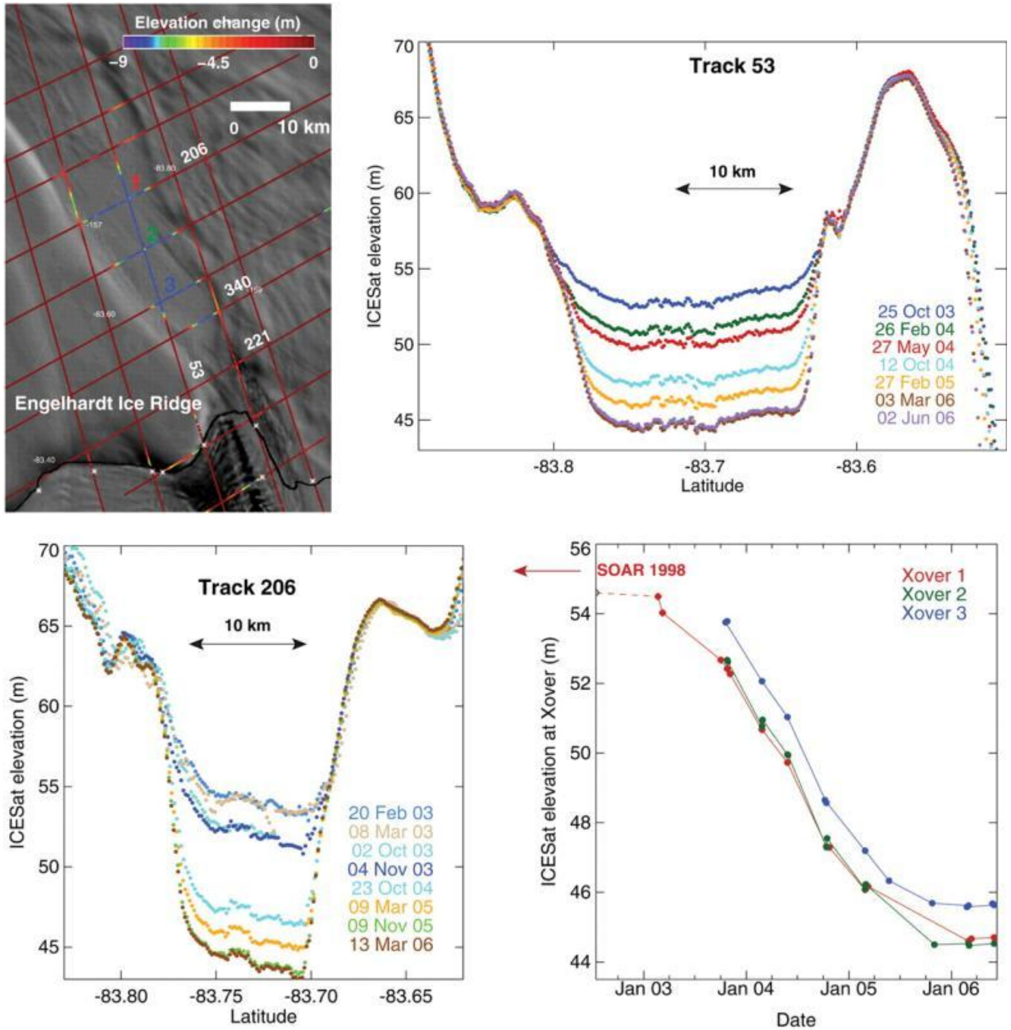
Dependence of speed on water pressure has changed
over time at a single glacier.



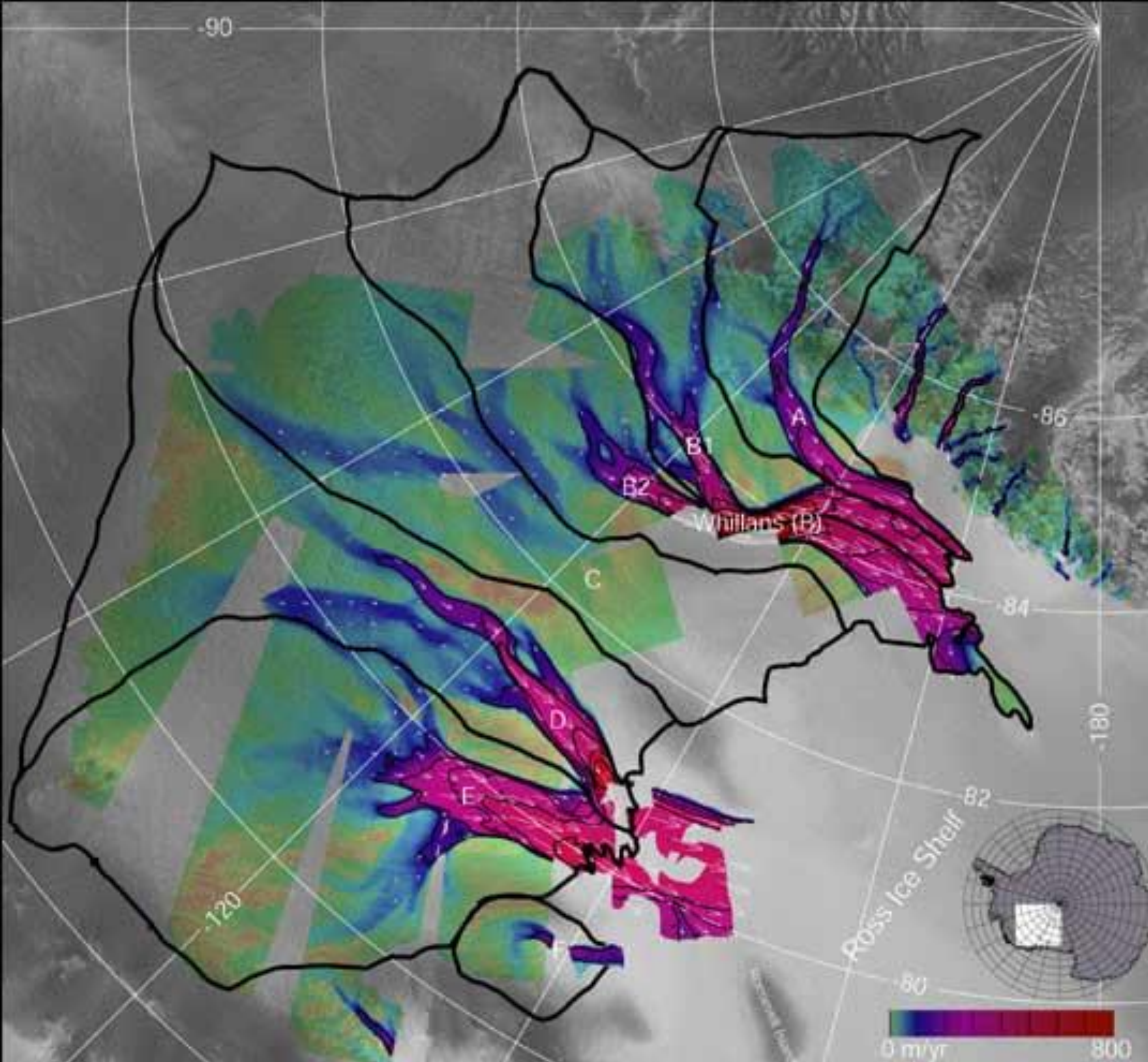
Hydrology of ice sheets

- Most of the interior of large ice sheets frozen to the bed.
- At least locally temperate ice near margins.
- Basal water plays important role in rapid movement of ice streams.
- Glacial geology as a way to infer conditions beneath ice sheets?

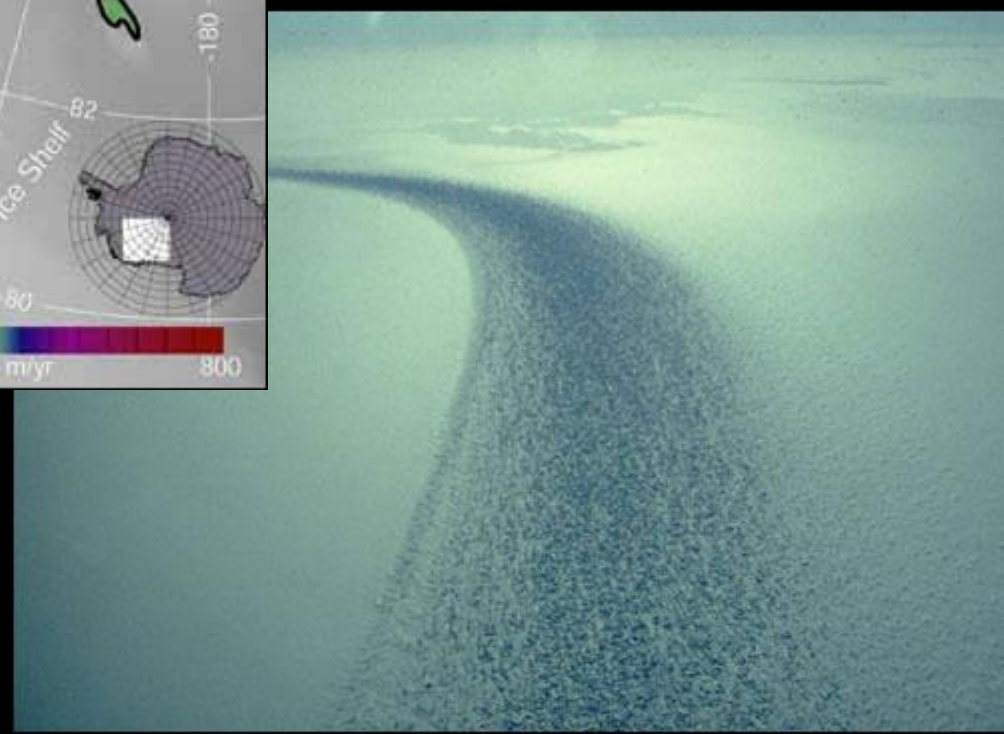
Antarctica



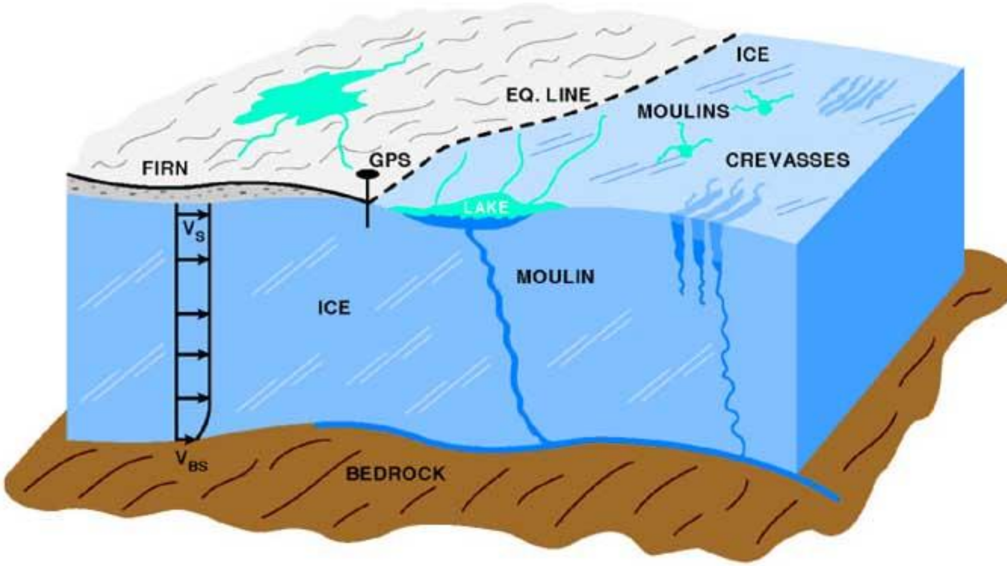
H A Fricker et al. Science 2007;315:1544-1548



Joughin



NASA


ICE
EQ. LINE
MOULINS
FIRN
GPS
CREVASSES
LAKE
V_S
MOULIN
ICE
V_{BS}
BEDROCK

Zwally




END
Jason Gulley