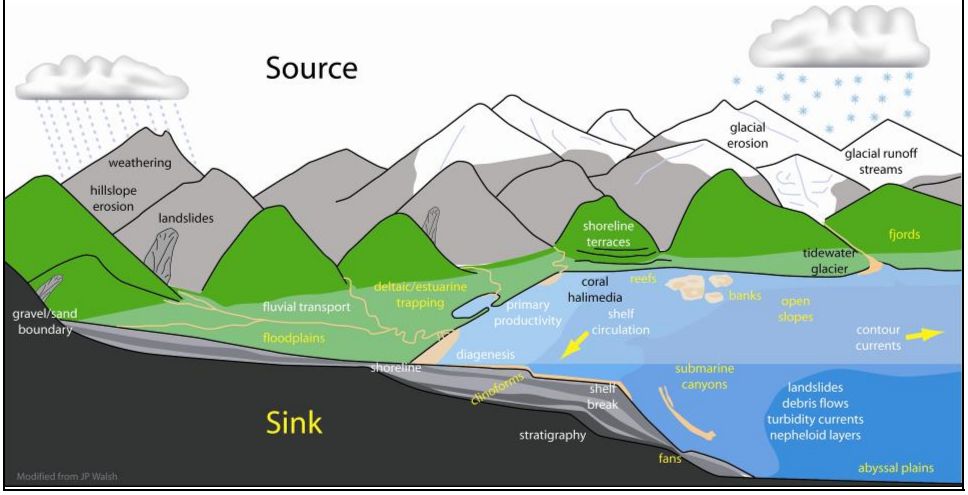
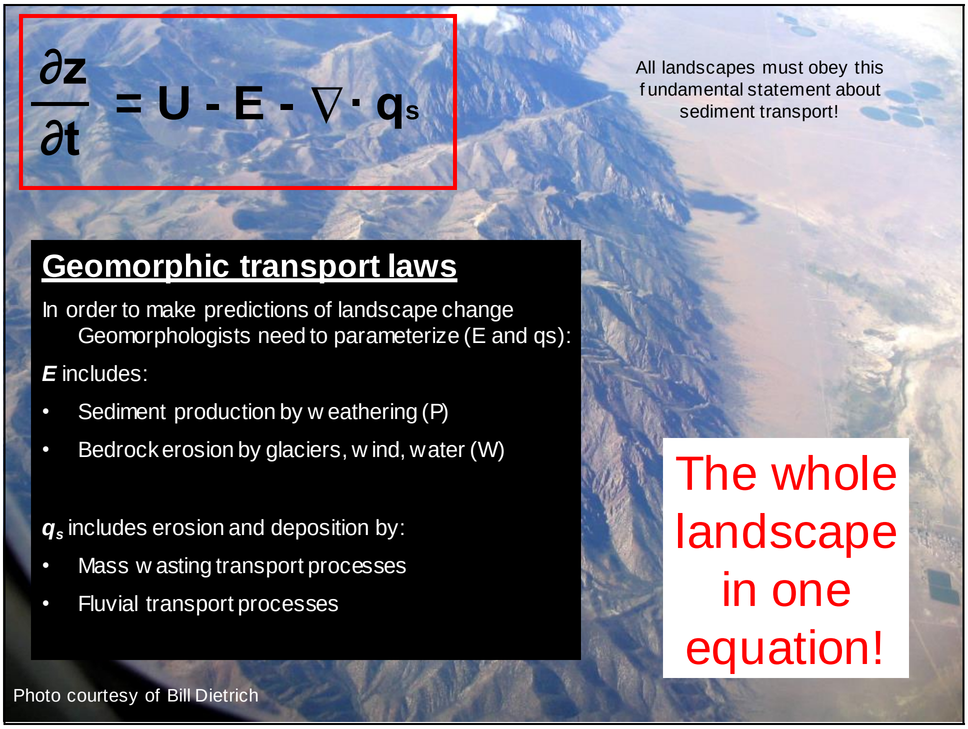
Goals of Glacial Geomorphology Lectures

1. Answer question: How do glaciers modulate landscape development?
2. To discuss the formation of glaciers and their movement
3. To discuss glacial erosion of bedrock as well as, material deposition, and transport.
4. To review landforms developed by glaciers.

How do glaciers modulate landscape development?

Up to now, we have thought about the landscape as having developed in the absence of external forcing. Periodically, changes in the climate cause the growth and development of glaciers, which cover the landscape, smearing sediment everywhere, disrupting mass movement and fluvial processes, and enhancing bedrock erosion.





$$\frac{\partial z}{\partial t} = U - E - \nabla \cdot q_s$$

All landscapes must obey this fundamental statement about sediment transport!

Geomorphic transport laws

In order to make predictions of landscape change Geomorphologists need to parameterize (E and qs):

E includes:

- Sediment production by weathering (P)
- Bedrock erosion by glaciers, wind, water (W)

q_s includes erosion and deposition by:

- Mass wasting transport processes
- Fluvial transport processes

The whole landscape in one equation!

Photo courtesy of Bill Dietrich

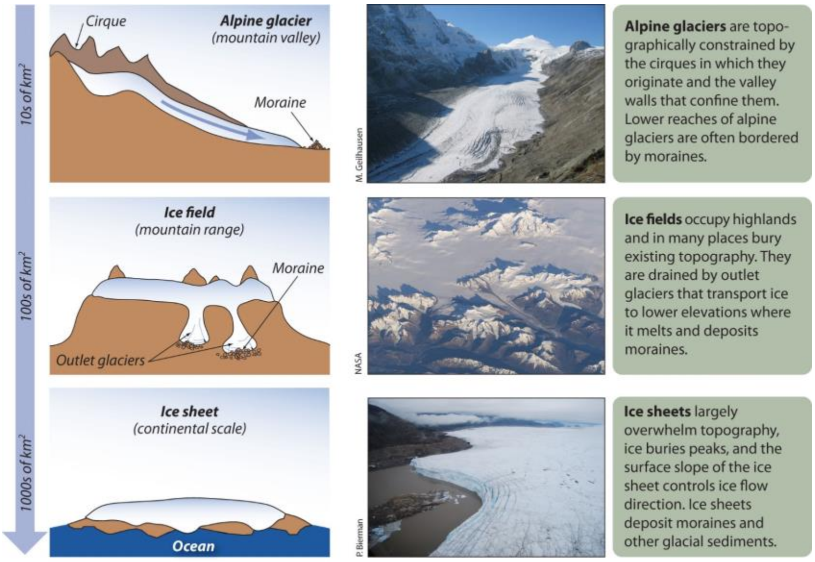
Glaciers

Glaciers are masses of ice and granular snow formed by compaction and recrystalization of snow, lying largely or wholly on land and showing evidence of past or present movement – Easterbrook, 1999.

Key concept: Ice must be on land and move, so sea ice and snow fields are not considered glaciers.

There are three basic types of glaciers: alpine (confined), ice fields (partially confined) and continental ice sheets (unconfined).

Types of glaciers



Alpine glaciers are topographically constrained by the cirques in which they originate and the valley walls that confine them. Lower reaches of alpine glaciers are often bordered by moraines.

Ice fields occupy highlands and in many places bury existing topography. They are drained by outlet glaciers that transport ice to lower elevations where it melts and deposits moraines.

Ice sheets largely overwhelm topography, ice buries peaks, and the surface slope of the ice sheet controls ice flow direction. Ice sheets deposit moraines and other glacial sediments.

Earth’s glacial history

Through most of geologic time, Earth has been free of glaciers, but at intervals of ~150Ma, ice ages occur.

They last tens of Ma with some portion of the land surface covered by glaciers or ice sheets.

It is widely held that the changes in climate that bring about an ice age are due to the changes in ***seasonality and location*** of solar energy around the Earth that occur due to ***Milankovitch Cycles***, which are variations in earth’s orbit.

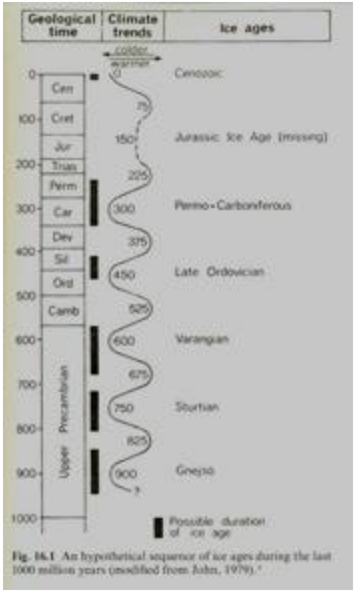
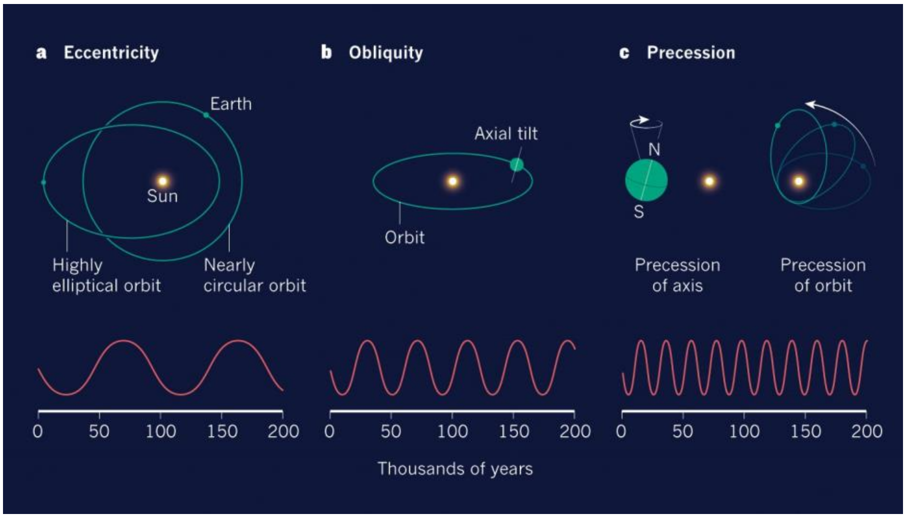


Fig. 16.1 An hypothetical sequence of ice ages during the last 1000 million years (modified from John, 1979).

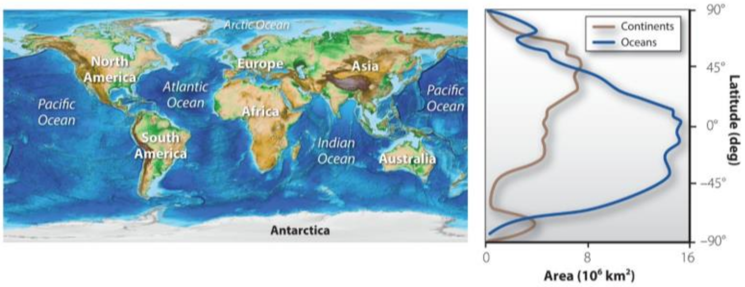
Selby, 1985

Milankovitch Cycles



Maslin (*Nature*, 2016)

Milankovitch Cycles and Glaciation



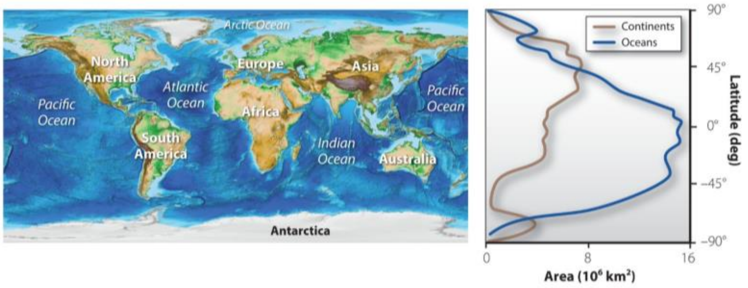
Both the **continents** and the **ocean basins** include large, relatively flat areas. On continents, these flat areas are the **cratons.** Under the oceans, these flat areas are the **abyssal plains.** Areas of higher elevation and **relief** include continental mountain ranges and **mid-ocean ridges.**

The area of ocean and continents are not equally distributed with latitude. There is more exposed land in the Northern Hemisphere and more ocean in equatorial regions.

Beirman and Montgomery, Ch 1, 2014

Land masses dominate northern hemisphere, so when the northern pole is turned away from the sun, the winters are longer and snow and ice remain on the surface for longer periods of time.

Milankovitch Cycles and Glaciation



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Beirman and Montgomery, Ch 1, 2014

Snow and ice have a much higher albedo than ground and vegetation, thus ice masses tend to reflect more radiation back into space, thus cooling the climate and allowing glaciers to expand.

Earth's Current Ice Cover

Areal Extent: 14.5 x 10^6 km^2 : 10% of Earth's surface

Volume: 32.1 x 10^6 km^3 (70% of Earth's freshwater reserve)

	Area		***Volume***	
Antarctica	12.1x10^6 km^2	83%	29 x 10^6 km^3	90%
Greenland	1.7 x 10^6 km^2	12%	2.95 x 10^6 km^3	9%
Other ice caps	0.7 x 10^6 km^2	5%	0.18 x 10^6 km^3	1%

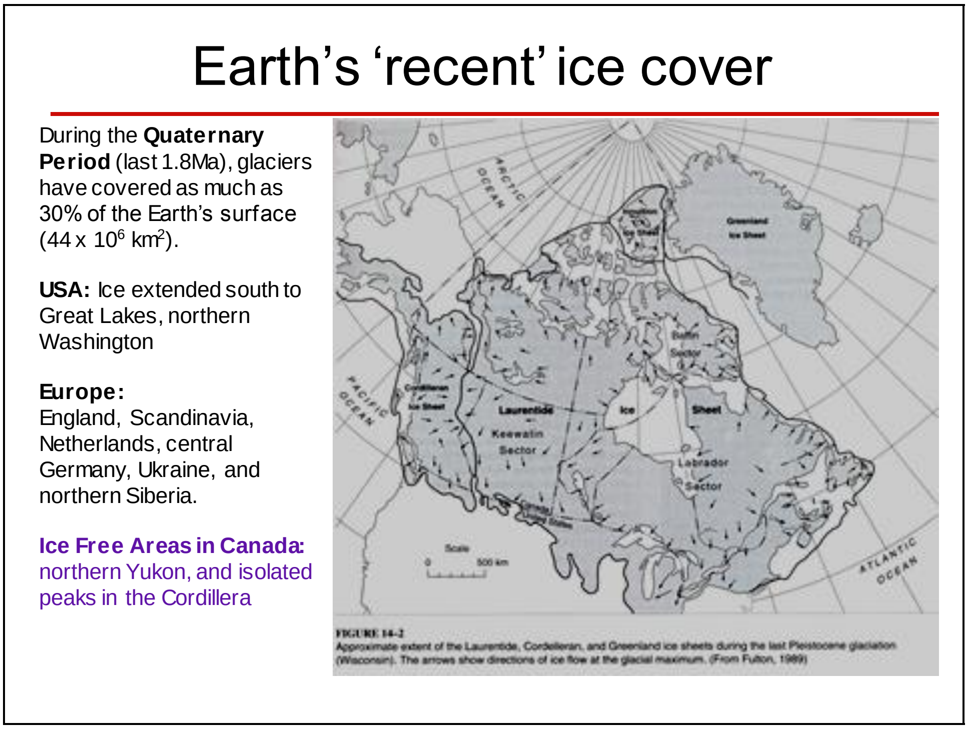
Max. thickness of Antarctic ice sheet is 4300 m, Greenland 2700 m.

Change in global sea level when the world's glaciers melt:

Antarctica:	68.0 m
Greenland:	7.4 m
All Ice:	75.9 m

But when will this occur?

(IPCC, 2001)



Earth’s ‘recent’ ice cover

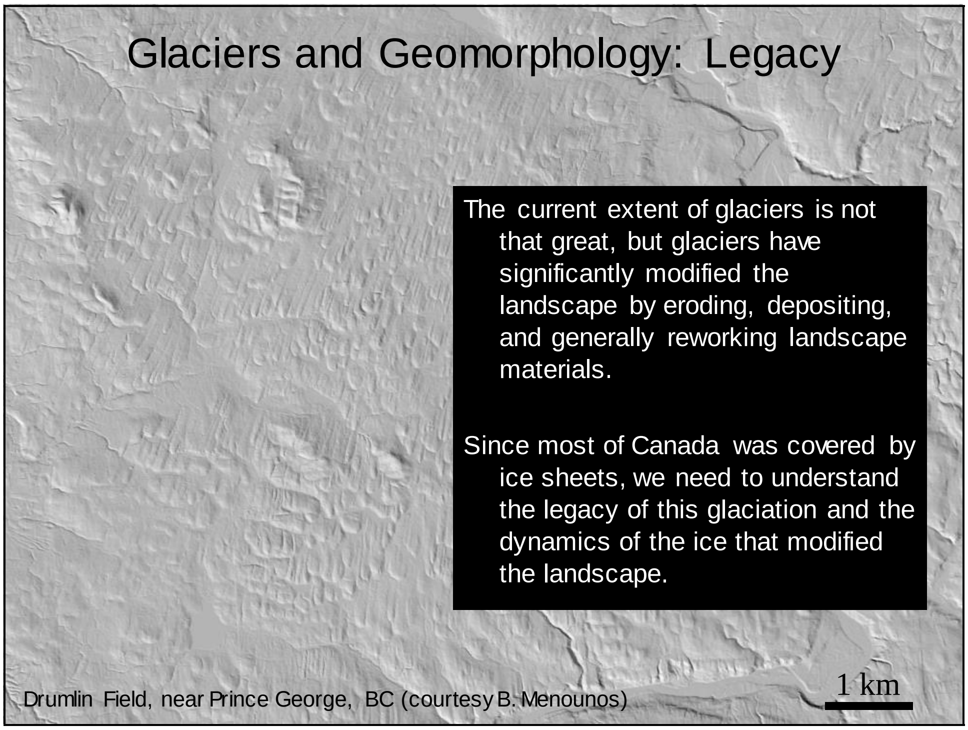
During the **Quaternary Period** (last 1.8Ma), glaciers have covered as much as 30% of the Earth’s surface (44×10^6 km^2).

USA: Ice extended south to Great Lakes, northern Washington

Europe:
England, Scandinavia, Netherlands, central Germany, Ukraine, and northern Siberia.

Ice Free Areas in Canada:
northern Yukon, and isolated peaks in the Cordillera

FIGURE 14-2
Approximate extent of the Laurentide, Cordelleran, and Greenland ice sheets during the last Pleistocene glaciation (Wisconsin). The arrows show directions of ice flow at the glacial maximum. (From Fulton, 1989)

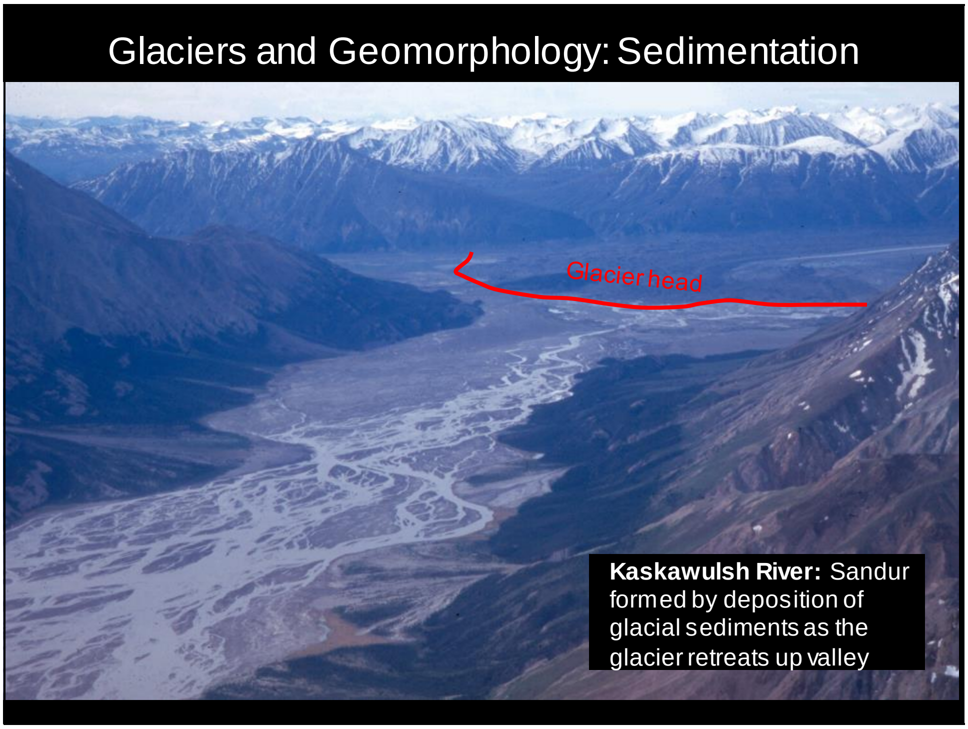


Glaciers and Geomorphology: Legacy

The current extent of glaciers is not that great, but glaciers have significantly modified the landscape by eroding, depositing, and generally reworking landscape materials.

Since most of Canada was covered by ice sheets, we need to understand the legacy of this glaciation and the dynamics of the ice that modified the landscape.

Drumlin Field, near Prince George, BC (courtesy B. Menounos)



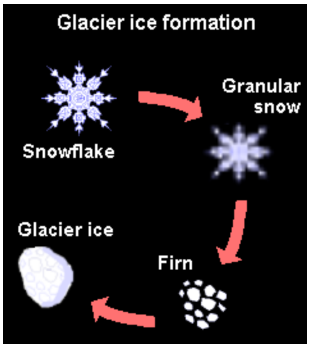
Glaciers and Geomorphology: Sedimentation

Kaskawulsh River: Sandur formed by deposition of glacial sediments as the glacier retreats up valley

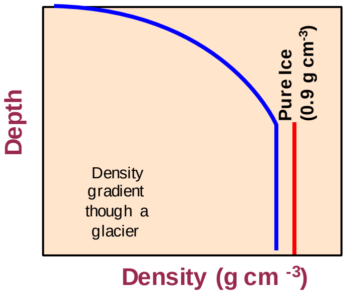
Glacial ice formation and material dynamics

Formation of glacial ice

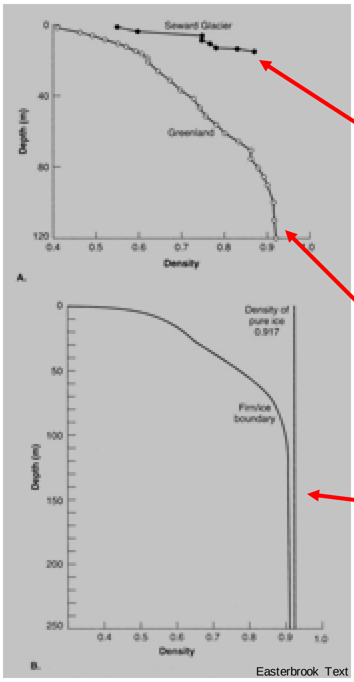
- Glacial ice begins as light fluffy snow with a density of 0.07 to 0.18 g/cm^3
- As snow accumulates, the weight on snow from above melts basal snow that recrystalizes in a more compact form called firn or neve (density of 0.4 to 0.8 g/cm^3)
- With further compaction and recystalization, firn becomes ice with a density of 0.8 to 0.9 g/cm^3



Luis Maria Benitez



Increase in density of snow/firn with depth



Easterbrook Text

Seward Glacier, Alaska

Greenland Ice Sheet

Antarctic Ice Sheet at Bryd Station, Antarctica

Ice dynamics

The dynamics of ice, and ultimately, glaciers ability to modify the landscape and impact landscape development processes is dependent on the properties of the ice and its movement, which is governed by:

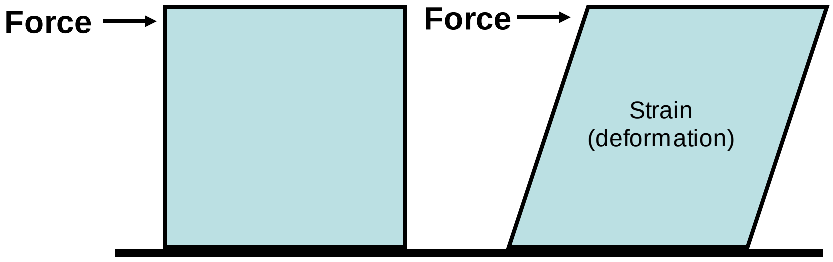
1) Ice rheology

2) Type of ice movement

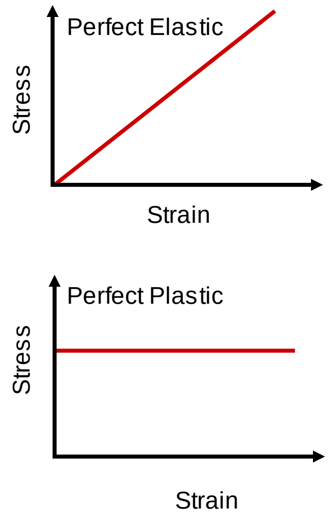
3) Temperature

Ice rheology: recall from previous lectures

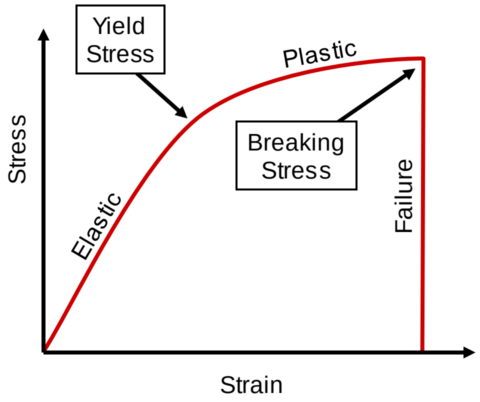
Definitions: ***Stress*** is a force applied to a surface area and ***strain*** is any deformation or change in shape or volume of a material caused by application of stress



Physical Characteristics of materials



Most earth materials exhibit mixed behavior. Yield stress is sometimes referred to as the plastic limit and the breaking stress is sometimes referred to as liquid limit (Atterberg limits).



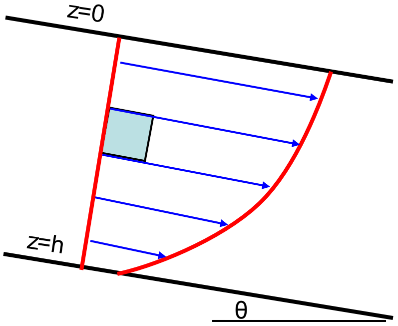
Ice movement: Stress and strain

Shear stress in a glacier

At any level in a glacier:

$$\tau = \rho_{ice} g z \sin\theta$$

τ = shear stress
ρ_{ice} = density of ice
g = gravitational acceleration
z = depth of the ice
sin θ = slope of the substrate below the ice

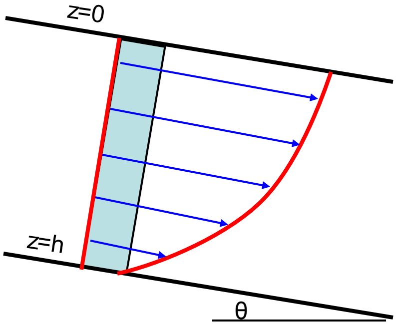


Basal Shear Stress

If z is the full depth of ice:

$$\tau_b = \rho_{ice} g h \sin\theta$$

T_b = basal shear stress
h = depth of the ice

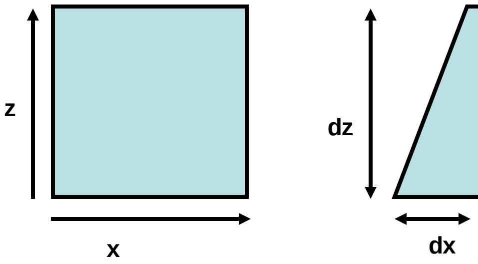


Thicker ice or ice on steeper slopes typically exerts greater stress on the bed of the glacier than thinner ice or ice on lesser slopes

Internal Motion of Ice

Consider an element within the ice column

Start **After a Short Time**



Strain is

$$\varepsilon = \frac{1}{2}\frac{dx}{dz}$$

Strain *Rate* is

$$\dot{\varepsilon} = \frac{1}{2}\frac{dx}{dz}\frac{1}{dt} = \frac{1}{2}\frac{du}{dz}$$

Glen's Law: governs plastic ice deformation

The relation between stress and strain is given by Glen's Law:

$$\dot{\varepsilon} = k\tau^n$$

$\dot{\varepsilon}$ = strain rate
τ = shear stress
k = temperature dependent constant
n = is a constant that varies between 1.3 and 4.5 (average ~3)

Small changes in the basal shear stress can produce major changes in deformation (ice becomes softer with greater imposed stress)

Ice Flow

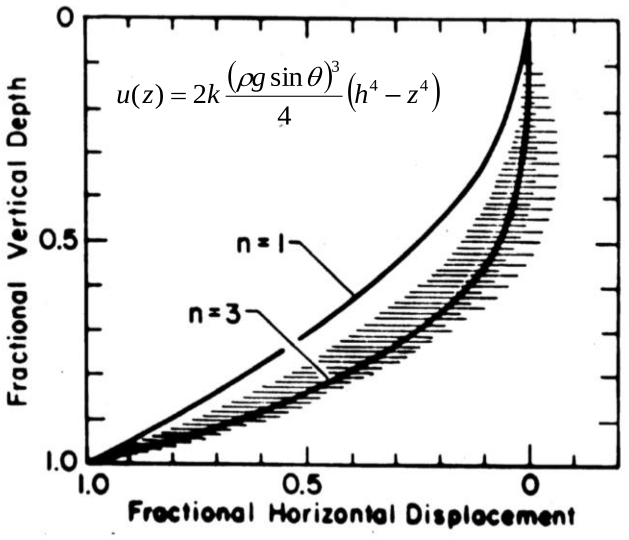
By combining the shear strain rate definition with Glen’s law we can find a relation for the velocity of ice within a glacier.

$$\frac{du}{dz} = 2k\tau^{n}$$

Using a little calculus, assuming n=3, and inserting the equation for the shear stress, we arrive at an equation for the ice velocity:

$$u(z) = 2k\frac{(\rho g \sin\theta)^{3}}{4}\left(h^{4} - z^{4}\right)$$

Ice Velocity Profile



Ice Velocity Profile

$$u(z) = 2k\frac{(\rho g \sin\theta)^3}{4}\left(h^4 - z^4\right)$$

If we integrate this equation over the full depth of ice (sum velocities at all heights) and divide by the depth, we get an equation for the mean velocity of the ice:

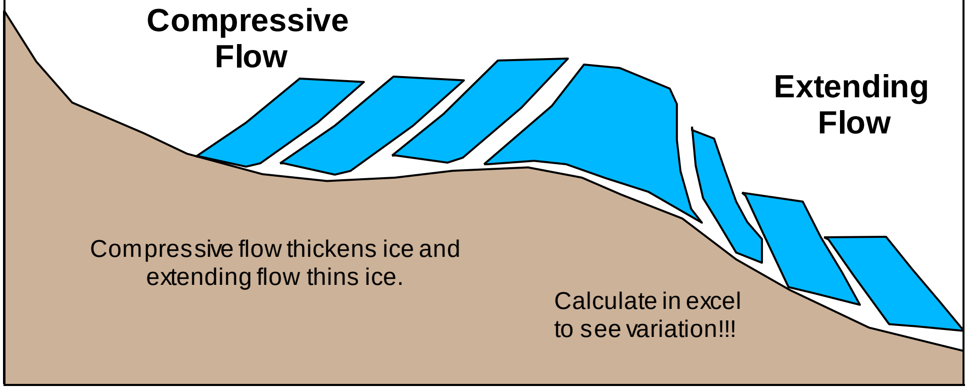
$$\bar{u} = 2/5k(\rho g \sin\theta)^3 h^4$$

Internal ice velocity is dependent upon slope, ice thickness, and temperature.

Ice movement

Topography exerts a first order control on flow rates.

$$\bar{u} = 2/5k(\rho g \sin\theta)^3 h^4$$



Compressive Flow

Extending Flow

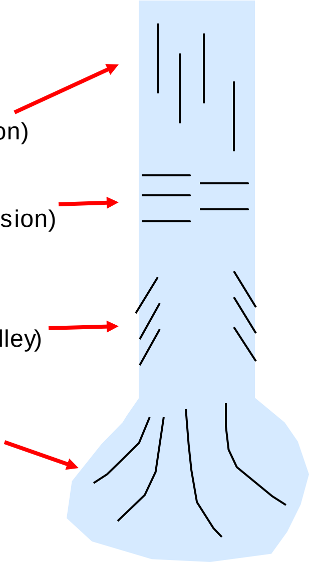
Compressive flow thickens ice and extending flow thins ice.

Calculate in excel to see variation!!!

Ice movement

Ice movement causes tensional cracks termed crevasses that reveal the types of movement occurring in the ice

Bird's Eye View



Longitudinal
(lateral extension)

Transverse
(downvalley extension)

Chevron
(friction along valley)

Radial
(spreading)

Courtesy: B. Menounos

Courtesy: B. Menounos

Ice movement: Thermal Regime

Thermal regime of glaciers

Internal Thermal Regime

Warm-based glaciers are at approximately the pressure melting point throughout their depth and contain water

Cold-based glaciers are well below the pressure melting point at depth

The temperature at which water freezes is 0 °C at atmospheric pressure and declines by ~1 °C for every 14 MPa (megapascal) of pressure.

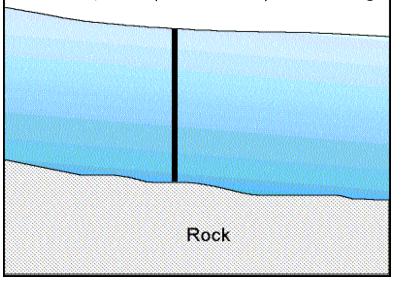
Under 20 MPa of pressure, ice at the base of the Antarctic ice sheet freezes at -1.6 °C.

Role temperature plays in glacial movement

Warm glaciers may slip at their boundary because of basal water.

Animation of ice deformation with slip

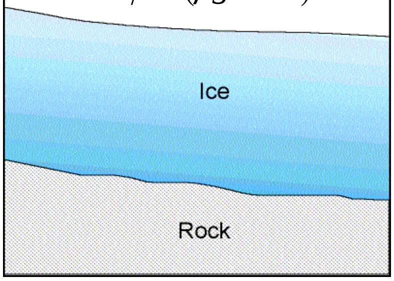
$$\bar{u} = 2/5k(\rho g \sin\theta)^3 h^4 + u_b$$



Cold glaciers freeze to the boundary, causing internal deformation

Animation of ice flow deforming a core

$$\bar{u} = 2/5k(\rho g \sin\theta)^3 h^4$$

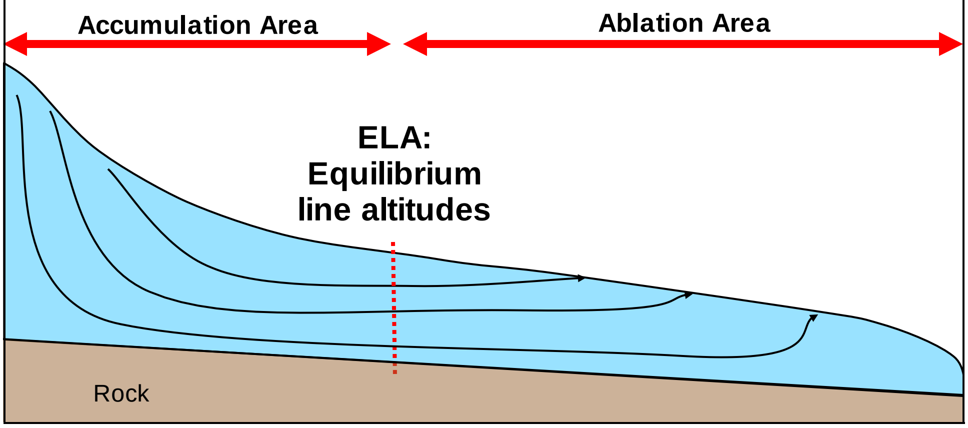


Animations courtesy: B. Menounos

Glacier Mass Balance

Mass balance Classification: Anatomy of a glacier

Although it is convenient to break glaciers into two groups (warm and cold), most glaciers exhibit different behaviors based on different zones.

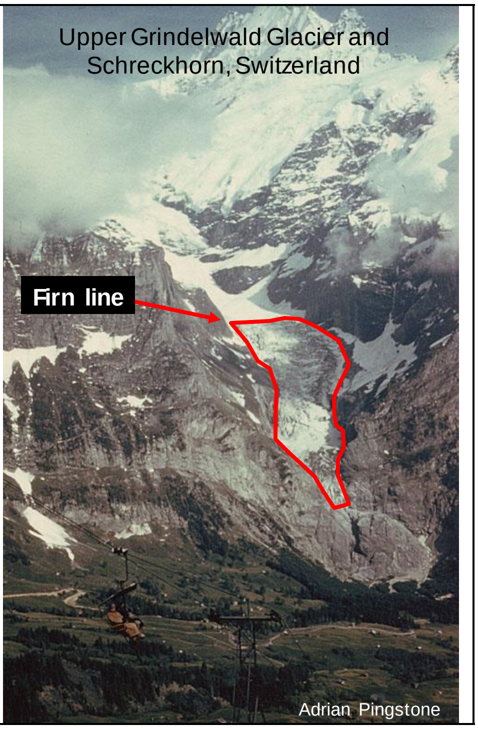


Ablation and accumulation areas

Accumulation includes all the processes responsible for adding snow to the glacier

Ablation includes all the processes responsible for snow or ice loss from the glacier

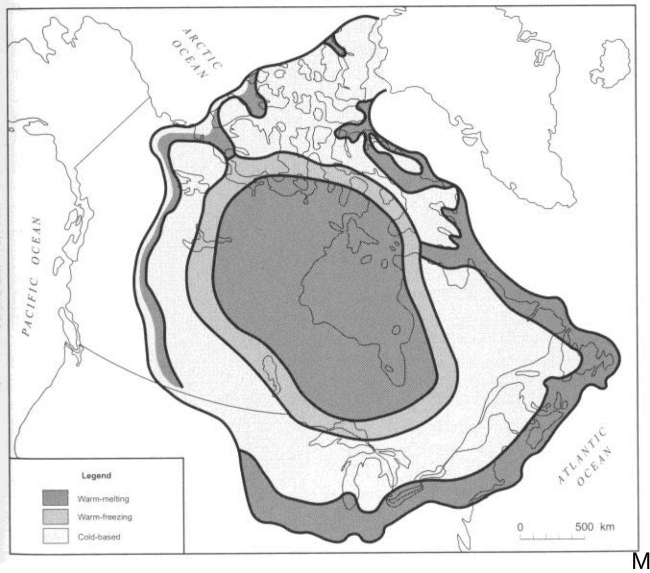
- Locally, melting by evaporation, sublimation, calving or wind erosion maybe important.
- However, melting is largely facilitated by low albedo, dark rock material on the surface of the glacier



Upper Grindelwald Glacier and Schreckhorn, Switzerland

Adrian Pingstone

Zonation of Laurentide ice sheet



Menzies (2002)

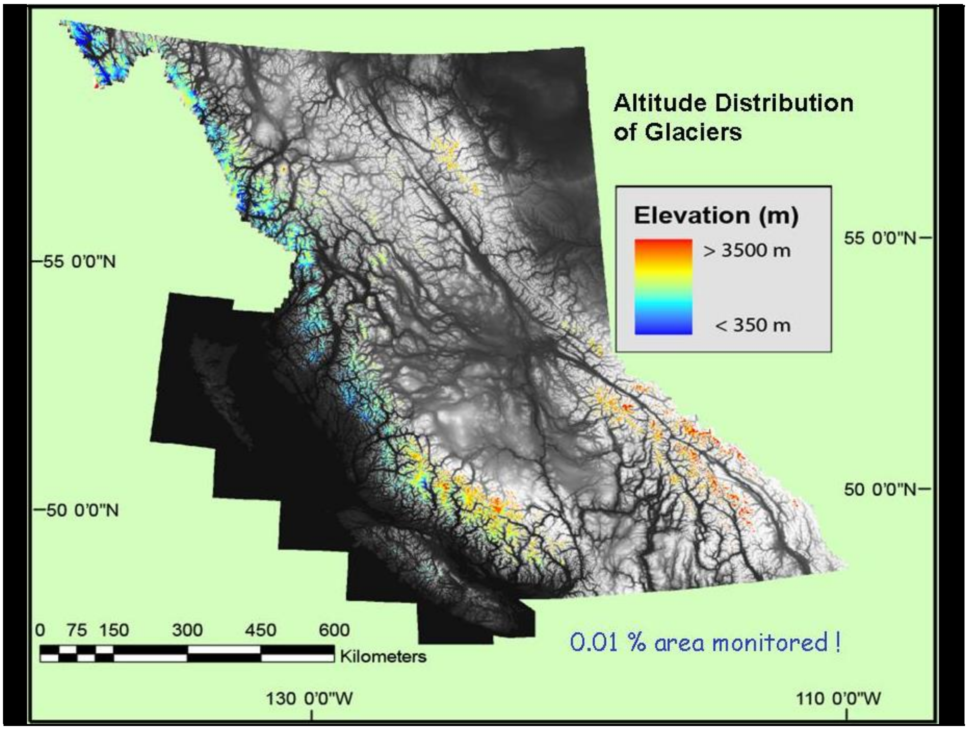
Mass balance of a glacier

A glacier’s mass balance is simply the difference between the annual accumulation and ablation volumes.

If the mass balance is positive, glaciers are growing

If mass balance is negative, glaciers are disappearing

Most of the world’s glaciers currently have a negative mass balance.



Altitude Distribution of Glaciers

0.01 % area monitored !

VANCOUVER SUN

News / Local News

B.C. glaciers 38 per cent thicker than expected, surprising study finds

Some glaciers might last a few years or even a decade longer, but that still won't save them from climate change

Randy Shore
Nov 27, 2020 • Last Updated 2 days ago • 3 minute read

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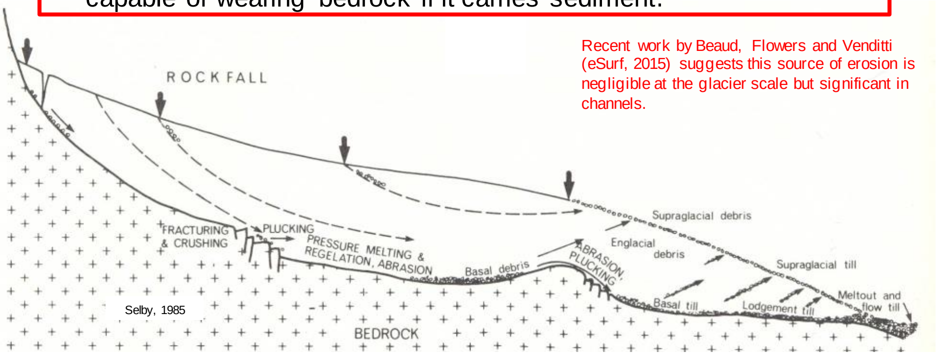
Glacial Erosion Processes

Glacial erosion processes

Three principle processes are responsible for glacial erosion:

1. **Abrasion**: bedrock scour by rock debris lodged in the basal ice
2. **Plucking (quarrying)**: where ice freezes to loose fractured bedrock and extracts blocks as it moves.
3. **Sub-glacial fluvial erosion**: water flow at the base of the glacier is capable of wearing bedrock if it carries sediment.



Recent work by Beaud, Flowers and Venditti (eSurf, 2015) suggests this source of erosion is negligible at the glacier scale but significant in channels.

Selby, 1985

Glacial erosion processes

Mohs scale

Hardness	**Mineral**	**Absolute Hardness**
1	Talc ($Mg_3Si_4O_{10}(OH)_2$)	1
2	Gypsum ($CaSO_4 \cdot 2H_2O$)	2
3	Calcite ($CaCO_3$)	9
4	Fluorite (CaF_2)	21
5	Apatite ($Ca_5(PO_4)_3(OH-,Cl-,F-)$)	48
6	Orthoclase Feldspar ($KAlSi_3O_8$)	72
7	Quartz (SiO_2)	100
8	Topaz ($Al_2SiO_4(OH-,F-)_2$)	200
9	Corundum (Al_2O_3)	400
10	Diamond (C)	1500

Ice is ~1.5 on Mohs hardness scale. As such it cannot erode bedrock on its own.

Erosion requires one of the following processes:

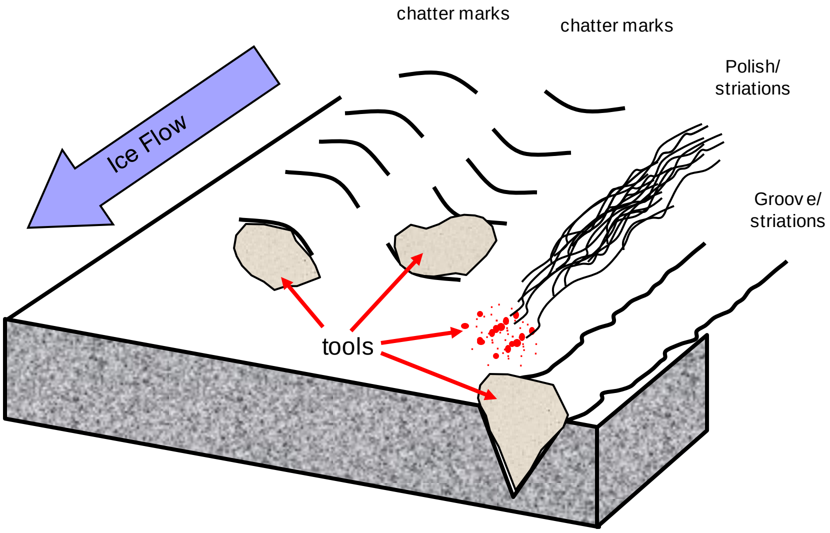
1. **Abrasion**
2. **Plucking (quarrying)**
3. **Sub-glacial water flow (carrying sediment)**

Abrasion is controlled by 3 factors:

i) basal contact pressure of tool

ii) rate of basal sliding

iii) concentration of tools in ice



Striations

photo by Karen Kleinspehn

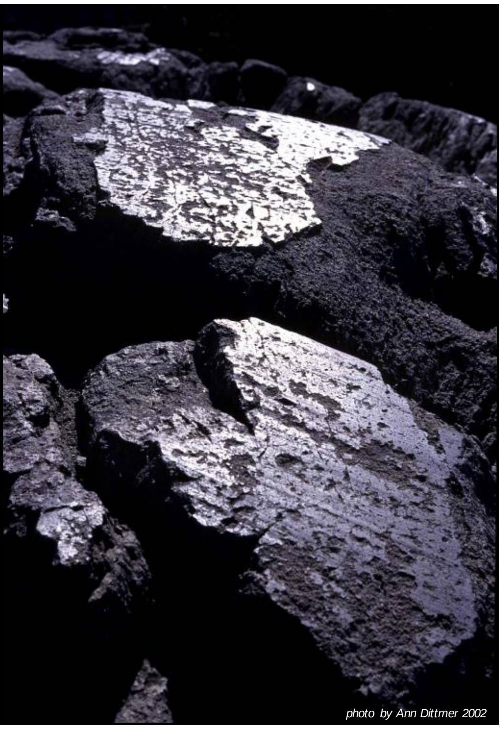


photo by Ann Dittmer 2002

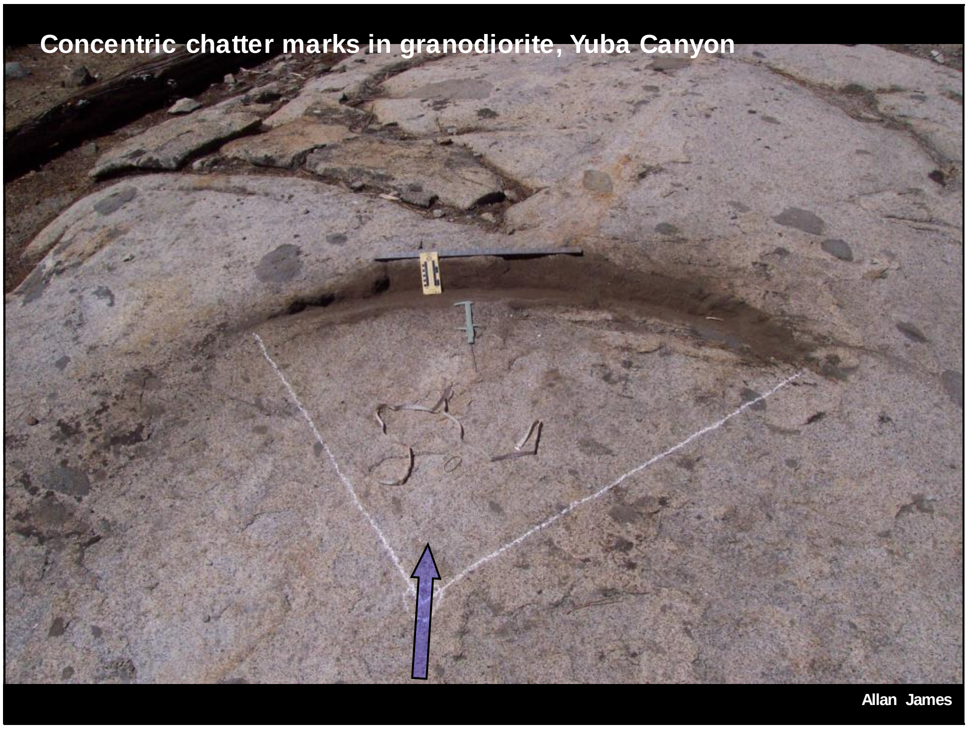
Polished bedrock

Lassen NP, Northern California.

photo by Ann Dittmer 2002

Yosemite NP

http://www.yosemite.ca.us/library/geologic_story_of_yosemite/final_evolution.html



Concentric chatter marks in granodiorite, Yuba Canyon

Allan James

Grooves

Glacial grooves caused by the Wisconsin glaciation at Kelleys Island, Ohio

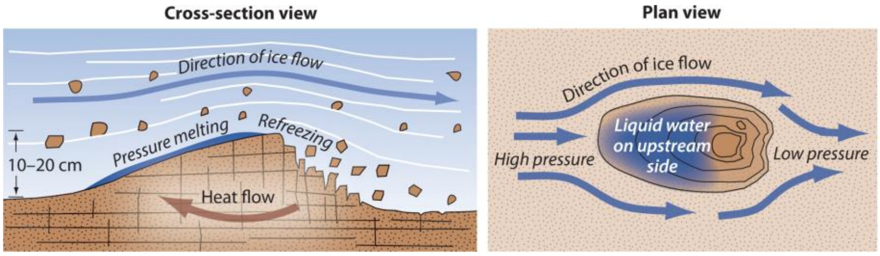
http://nsidc.org/glaciers/gallery/grooves.htm

Glacial grooves in rock panels, Churchill, Manitoba, Canada.

Linear striations, chatter marks, polish, grooves in background


Photo by John P. Lockwood

Plucking by Regelation



Regelation occurs when ice flows over rock obstacles on the glacier bed. Pressure-melting of ice up-glacier of an obstacle releases water, which then travels down ice to areas of lower pressure and consequently refreezes. This refreezing may incorporate debris and enrich the remaining solution in elements such as calcium, which precipitates and forms calcium carbonate coatings on subglacial rock surfaces. Regelation facilitates the movement of warm-based glacial ice over rough bedrock beds.

Roche Moutonnee formed by regelation

Ice Flow

Rock plucked from lee of bedrock knob by refreezing ice

Allan James 2002

Roche Moutonnee

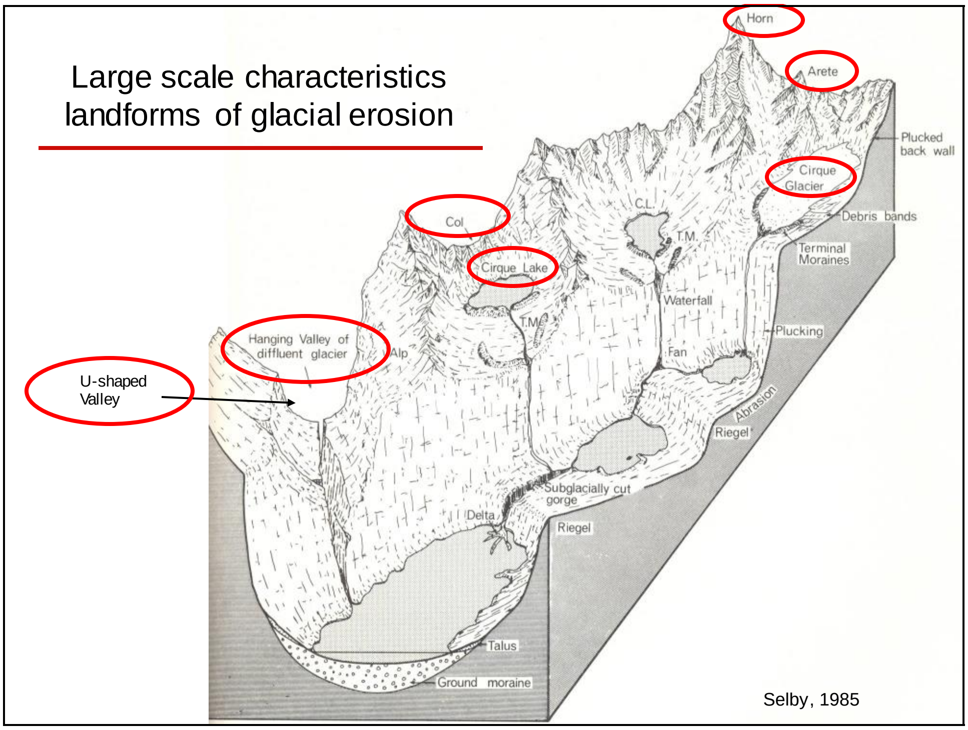
Ice Flow

Rock plucked from lee of bedrock knob by refreezing ice

Goncalo Vieira 2002

Glacial Landforms

Large scale characteristics landforms of glacial erosion



Selby, 1985

Large scale characteristics landforms of glacial erosion

Cirque: an amphitheater-shaped bedrock feature created as glaciers scour back into the mountain.

Arete: a steep-sided, sharp-edged bedrock ridge formed by two glaciers eroding away on opposite sides of the ridge.

Col: a low spot or pass along a cirque or an arete.

Horn: a pyramid-shaped mountain peak created by several glaciers eroding away at different sides of the same mountain.

Hanging Valley: a valley eroded by a small tributary glacier, such that the elevation of the valley floor is higher than the elevation of the valley floor that the hanging valley joins.

U-Shaped Valley: a valley with a cross-section that is U shaped.

Cirques, aretes, horns

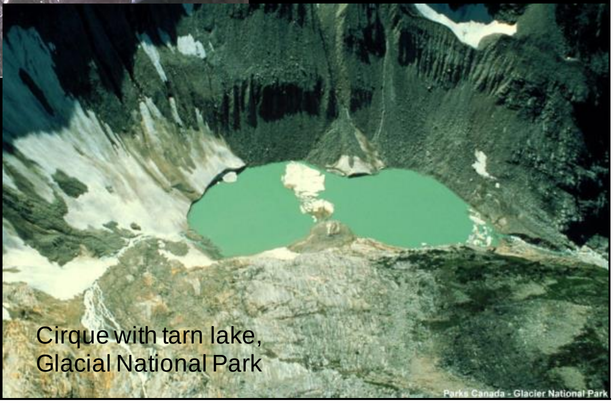
Cirque is an amphitheatre-like valley (or valley head) of glacial origin, formed by glacial erosion at the head of the glacier.

Iceberg Cirque, Glacier National Park, Montana

http://www.nps.gov/glac/gallery/parkpics.htm

Cirques

Cirque with filling lake,
Juneau Icefield



Cirque with tarn lake,
Glacial National Park

Parks Canada - Glacier National Park

Richard Kesel

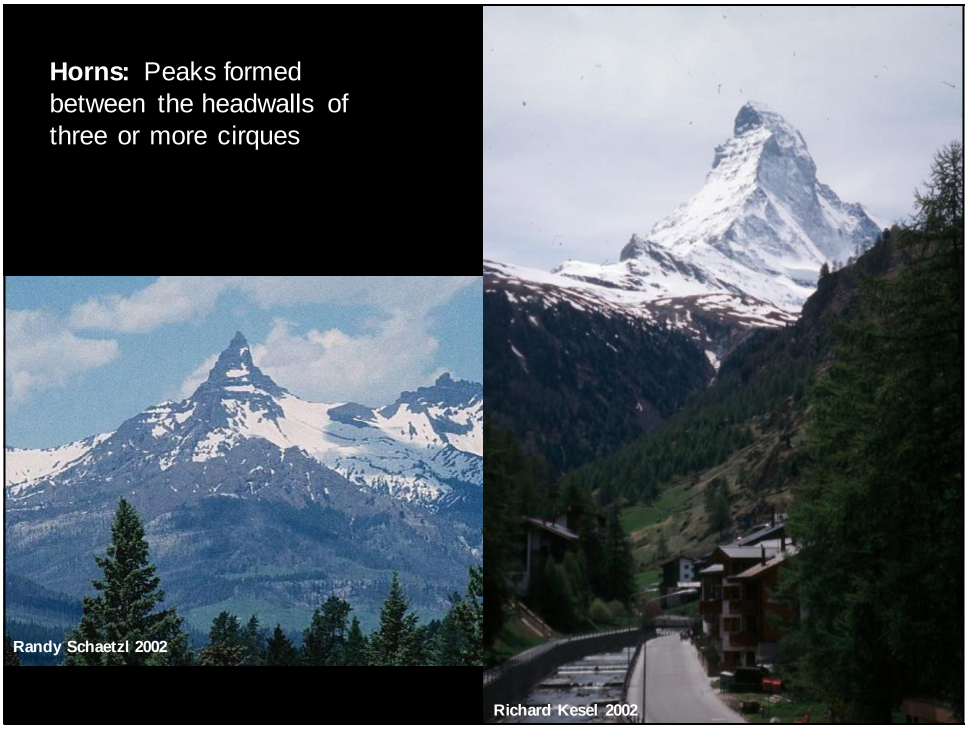
Aretes: Ridge formed between the headwalls of two cirques

Cumbria England

Photo by: Sean Ross.

Angel Pass, Wind River Range, WY

William Locke 2002



Horns: Peaks formed between the headwalls of three or more cirques

Randy Schaetzl 2002

Richard Kesel 2002

Geomorphic transport law for wear rate by ice

At present, there is no geomorphic transport law that has been tested against erosion rate data.

Hallet (1989; Journal of Glaciology) has suggested that erosion rates are proportional to basal ice velocity (U_b) such that:

$$W_{ice} = cU_b$$

Even without erosion data, some numerical modeling has demonstrated that this erosion rule can be used to reproduce the main characteristics of glaciated valleys.

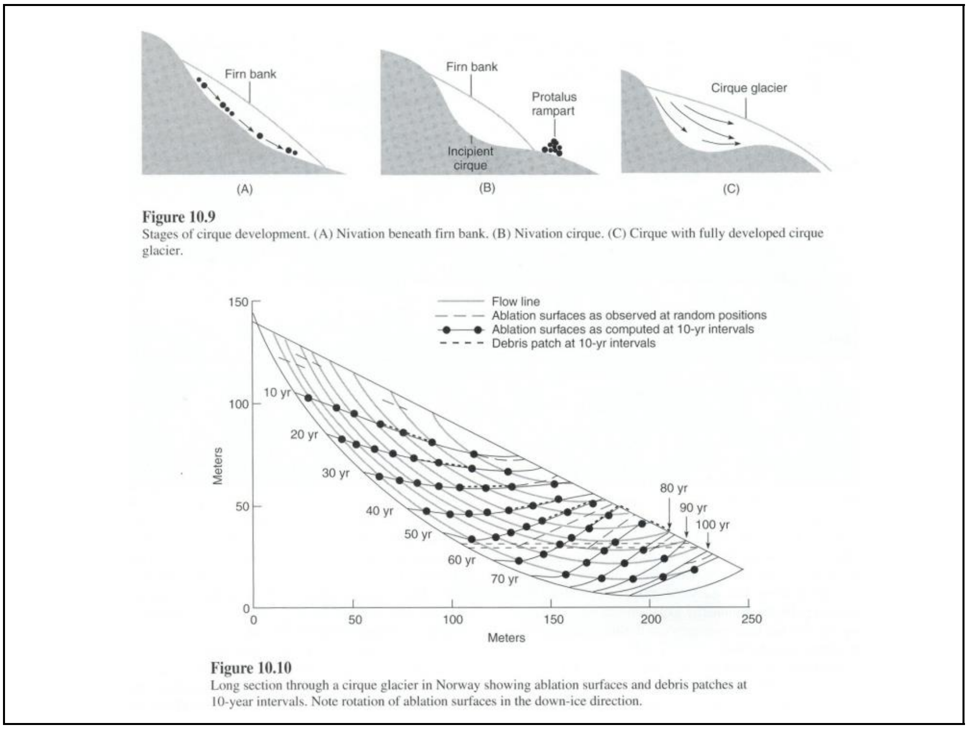
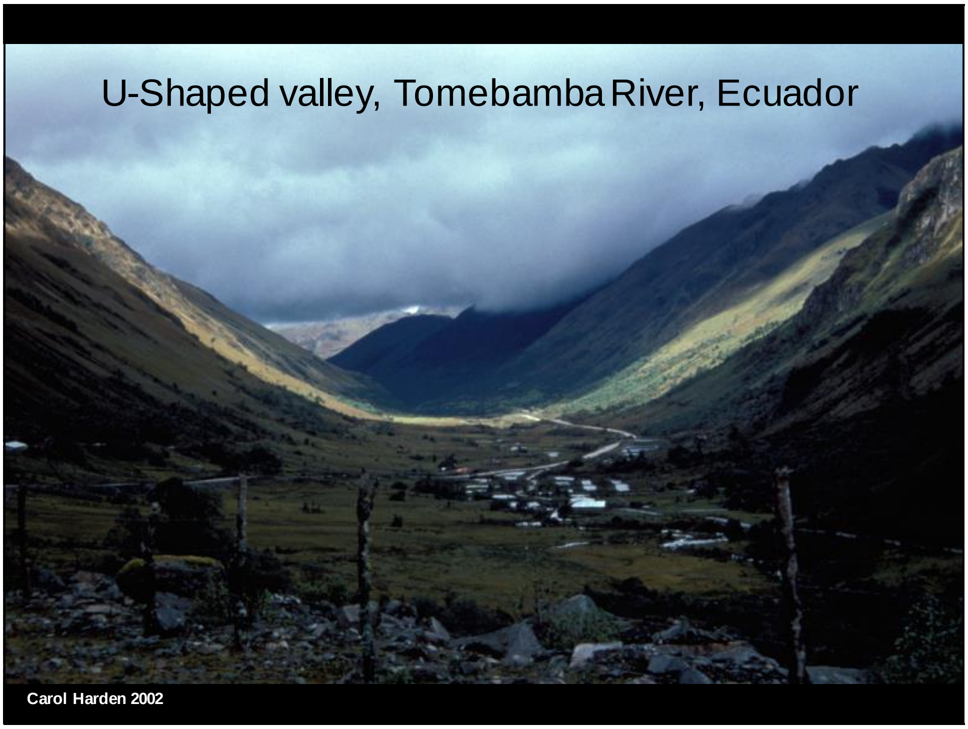


Figure 10.9
Stages of cirque development. (A) Nivation beneath firn bank. (B) Nivation cirque. (C) Cirque with fully developed cirque glacier.

Figure 10.10
Long section through a cirque glacier in Norway showing ablation surfaces and debris patches at 10-year intervals. Note rotation of ablation surfaces in the down-ice direction.

U-shaped and hanging valleys



U-Shaped valley, Tomebamba River, Ecuador

Carol Harden 2002

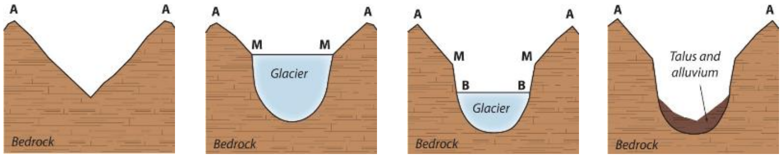
New Zealand

Hanging valley along along Kootenay river, B.C

Mariette Prent 2002

Glacial Trough Formation

Valleys are cut by rivers, and subsequently modified by glaciers



Unglaciated Valley
A–A Unglaciated Valley

Maximum Vertical Ice Extent
A–A Glacial Valley
M–M Active Glacial Channel and Zone of Glacial Influence

Ice Extent Less Than Maximum
A–A Glacial Valley
M–M Zone of Glacial Influence
B–B Active Glacial Channel

After Deglaciation
A–A Glaciated Valley

Harbor (1992; GSA Bulletin) explored the problem of glacial trough formation using a numerical model and assuming that:

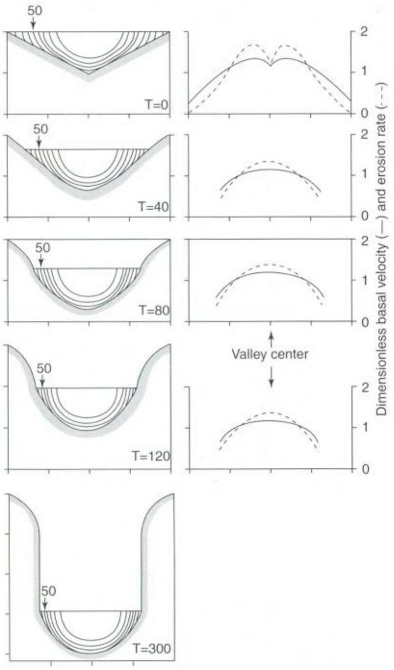
$$W_{ice} = cU_b \qquad u(z) = 2k\frac{(\rho g \sin\theta)^3}{4}\left(h^4 - z^4\right)$$

Glacial Trough Formation

Harbor's analysis suggests that initially, ice velocity, and hence erosion rates, increase towards the center of the valley where ice depth is greatest.

But, a zone of lower flow exists at the valley axis. This promotes erosion of the valley walls.

As this erosion continues, velocities become more uniform across the valley and the glacier incises.



Depositional glacial landforms

Glacial deposition processes

Glacial deposits are derived from:

1) material eroded by plucking of bedrock at the base and sides of the glacier
2) abrasion of bedrock
3) pre-glacially weathered soil and sediment
4) concurrent slope processes

The material has a wide variety of possible mineral and lithological characteristics.

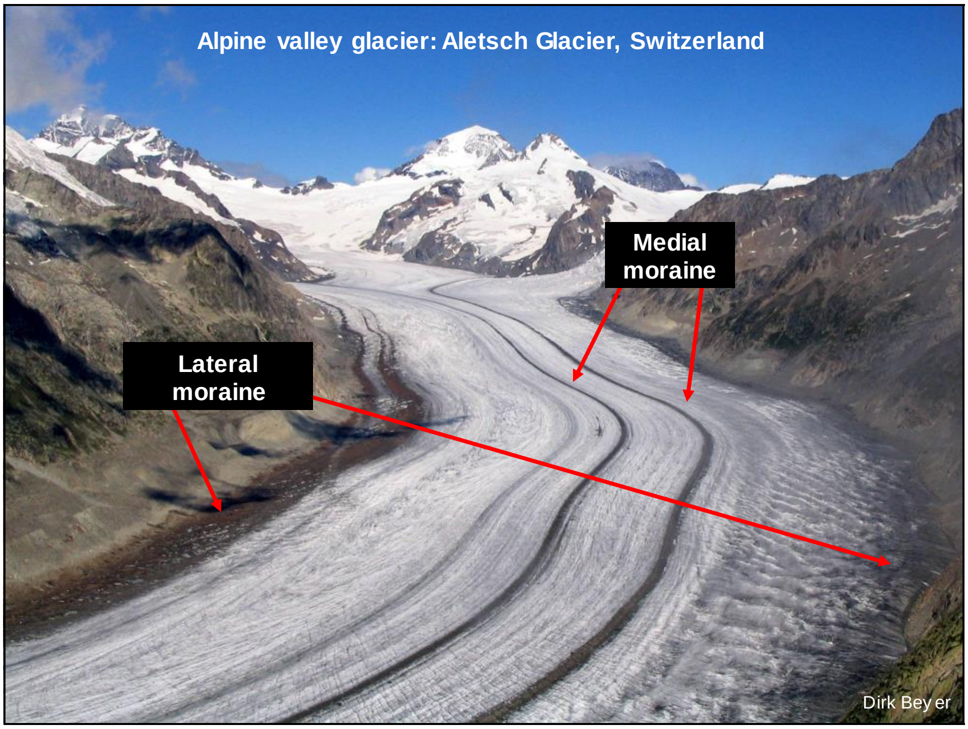
Chilliwack river valley - till

MCR

Depositional Landforms: Moraines

There are 4 primary types of moraines:

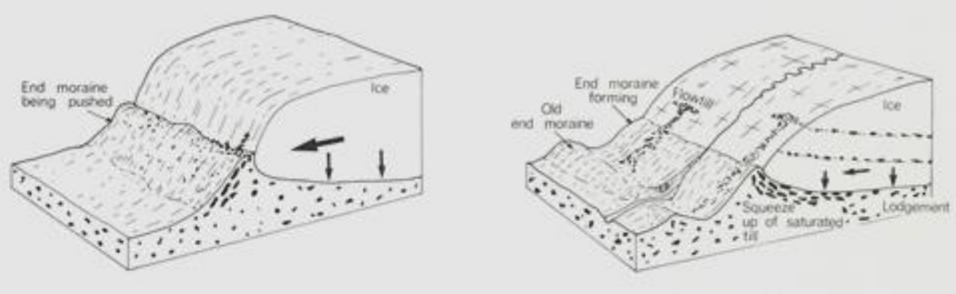
1) **Medial**: formed where two valley galciers join
2) **Lateral**: formed at the edges of a valley glacier
3) **End**: formed at the head of a glacier
4) **Ground**: deposited from the base of glaciers in a non-uniform pattern


Alpine valley glacier: Aletsch Glacier, Switzerland

Dirk Beyer

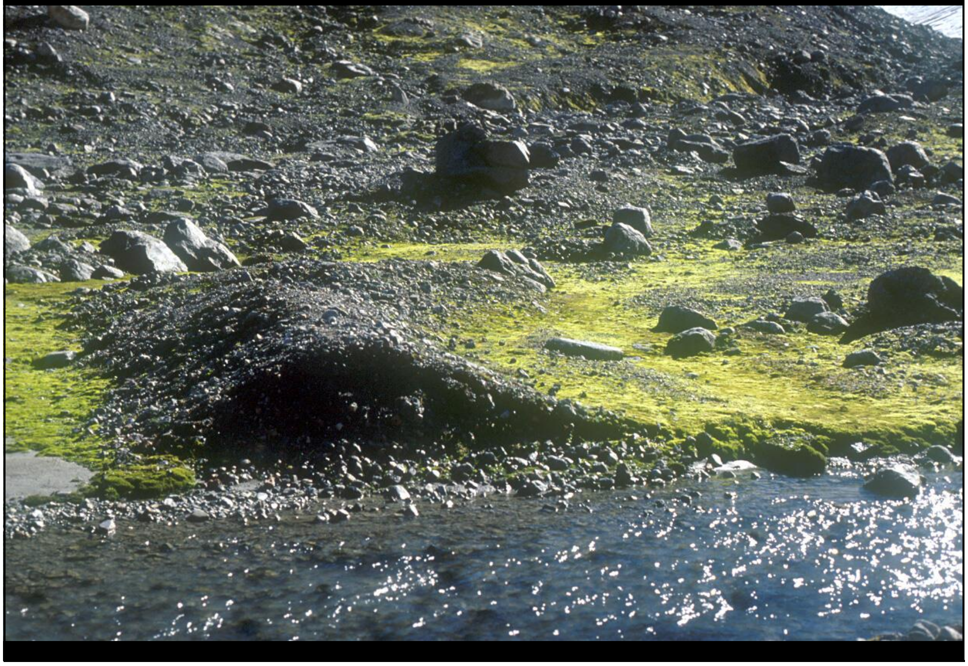
End moraine formation

End moraines are formed at the nose of a glacier as it advances. Sediments are piled at the nose and left behind when the glacial ice ceases to move.



Terminal moraine: records the final ice advance

End Moraine deposits



Moraines of the Midwestern US formed by the Laurentide ice sheet movement

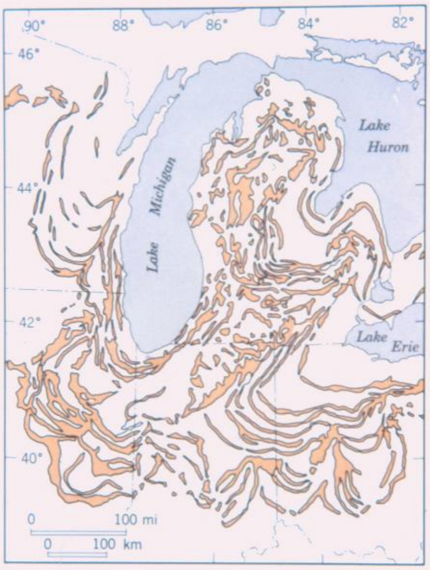
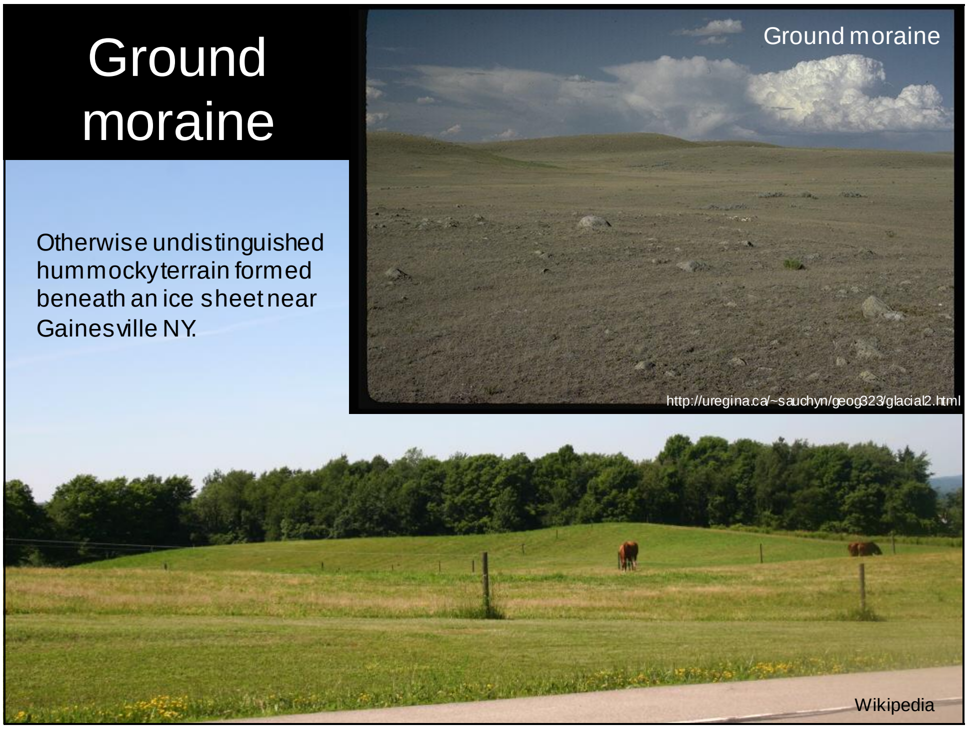


Figure 23.20 **Moraine belts of the north-central United States have a festooned pattern left by ice lobes. (After R. F. Flint and others, *Glacial Map of North America*, 1945.)**



Ground moraine

Otherwise undistinguished hummocky terrain formed beneath an ice sheet near Gainesville NY.

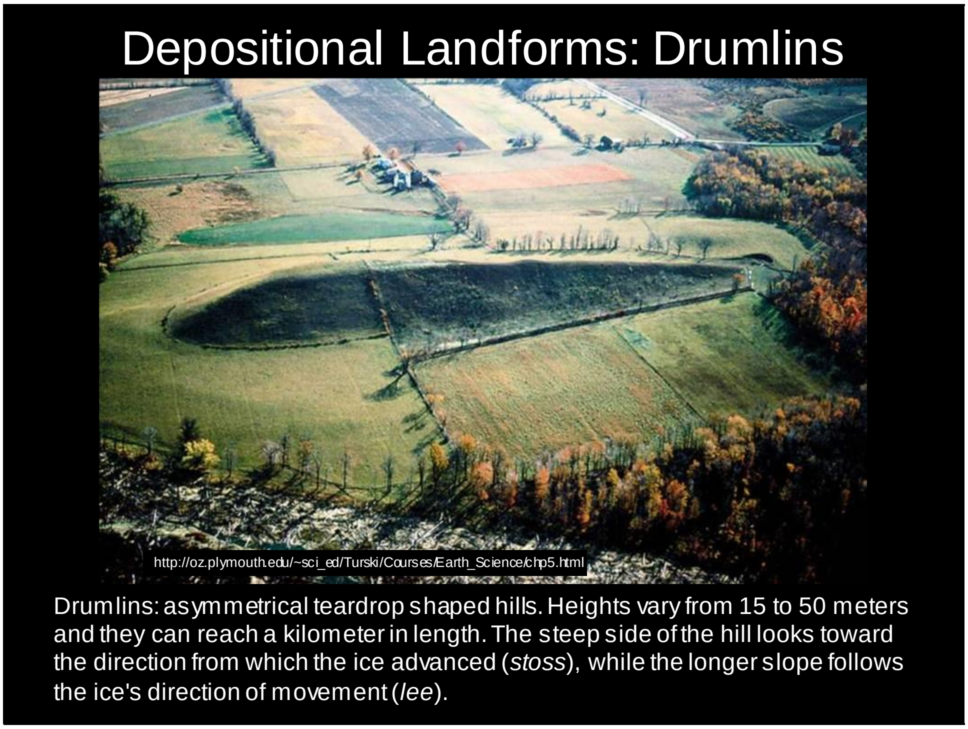
http://uregina.ca/~sauchyn/geog323/glacial2.html

Wikipedia

Dead ice (ground) moraine with kames and kettles

Kames are simply deposits of till formed when ice is melting.
Kettles are depressions in the landscape formed when ice melted.

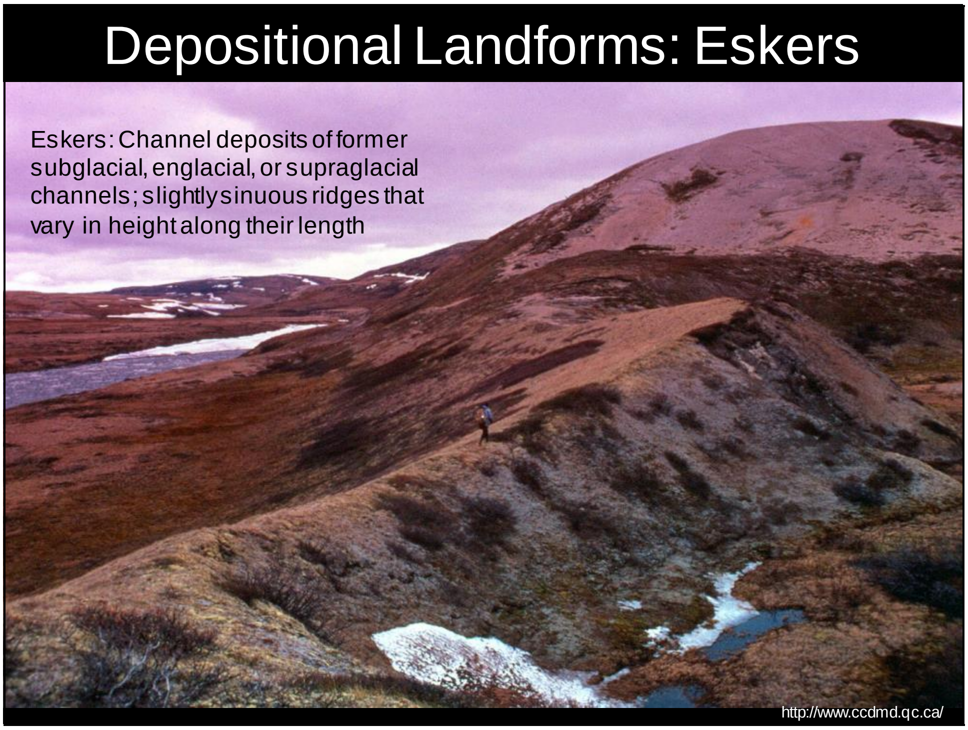
http://uregina.ca/~sauchyn/geog323/glacial2.html



Depositional Landforms: Drumlins

http://oz.plymouth.edu/~sci_ed/Turski/Courses/Earth_Science/chp5.html

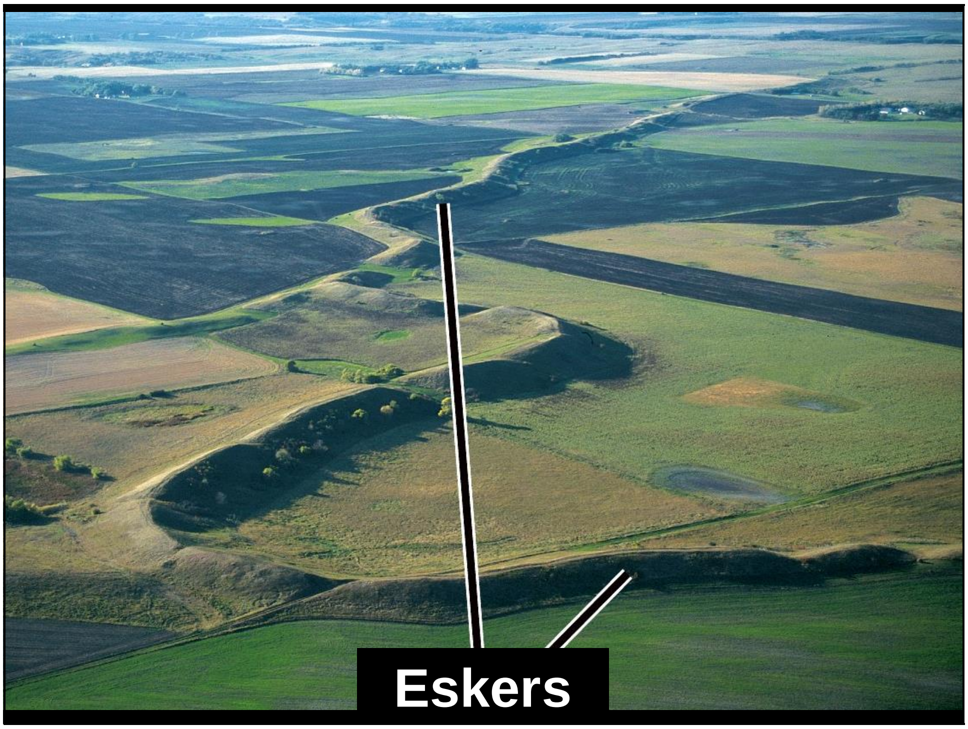
Drumlins: asymmetrical teardrop shaped hills. Heights vary from 15 to 50 meters and they can reach a kilometer in length. The steep side of the hill looks toward the direction from which the ice advanced (*stoss*), while the longer slope follows the ice's direction of movement (*lee*).



Depositional Landforms: Eskers

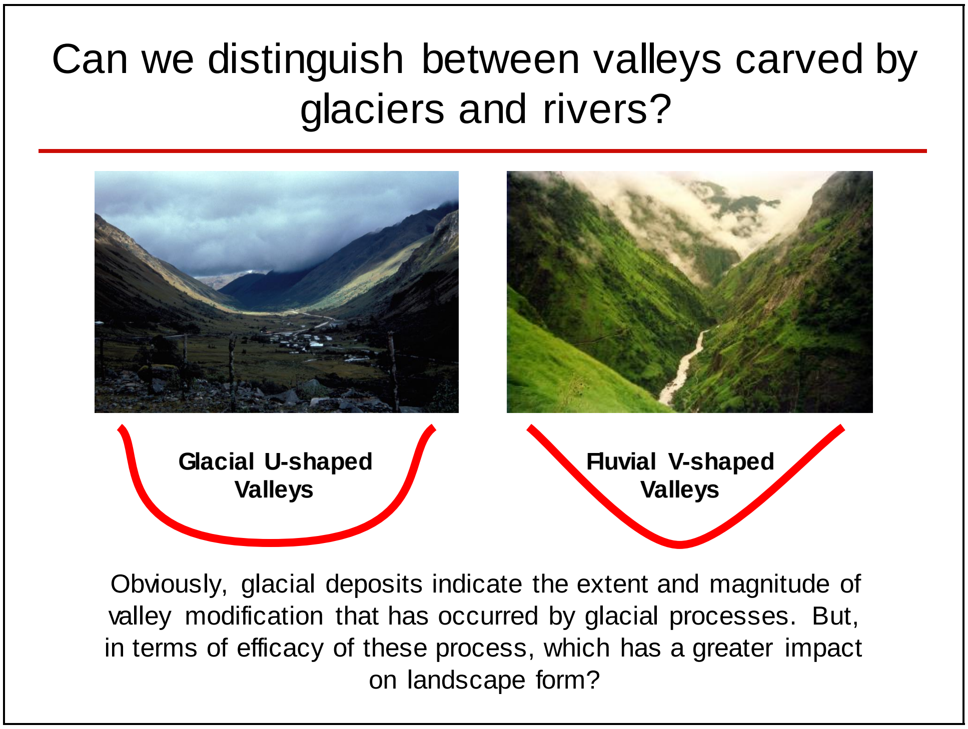
Eskers: Channel deposits of former subglacial, englacial, or supraglacial channels; slightly sinuous ridges that vary in height along their length

http://www.ccdmd.qc.ca/


Eskers


Glacial erratic on a sandur in Norway

Can we distinguish between valleys carved by fluvial and glacial erosion?



Can we distinguish between valleys carved by glaciers and rivers?

Glacial U-shaped Valleys

Fluvial V-shaped Valleys

Obviously, glacial deposits indicate the extent and magnitude of valley modification that has occurred by glacial processes. But, in terms of efficacy of these process, which has a greater impact on landscape form?

Valley formation by fluvial and glacial erosion

David R. Montgomery
Department of Earth and Space Sciences, University of Washington, Seattle, Washington 98195, USA

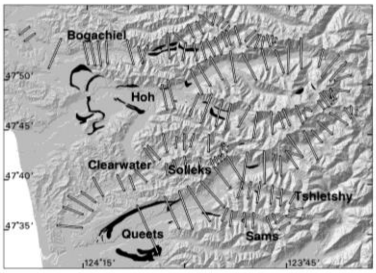
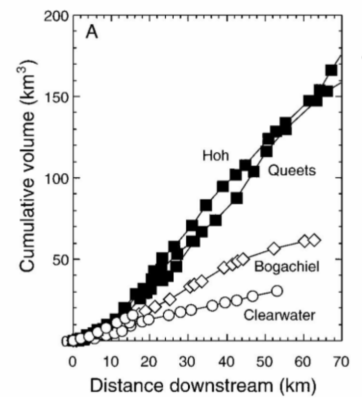


Figure 1. Shaded relief map of west slope of Olympic Mountains, Washington, showing locations of basins studied, cross sections (white bars), and moraines (black areas) as portrayed on 1:100 000 scale geologic maps (Washington Division of Geology and Earth Resources Staff, 2001).

Valleys excavated by glaciers are 2x to 4x larger (in cross-section and volume) and have ~500m greater relief!



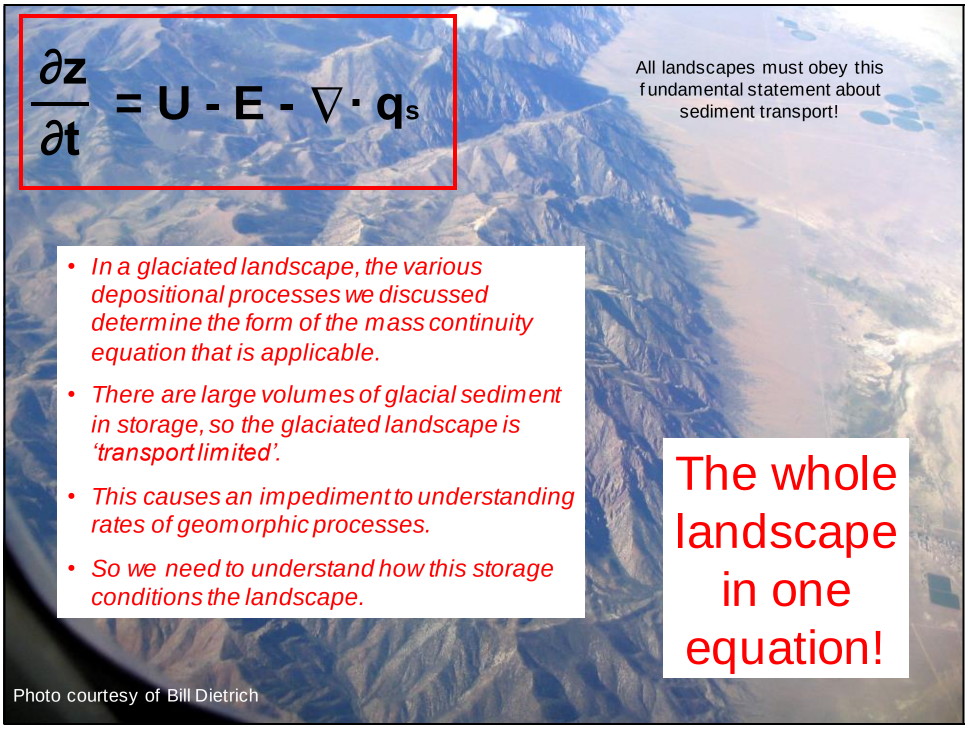
Glaciated

Partly glaciated

Unglaciated

What is the long term effect of glaciers on landscapes?

The glacial hangover



$$\frac{\partial z}{\partial t} = U - E - \nabla \cdot q_s$$

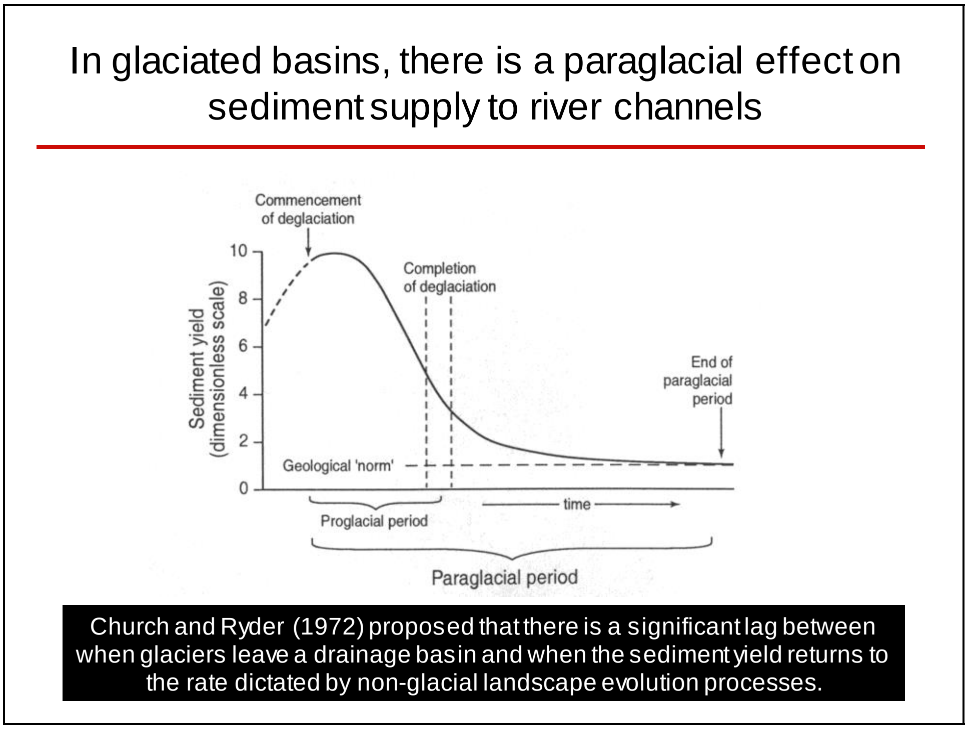
All landscapes must obey this fundamental statement about sediment transport!

- *In a glaciated landscape, the various depositional processes we discussed determine the form of the mass continuity equation that is applicable.*
- *There are large volumes of glacial sediment in storage, so the glaciated landscape is 'transport limited'.*
- *This causes an impediment to understanding rates of geomorphic processes.*
- *So we need to understand how this storage conditions the landscape.*

The whole landscape in one equation!

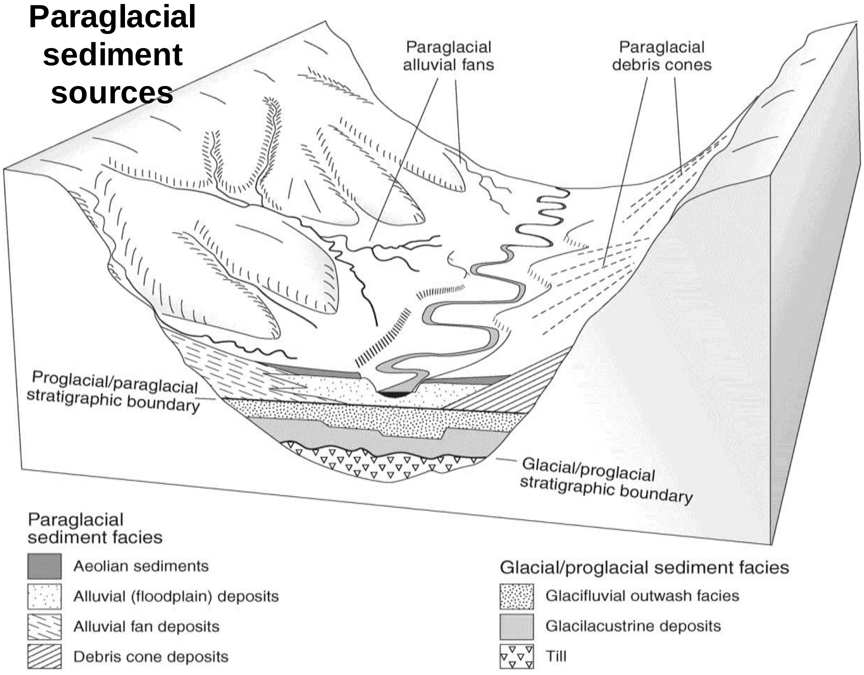
Photo courtesy of Bill Dietrich

In glaciated basins, there is a paraglacial effect on sediment supply to river channels



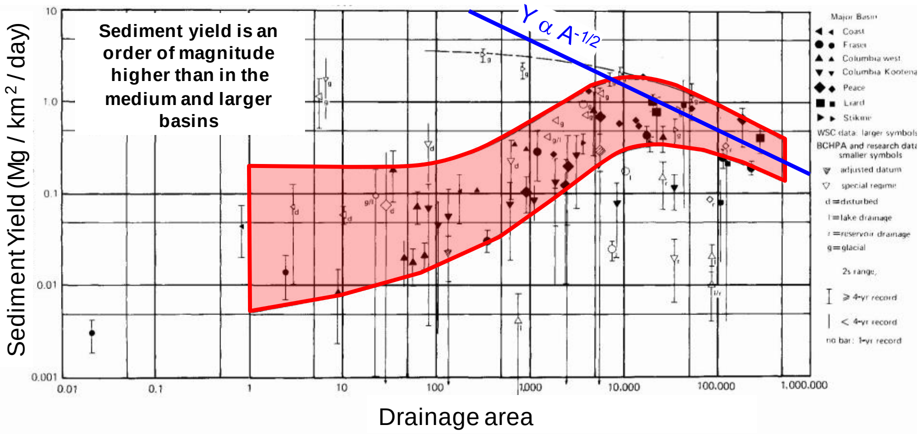
Church and Ryder (1972) proposed that there is a significant lag between when glaciers leave a drainage basin and when the sediment yield returns to the rate dictated by non-glacial landscape evolution processes.

Paraglacial sediment sources



Disequilibrium of Holocene sediment yield in glaciated British Columbia

Michael Church & Olav Slaymaker

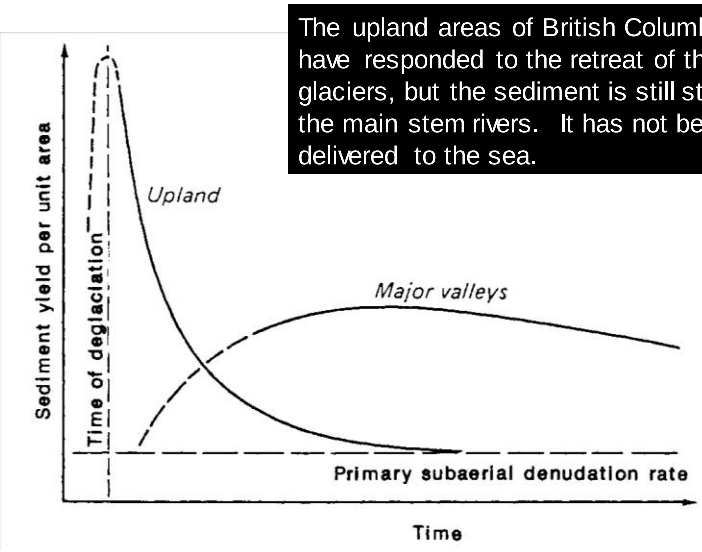


Sediment yield is an order of magnitude higher than in the medium and larger basins

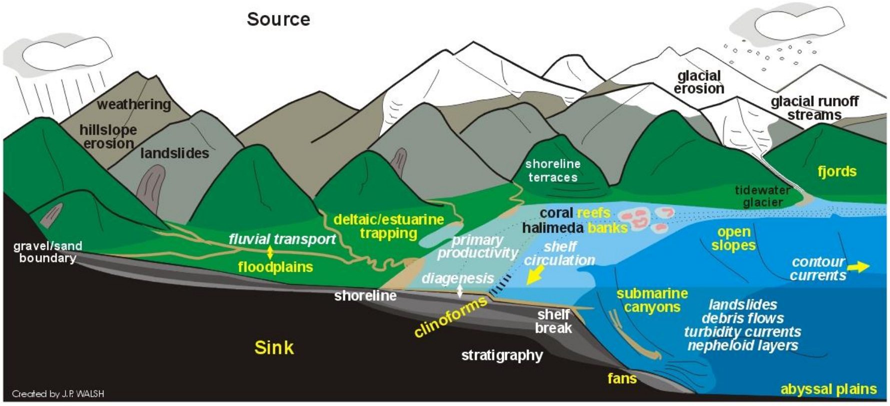
Fig. 1 Specific sediment yield as a function of drainage area for fluvial suspended-sediment-transport records in British Columbian rivers. Closed symbols indicate data for the natural landscape; open symbols indicate yields influenced by natural or human disturbance factors. The main trend of undisturbed yields was sketched by eye. See ref. 10 for a detailed discussion of the data.

The paraglacial sedimentation cycle

The upland areas of British Columbia have responded to the retreat of the glaciers, but the sediment is still stored in the main stem rivers. It has not been delivered to the sea.



The primary contemporary effect of the glaciers on landscape development is that large volumes of glacial sediment are now stored in terraces, fans, and river beds/floodplains. Thus, the rate of landscape denudation is out of equilibrium with the non-glacial processes.



Read this paper as a review of the class, and because it will be on your final exam.

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IS THERE LIFE ON THIS PLANET?

The search for a topographic signature of life

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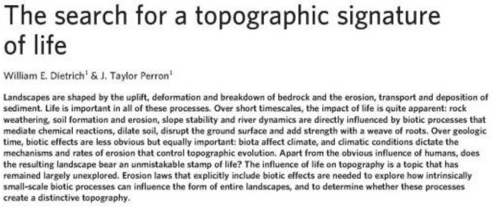

The search for a topographic signature of life

William E. Dietrich[1] & J. Taylor Perron[1]

Landscapes are shaped by the uplift, deformation and breakdown of bedrock and the erosion, transport and deposition of sediment. Life is important in all of these processes. Over short timescales, the impact of life is quite apparent: rock weathering, soil formation and erosion, slope stability and river dynamics are directly influenced by biotic processes that mediate chemical reactions, dilate soil, disrupt the ground surface and add strength with a weave of roots. Over geologic time, biotic effects are less obvious but equally important: biota affect climate, and climatic conditions dictate the mechanisms and rates of erosion that control topographic evolution. Apart from the obvious influence of humans, does the resulting landscape bear an unmistakable stamp of life? The influence of life on topography is a topic that has remained largely unexplored. Erosion laws that explicitly include biotic effects are needed to explore how intrinsically small-scale biotic processes can influence the form of entire landscapes, and to determine whether these processes create a distinctive topography.