

Glaciers

- A glacier is a mass of ice on land consisting of compacted and recrystallized snow that flows under its own weight.
- The sea ice of the Arctic Ocean, ice shelves adjacent to Antarctica, and icebergs are not glaciers.
- Glaciers cover 1/10 of Earth's land surface
- The vast glaciers of the **Pleistocene** (1.6 million to 10,000 years before present) **Ice Age** produced many erosional and depositional landforms across much of the Northern Hemisphere.



Wicander and Monroe (2002)

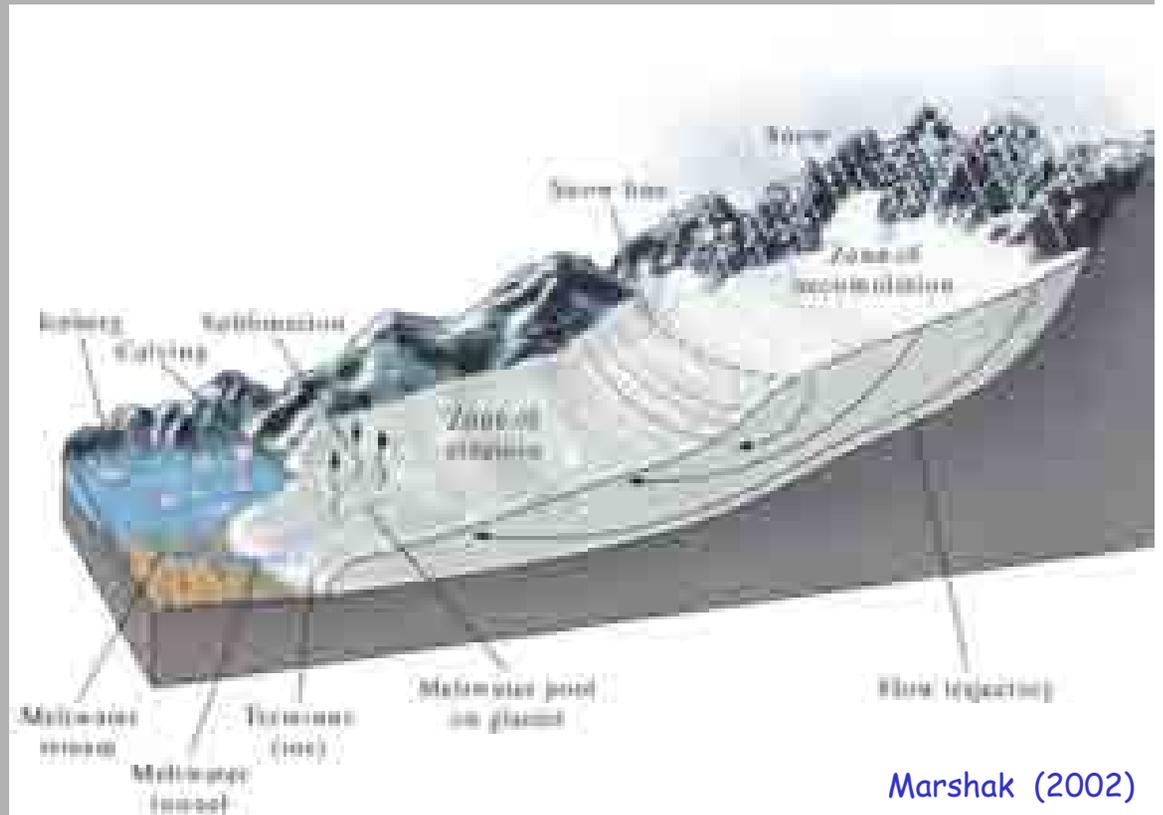
Glaciers & the Hydrologic Cycle

- Glaciers are one of the several reservoirs of the hydrosphere.
- **Glacial ice is formed of the snow that falls over land.**
- **Freshwater may be stored in glaciers as ice for thousands of years before it is eventually returned to the sea, often passing through other reservoirs on its journey.**
- In the Western U.S. and Canada, glaciers help supply streams with water during the dry season.



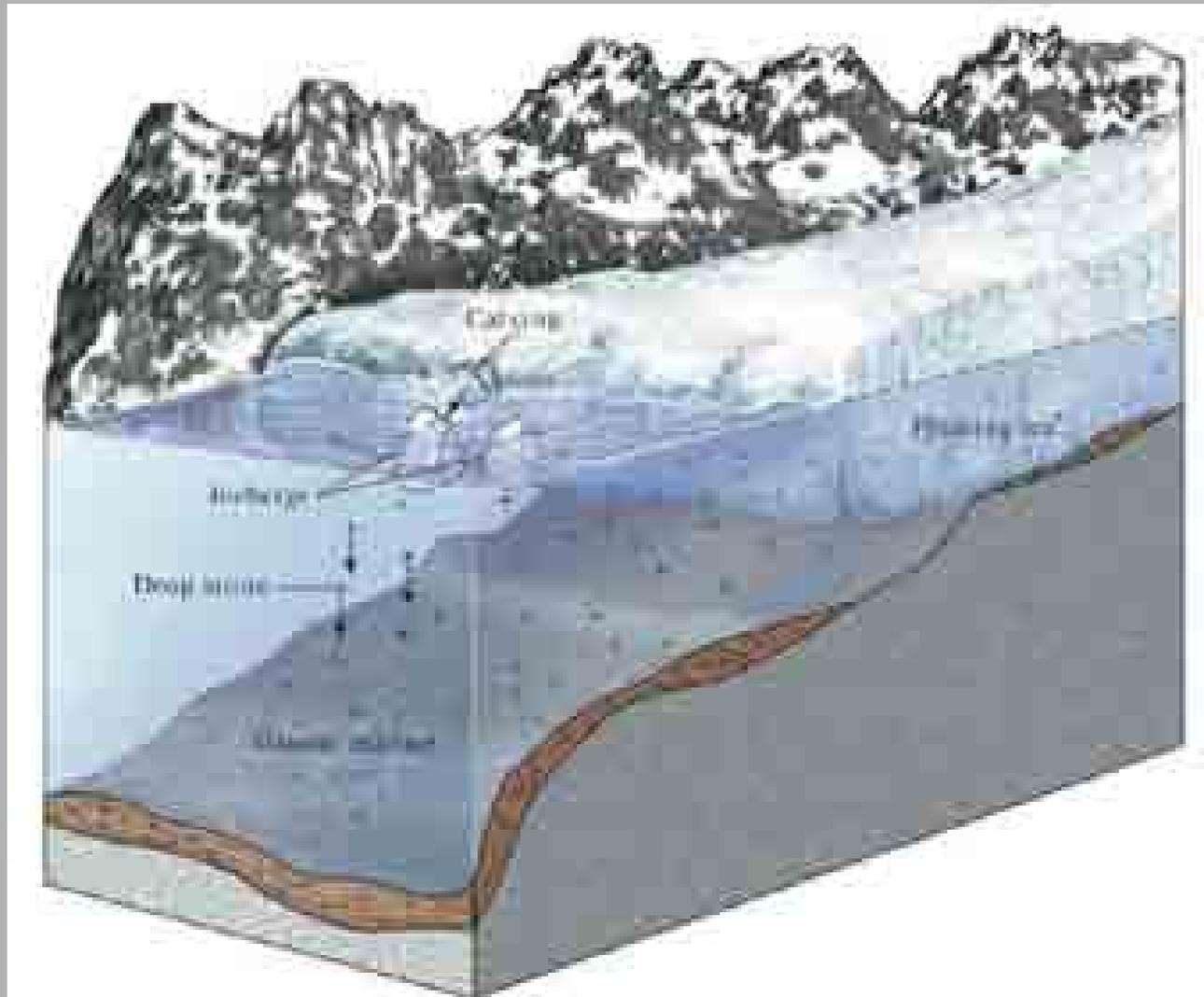
Origin of glaciers

- Once the snow pack reached ~30m it will begin to behave as a viscous fluid and “flow” downhill. This plastic flow is restricted to the base of the glacier while the upper layers remain brittle
- Glaciers ablate, or waste away by melting or calving.



Marshak (2002)

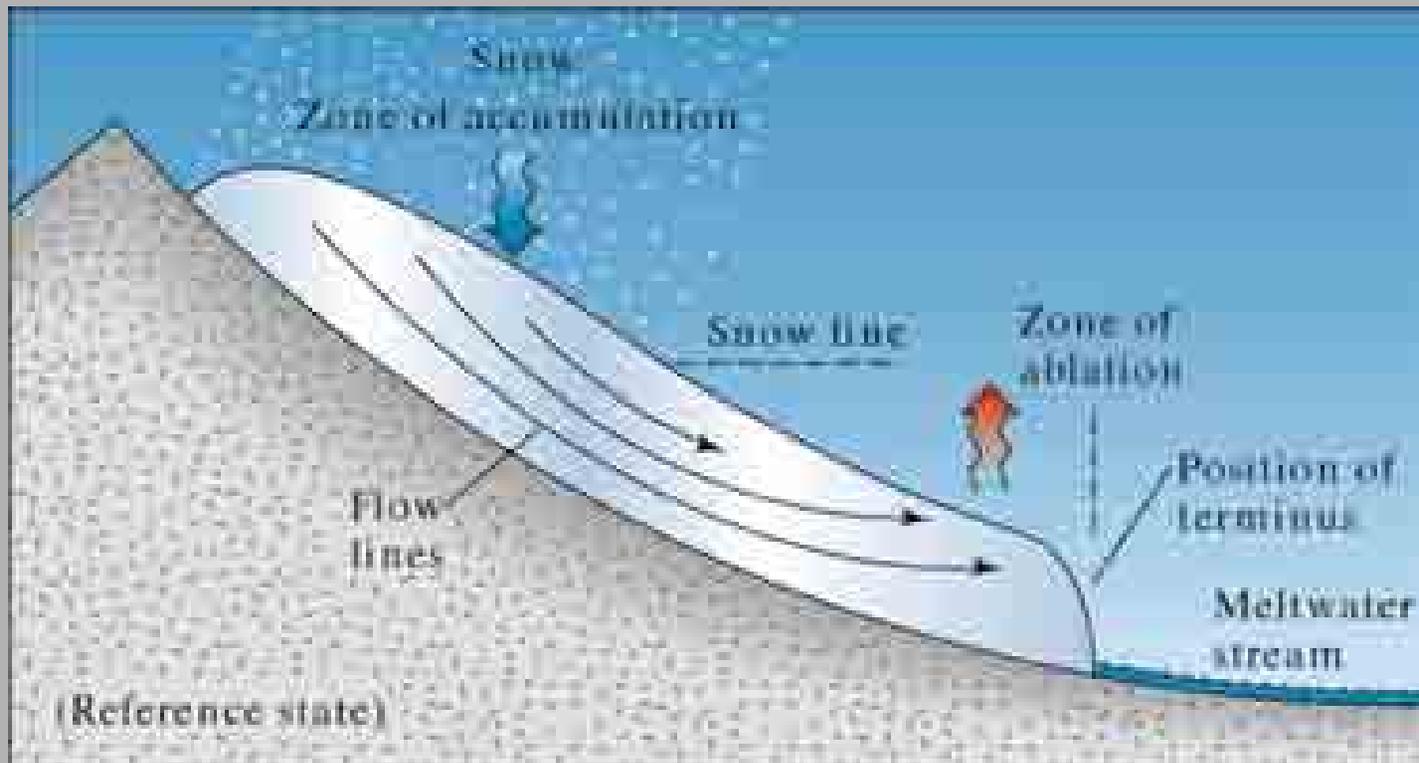
Calving



Marshak (2002)

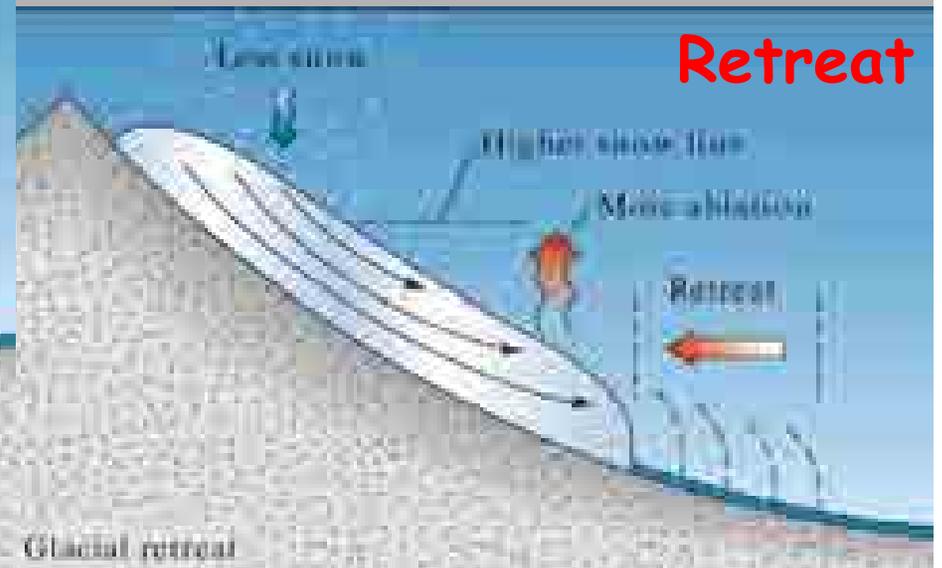
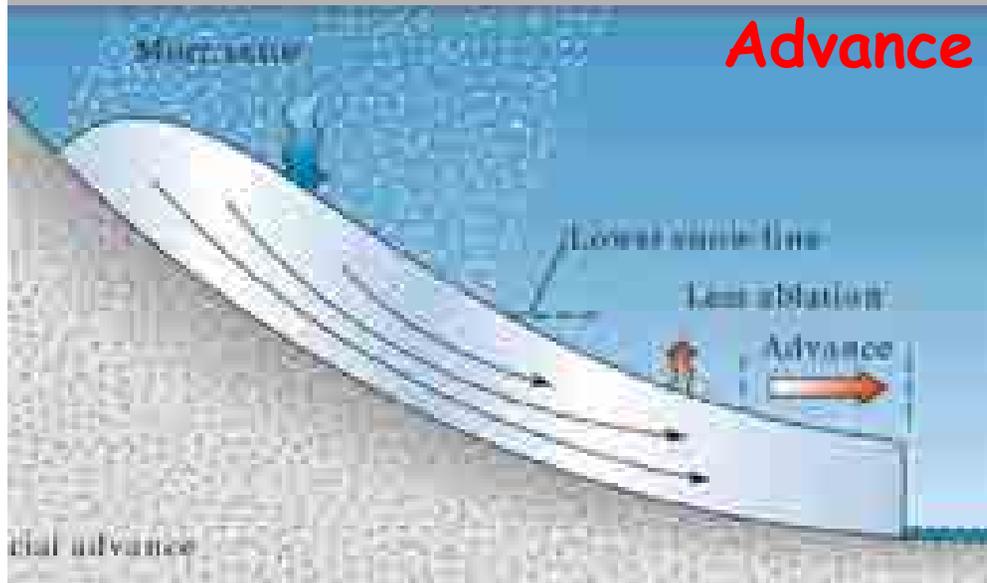
Origin of glaciers

- **Glaciers move at rates of a few metres to 10s of metres per day depending on the slope, however they also retreat or advance within the valley**



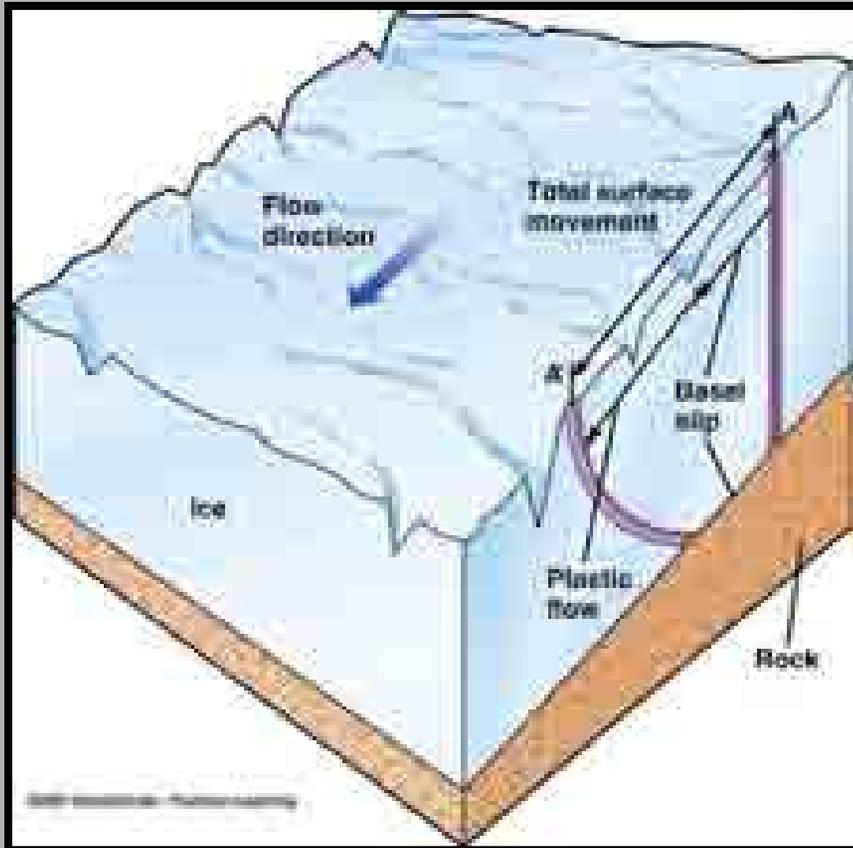
Origin of glaciers

- **If the rate of melting is less than the rate of glacier advance then the glacier will advance, if it is not then the glacier will retreat. Glaciers typically retreat in the summer and advance in the winter. Global climate change can modify this process**



Marshak (2002)

How Do Glaciers Move?

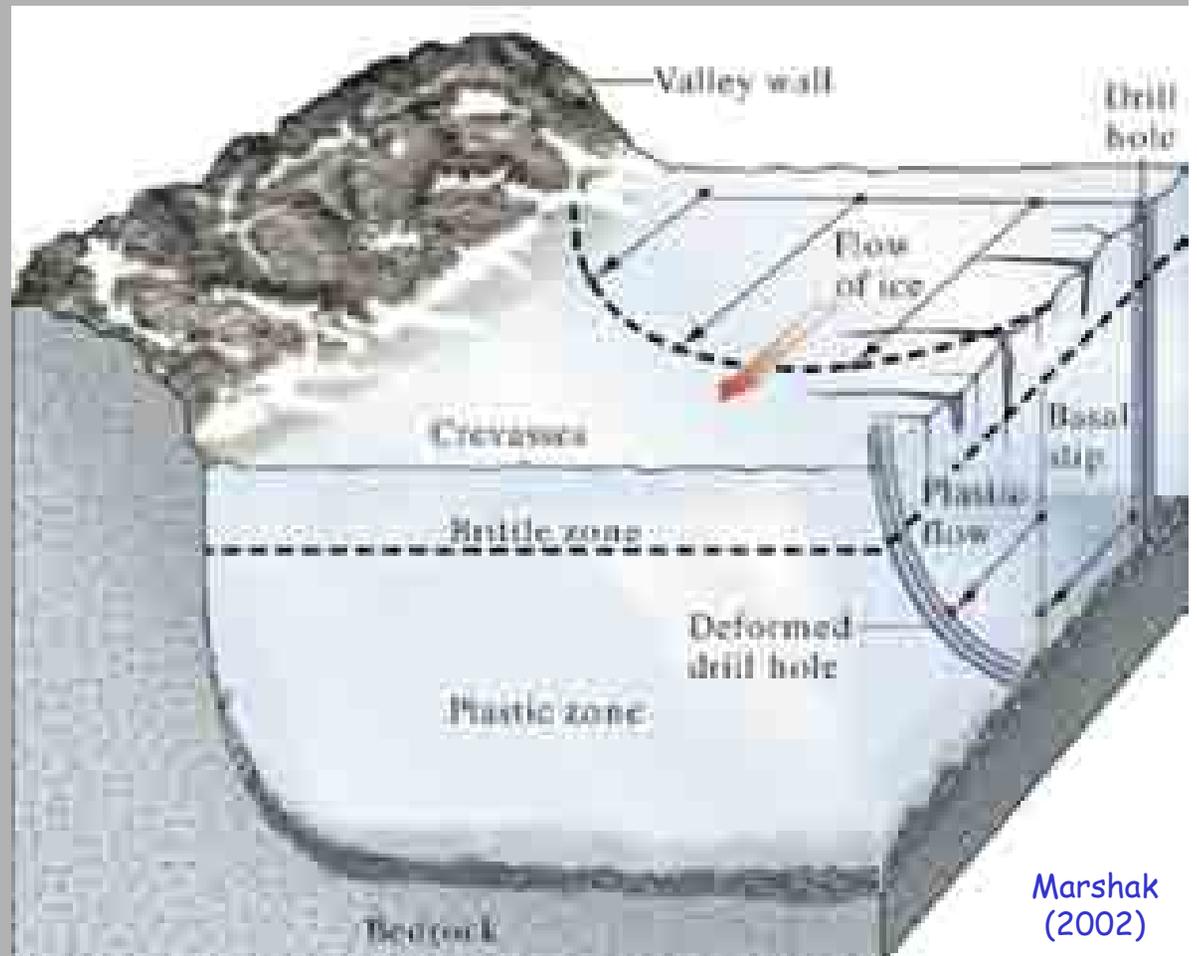


- When snow and ice reach a critical thickness of about 30m, the stress/pressure on the ice at depth is great enough to induce plastic flow. Plastic flow is a type of permanent deformation that involves no fracturing. As the ice deforms by plastic flow, the glacier slowly moves.

Wicander and Monroe (2002)

How do glaciers move?

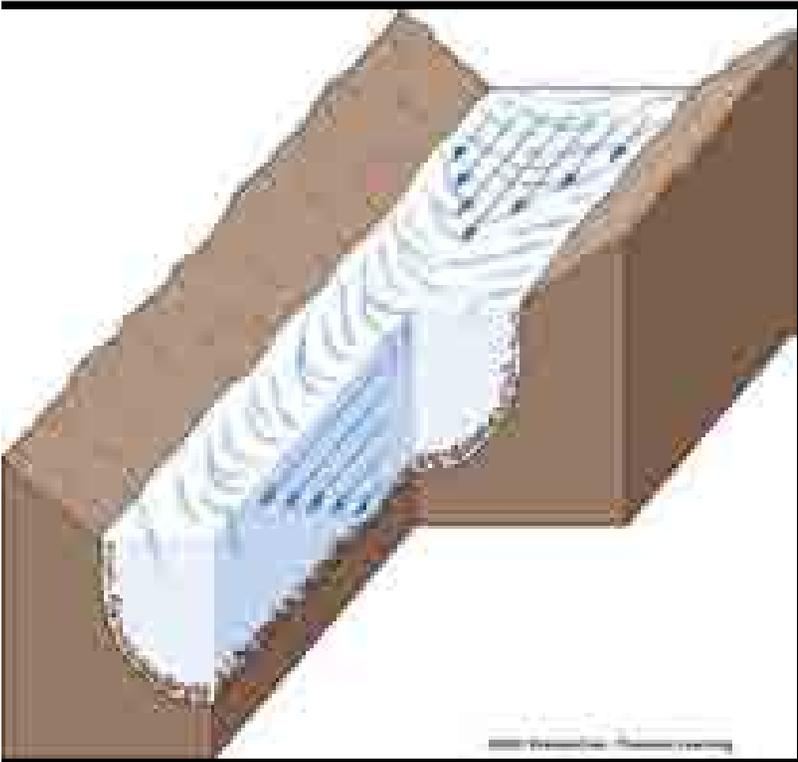
Glaciers also slide along the surface of the material they overlie in a process called **basal slip**, which is greatly aided by the lubricating effect of water. Basal slip is sporadic and varies depending on season, but plastic flow is continuous and the primary means by which glaciers move.



Marshak
(2002)

How Fast Do Glaciers Move?

- **Valley glaciers flow more rapidly than continental glaciers, both ranging from cms to 10s of meters/day.**
- **Valley glaciers move faster because basal slip contributes to their movement during the warm season. Continental glaciers are frozen to the underlying surface most of the time and undergo little basal slip.**
- **Flow rate within ice increases down the glacier toward the firn limit, and then decreases from the firn limit toward the terminus. For valley glaciers, flow velocity is greatest at the top-center of the ice tongue and lowest along the edges and base where friction retards flow.**



Wicander and Monroe (2002)

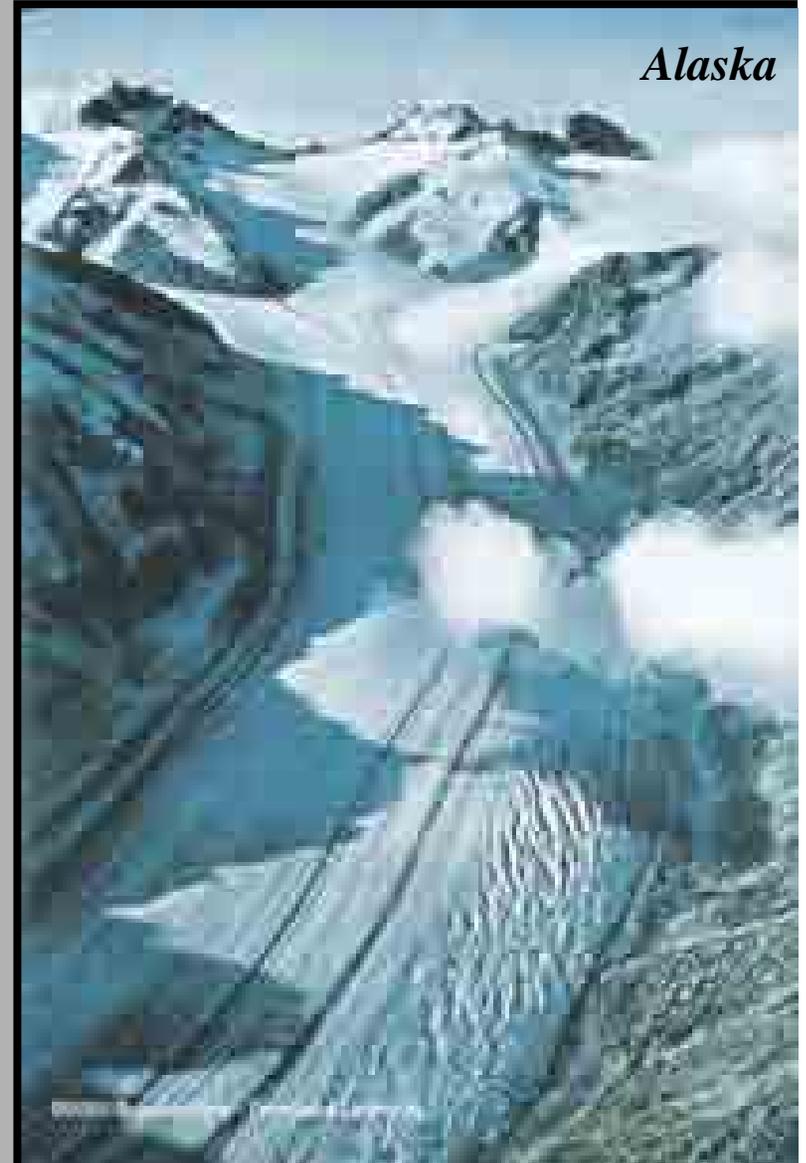
Types of glaciers.



Chernicoff & Whitney (2002)

Types of Glaciers

- **Valley glaciers are tongues of ice confined to mountain valleys through which they flow from higher to lower elevation.** Like streams, many valley glaciers have smaller tributary glaciers.
- Valley glaciers may be several kilometers wide, 200 km long, and hundreds of meters thick. The Bering Glacier of Alaska is about 200 km long, and the Saskatchewan Glacier in Canada is 555 m thick.

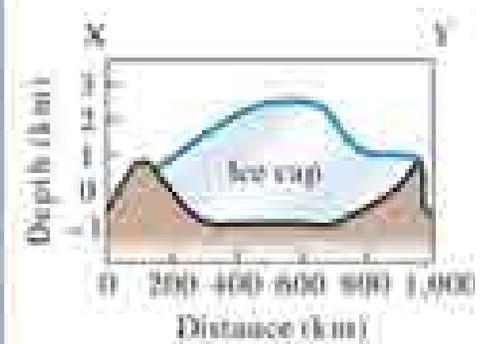
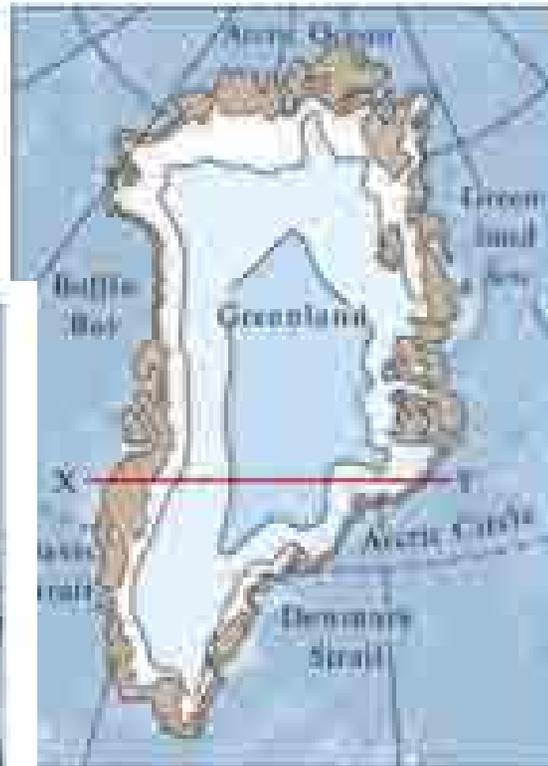


Types of Glaciers

- **Continental glaciers, or ice sheets, cover at least 50,000 km² and are unconfined by topography.** Continental glaciers are blanket-like accumulations of snow and ice that drape the land surface and flow outward in all directions from a central area of greatest thickness toward thinner areas along the margins.
- Continental glaciers are currently found in Antarctica and Greenland where their thickness exceeds 3000 m. During the Ice Age, continental glaciers covered much of North America and Eurasia.



Icesheets



Marshak (2002)

Erosion and Transport

- Glaciers are moving solids and can erode and transport huge amounts of material, especially **sediment, and soil**.
- **Bulldozing** takes place as a glacier shoves or pushes unconsolidated material along its path. **Plucking** results when glacial ice freezes in the crevices of a bedrock projection and eventually pulls loose blocks of the rock. **Abrasion** takes place as bedrock underlying a glacier is eroded by the flowing sediment-laden ice.
- Most of the sediment carried by continental glaciers is concentrated at the base of the ice and derived from the materials across which they flow. **Valley glaciers carry sediment in all parts of the ice. Much of their sediment is supplied by mass wasting along valley walls.**

Erosion and Transport



Marshak (2002)



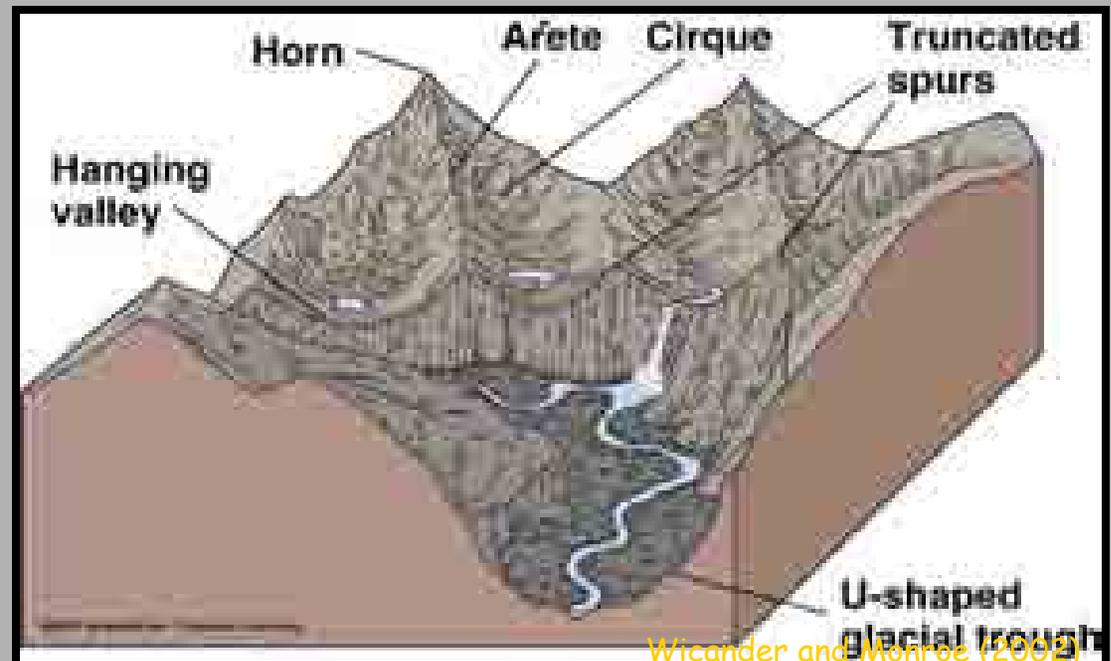
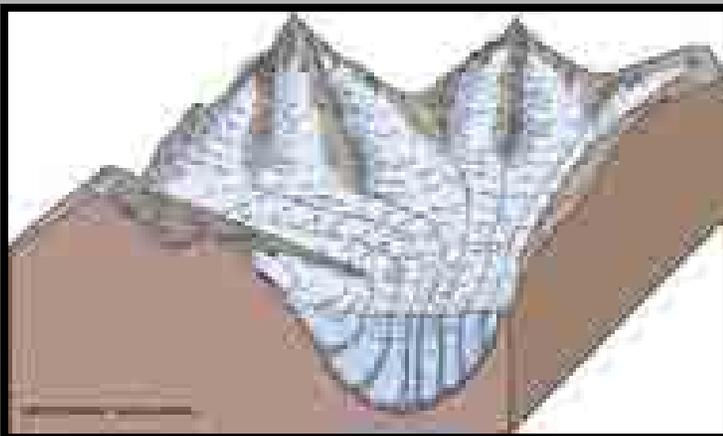
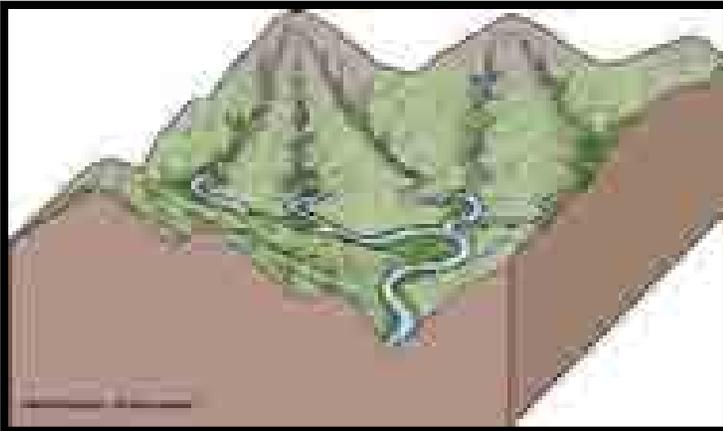
Michigan

- Abrasion of bedrock by sediment-laden glacial ice produces **glacial polish**, a smooth surface that glistens in reflected light.
- Abrasion can also produce **glacial striations**, straight scratches a few mm deep on rock surfaces
- Abrasion grinds rocks to clay- and silt-size particles collectively known as **rock flour**. This material gives glacial streams a milky look.

Wicander and Monroe (2002)

Erosion by Valley Glaciers

Some of the world's most inspiring scenery was erosionally sculpted by valley glaciers. When peaks and V-shaped stream-cut valleys of mountain ranges are modified by valley glaciers, a landscape of angular ridges and peaks in the midst of a broad valley is formed. Among these features are horns, aretes, cirques, etc.



Wicander and Monroe (2002)

A U-shaped valleys

Bighorn Mountains, Wyo.-Mont.



Wicander and Monroe (2002)

U-shaped glacial troughs are one of the most distinctive features of valley glaciation. Glaciers deepen, widen, and straighten V-shaped stream valleys to form broad, steep-sided valleys (left). Many glacial troughs contain triangular-shaped truncated spurs, cut off ridges that extend into the original valley. **Fiords are glacial troughs that were flooded by the sea.**

U-shaped valleys & fjords



Wicander and Monroe (2002)

Hanging valleys

Hanging valleys are glaciated tributary valleys whose floors are higher than that of the main valley. Large glaciers in the main valley erode more vigorously than smaller glaciers in tributary valleys. When the glaciers disappear, the floors of tributary valleys are left high above the floor of the main valley. Streams flowing from these hanging valleys produce beautiful water falls, such as Bridal Veil Falls in Yosemite National Park, California.



A

Cirques



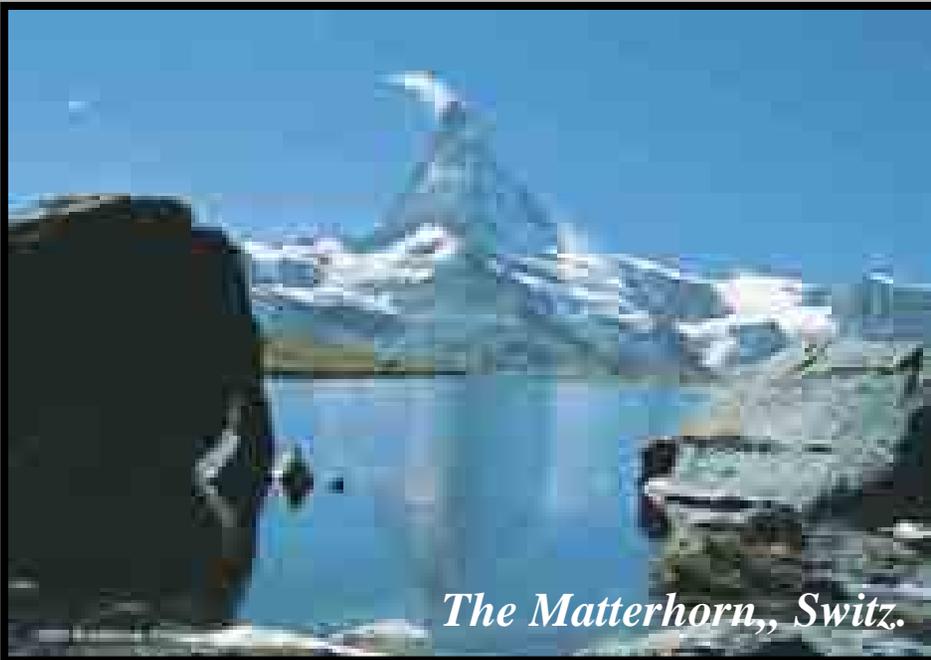
- **Cirques are bowl-shaped depressions at the heads of glacial troughs (left).**
- **Cirques are steep-walled on three sides, but one side is open and leads to the glacial trough.**
- **Many cirques contain small lakes known as **tarns**.**

Arêtes

- **Arêtes** are narrow, serrated, knife-edge ridges forming a thin partition between two cirques or adjacent parallel glacial troughs
- **Horns** are pyramidal, steep-walled mountain peaks formed by headward erosion of cirques. To form, a horn must have at least three cirques on its flanks

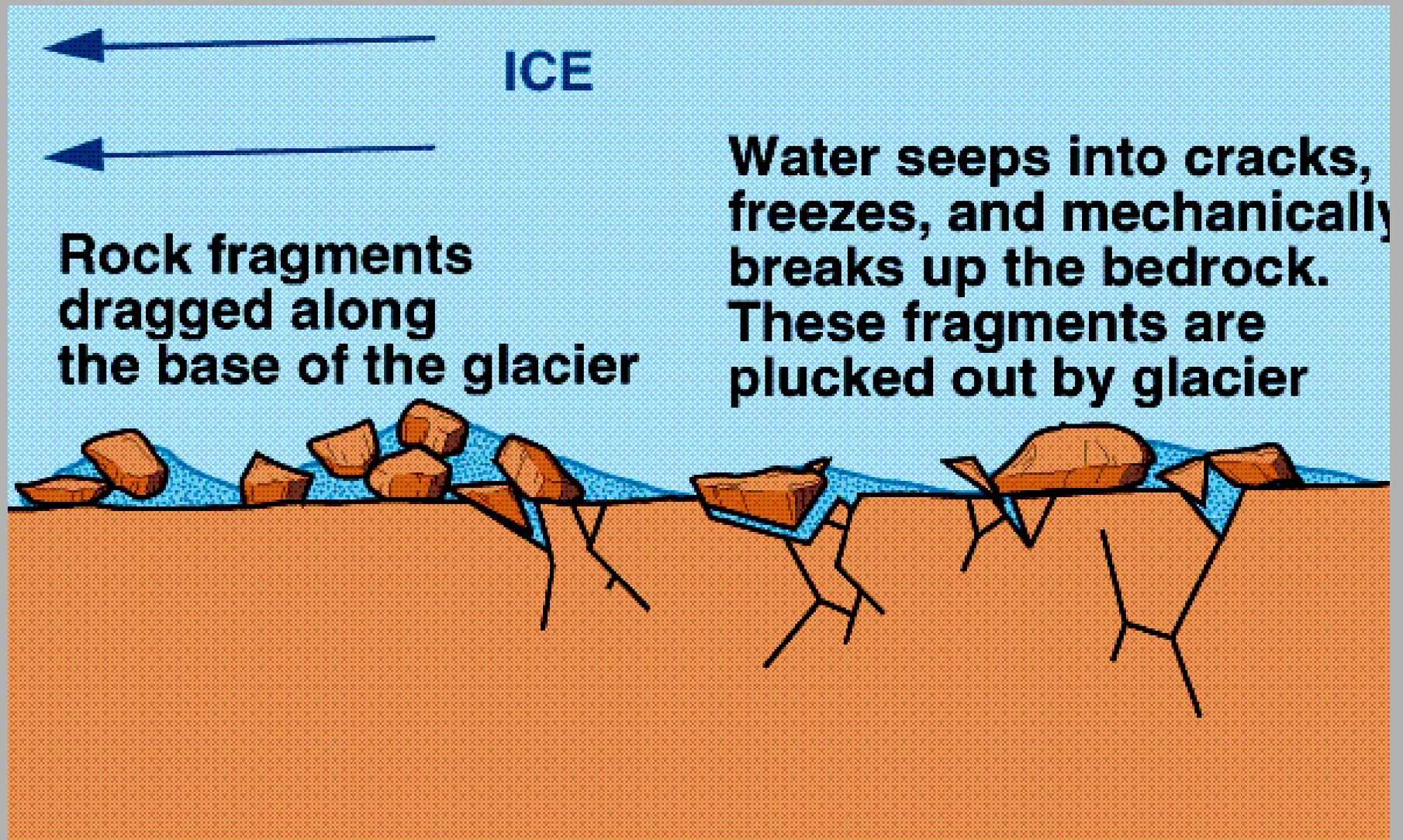


California

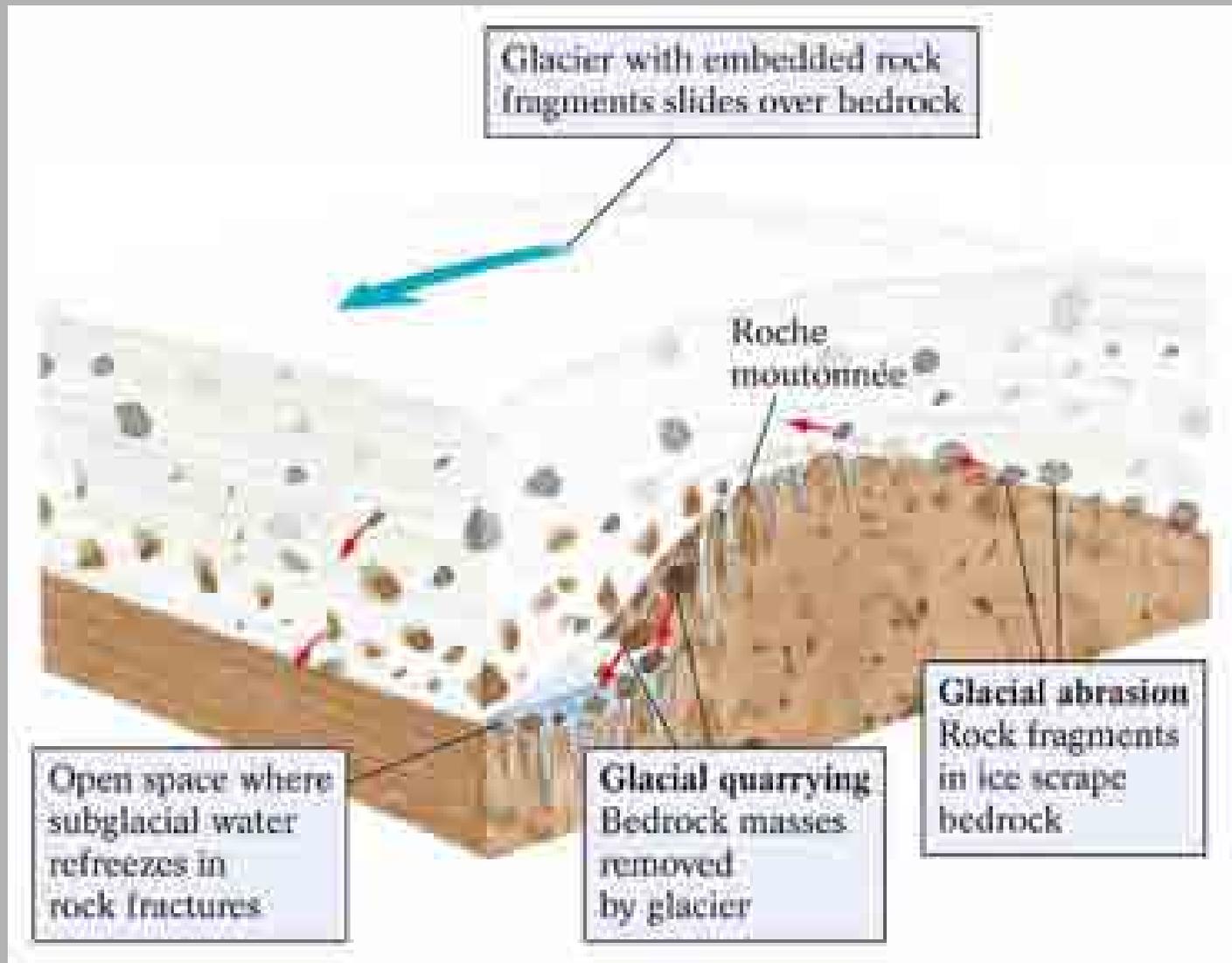


The Matterhorn,, Switz.

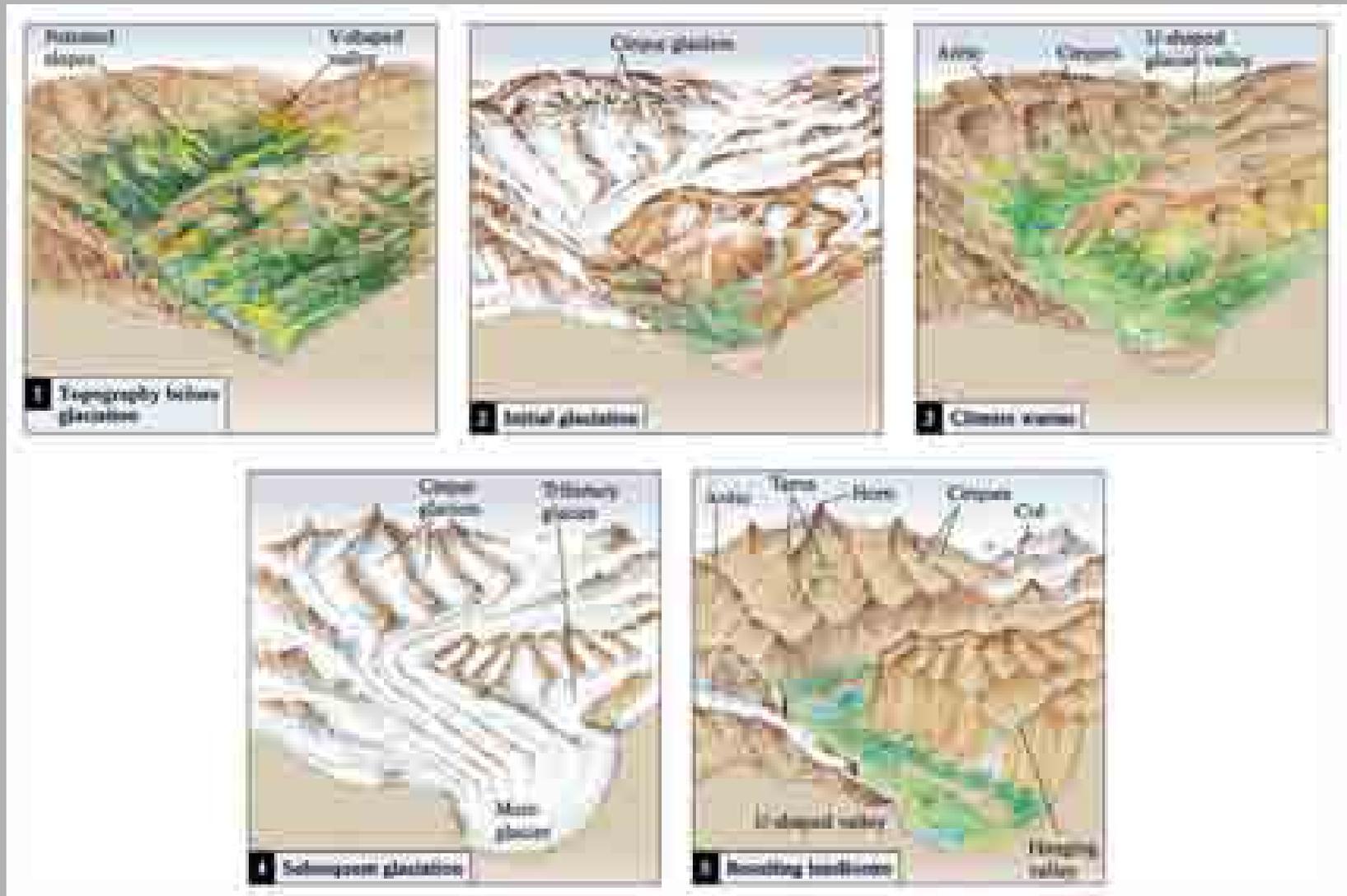
Plucking and abrasion



Roche moutonnée.



Effects of Alpine glaciation



Erosion by Continental Glaciers

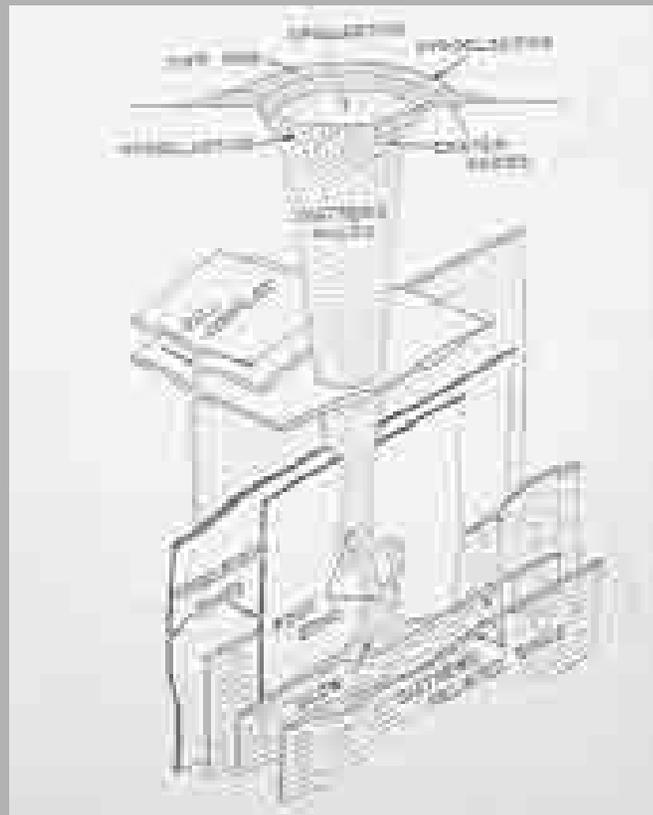
- Erosion by continental glaciers produces smooth and rounded landscapes. High areas that project into the ice are beveled and abraded to form a relatively flat topography interrupted by rounded hills. Ice-scoured plains characterized by deranged drainage with numerous lakes and swamps, extensive bedrock exposures, and little or no soil are an example of erosion by continental glaciers.



Northwest Territories, Canada

Wicander and Monroe (2002)

How this erosion helps geologist's find Kimberlites!



Mitchell, 1986

The Indicator Mineral Train

Pyrope Garnet

Diamonds

Mantle Xenolith





Pyrope Garnet,
Clinopyroxene, Olivine,
Ilmenite



Till Sampling

Frost Boil



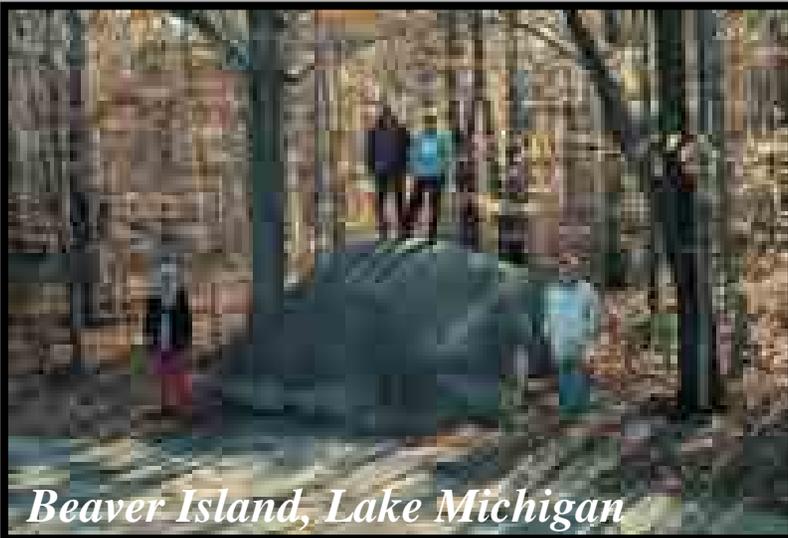




Glacial Deposits



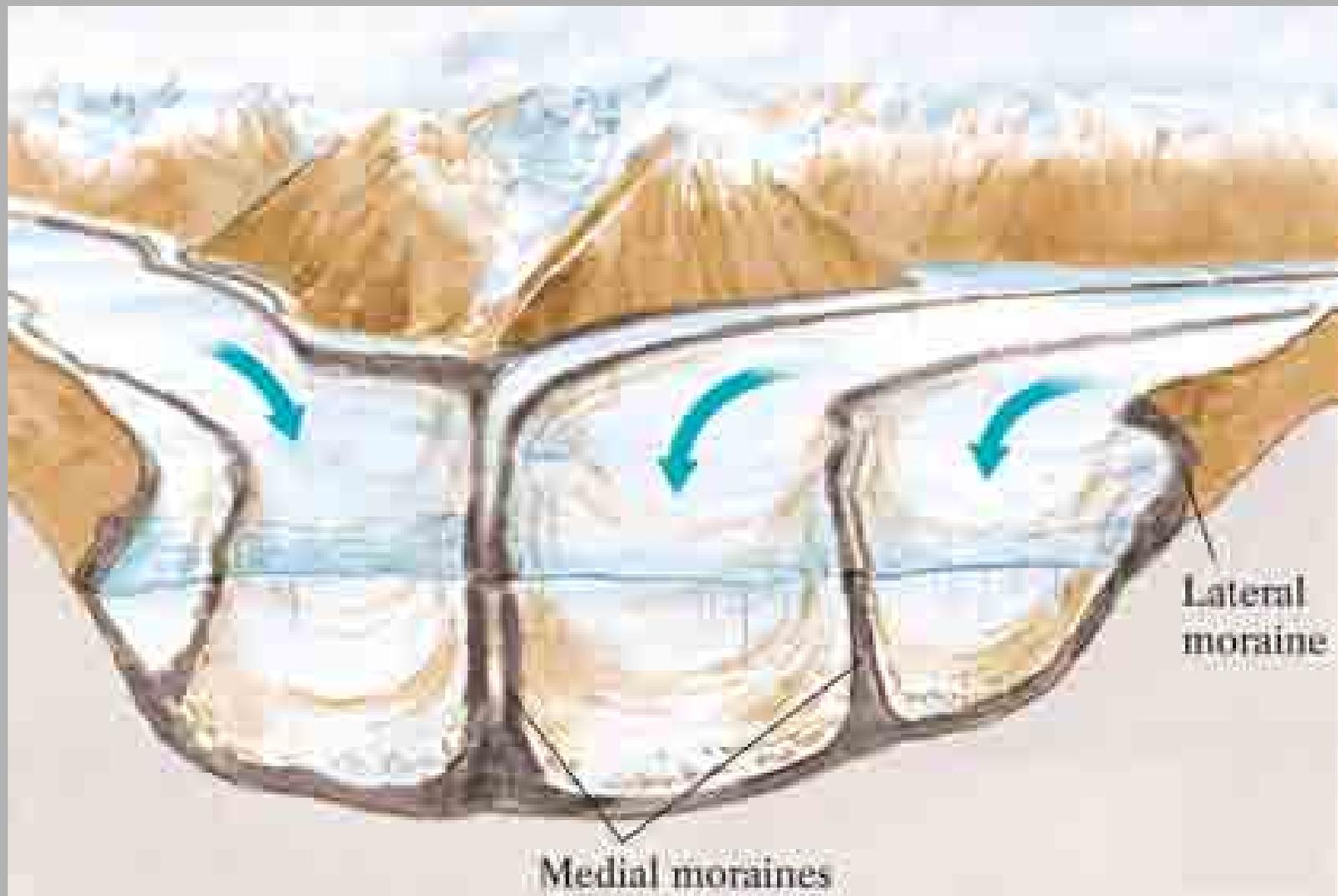
Hammond, New York



Beaver Island, Lake Michigan

- Both valley and continental glaciers deposit their sediment load as **glacial drift**, a general term for glacially deposited material. A vast sheet of glacial drift of the Pleistocene Epoch blankets the northern U.S. and adjacent Canada.
- **Erratics** are boulders eroded and transported by glaciers and deposited in areas from which they were obviously not derived. **Till** is poorly sorted sediment deposited by glacial ice. Stratified drift is layered, sorted sediment deposited by flowing meltwater.

Moraines.

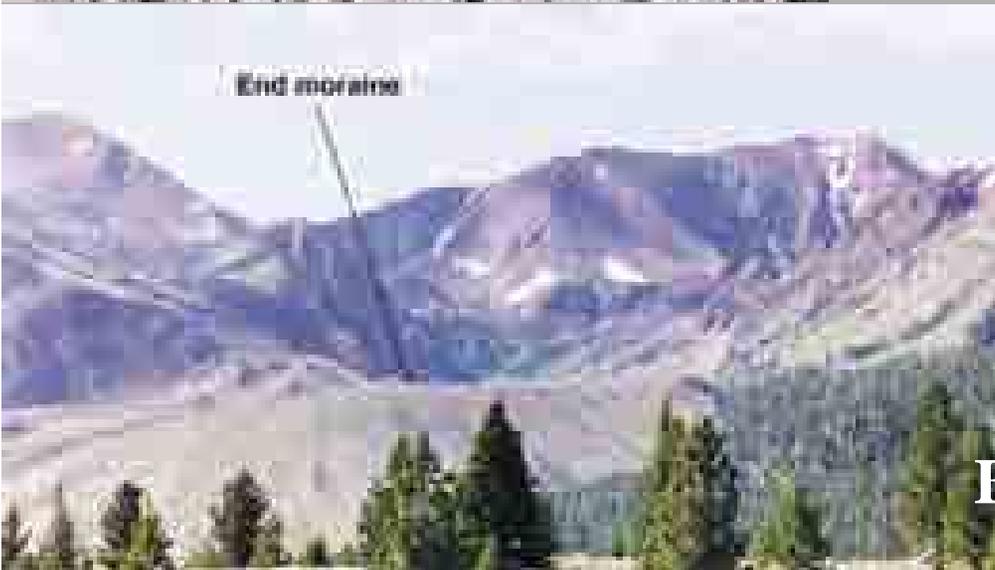


Landforms Composed of Till



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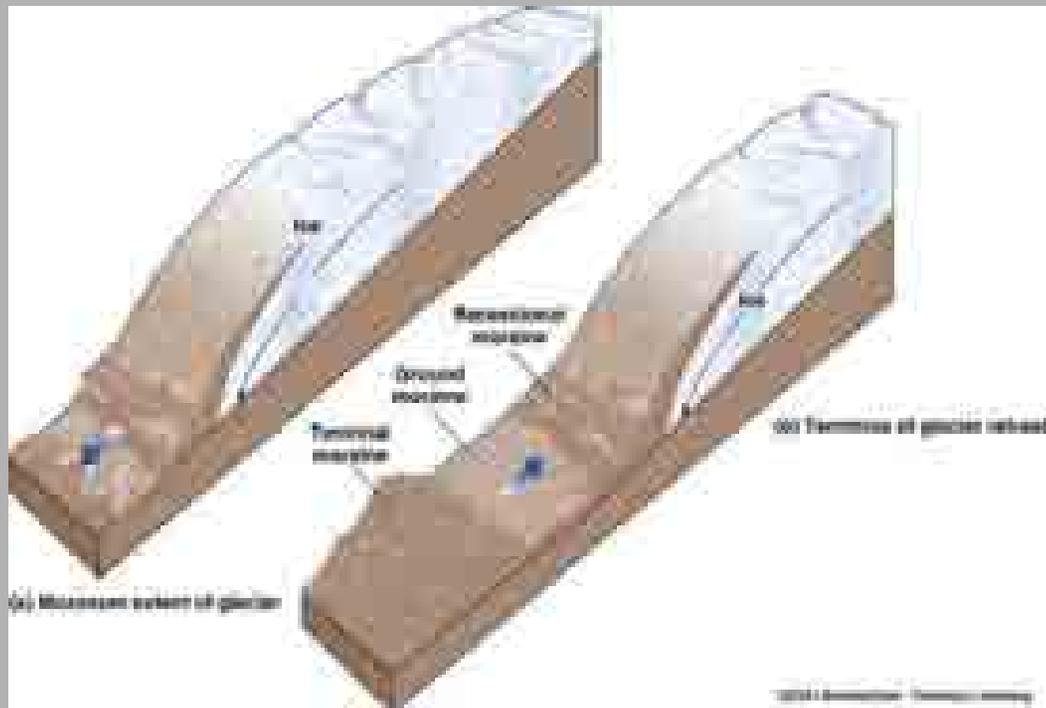
- End moraines are piles of poorly sorted sediment, till, delivered by flowing ice to the terminus of a stationary glacier. They are deposited by both valley and continental glaciers.
- As the sediment is dumped, an end moraine builds up to form crescent-shaped hills fringing the ice margin.



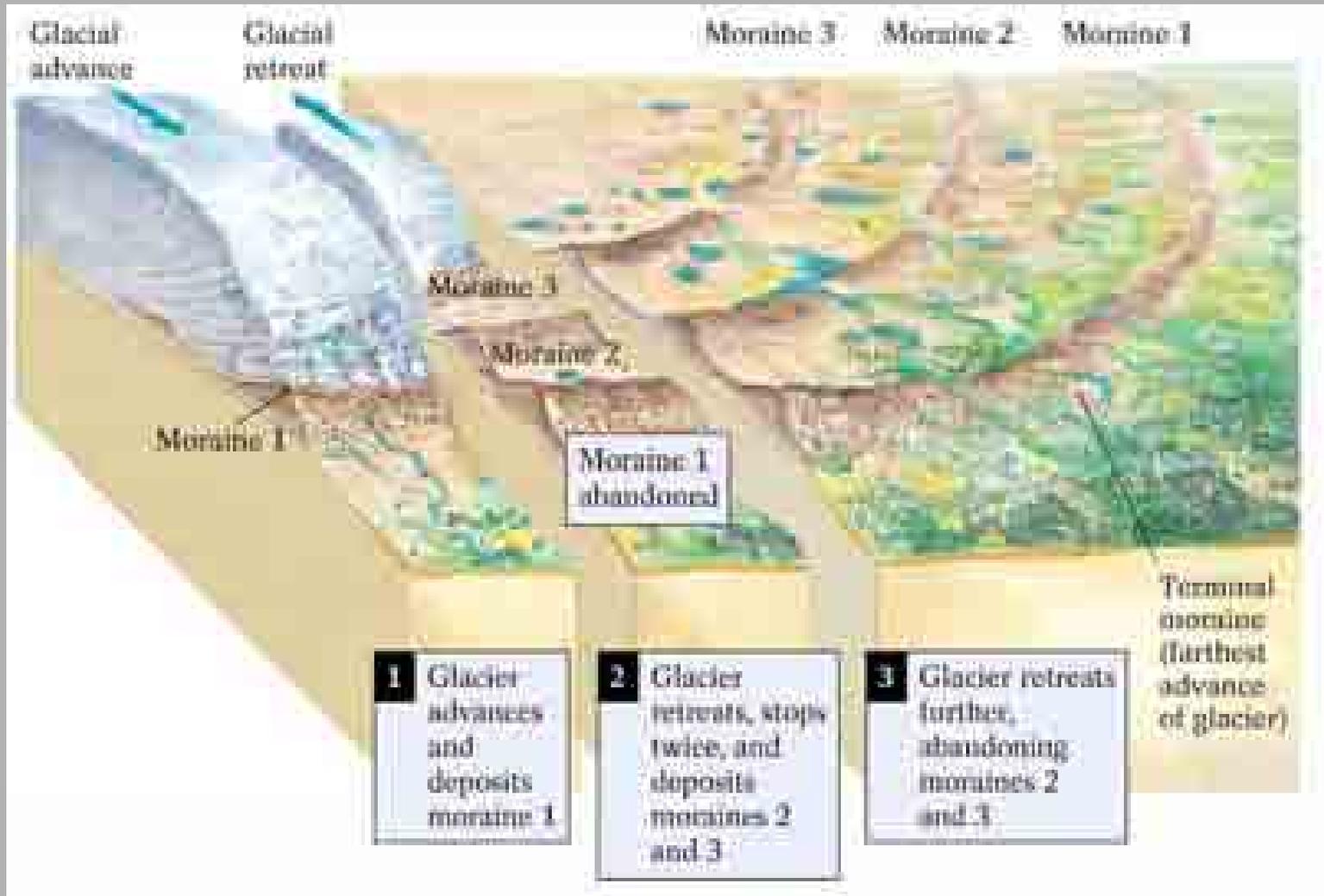
B

Morraines

- The outermost end moraines deposited when the glacier was at its greatest extent are called **terminal moraines**. If the glacier recedes and eventually stabilizes at a new location, an **end moraine** known as a **recessional moraine accumulates at the terminus**. Ground moraines are deposited as glaciers recede and sediment is liberated from the melting ice. Ground moraines have an irregular, rolling topography.



Deposition of moraines.



A

Moraines



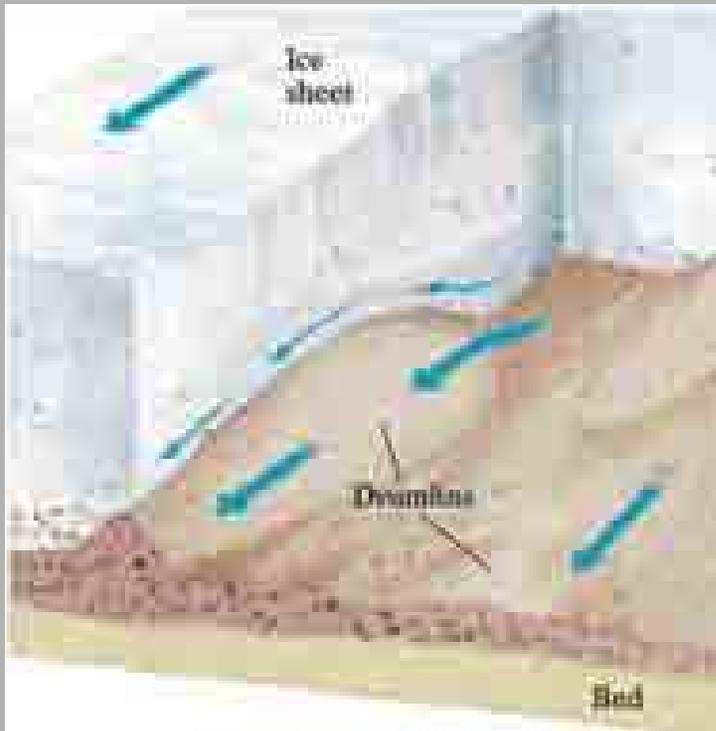
Wicander and Monroe (2002)

- **Lateral and medial moraines are produced by valley glaciers.** Lateral moraines are long ridges of till deposited along the edges of the glacier
- **Medial moraines** occupy positions that were near the center of the valley glacier. Medial moraines form by the coalescence of the lateral moraines of two tributary glaciers

Drumlins

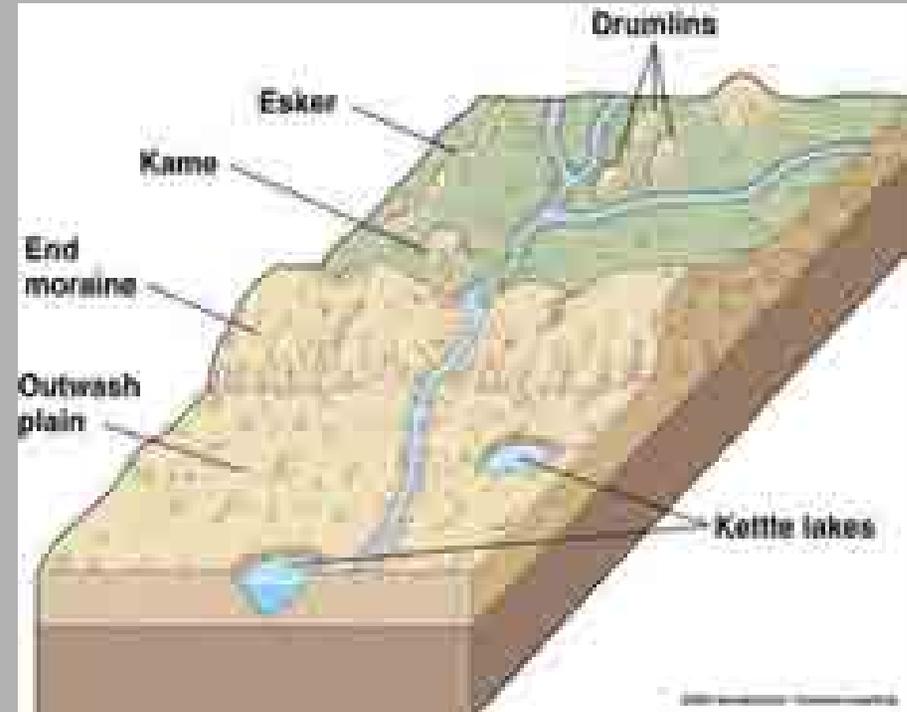
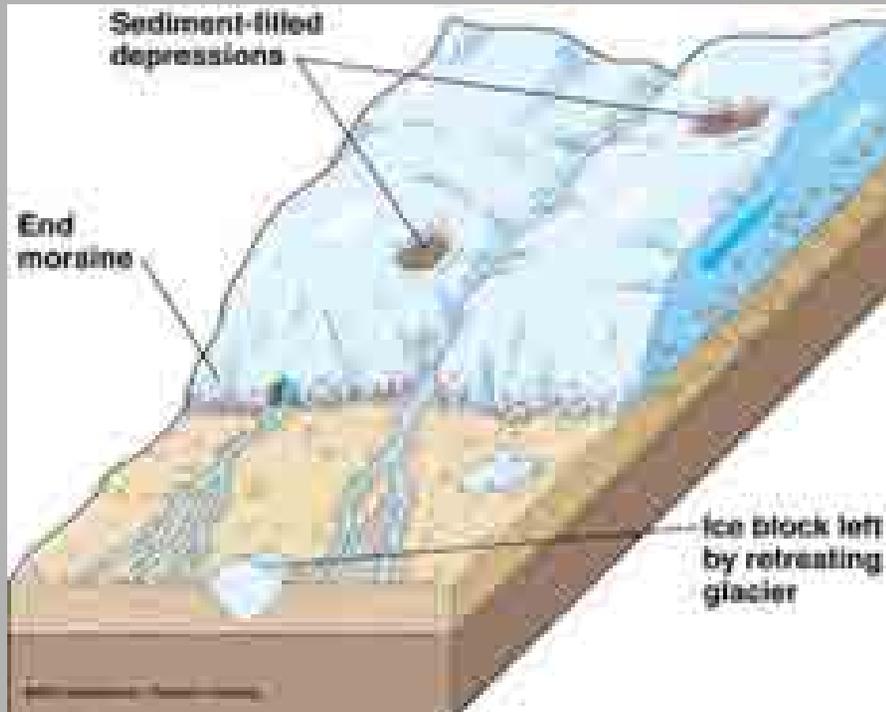
- Drumlins are elongated hills composed of till and shaped like an inverted spoon. Some are 50 m high and 1 km long, but most are smaller. Drumlins occur in drumlin fields containing hundreds or thousands of drumlins.
- **Drumlins are depositional landforms constructed by continental glaciers.**

Chernicoff & Whitney (2002)



Landforms Composed of Drift

- Stratified drift is deposited by both valley and continental glaciers, but is more extensive in areas of continental glaciation.
- Outwash plains, kames, eskers, and kettle lakes are some common landforms formed of or in stratified drift.



Landforms Composed of Drift

- **Outwash plains are vast blankets of stratified drift deposited by braided glacial meltwater streams in front of the terminus of continental glaciers.**
- **Blocks of ice stranded by receding glaciers are buried by sediments of outwash plains and valley trains. Circular to oval depressions formed when the ice blocks melt are kettles. Kettle lakes result when these depressions fill with water. Some outwash plains have so many kettles they are called pitted outwash plains.**

Kames

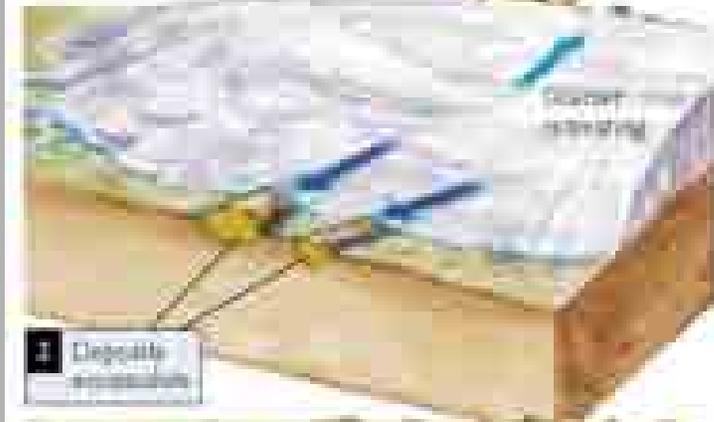


Kames are conical hills up to 50 m high composed of stratified drift (left). Many form when streams deposit sediment in a depression on a glacier's surface; as the ice melts, the deposit is lowered to the ground surface.

Wicander and Monroe (2002)

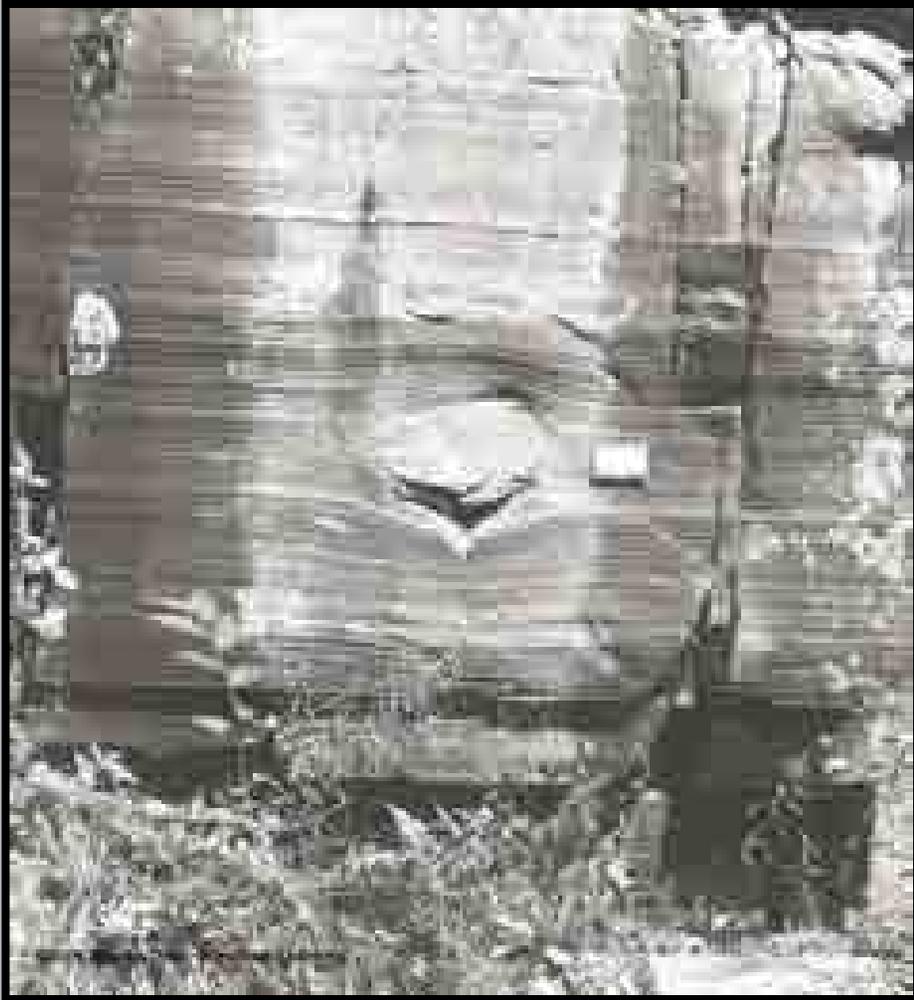
Eskers

Eskers are low, sinuous ridges of stratified drift deposited by streams flowing in tunnels beneath stagnant ice. They range to 100 m in height and 100 km in length.



Chernicoff & Whitney (2002)

Deposits in Glacial Lakes



Wicander and Monroe (2002)

- Proglacial lakes formed by meltwater accumulation along the margins of glaciers such that one shoreline was glacial ice.
- **Varves are proglacial lake deposits consisting of alternating laminations of light and dark fine-grained sediment.** Each light-dark couplet represents one annual cycle of deposition. Light layers formed during spring and summer and consist of silt, whereas dark layers formed during the winter and consist of clay.

Effects of Glaciation

The Pleistocene glaciations have had a significant impact on modern society

- Soil distribution
- Groundwater distribution
- Sea level changes
- Pleistocene lakes
- Isostatic rebound
- Drainage patterns



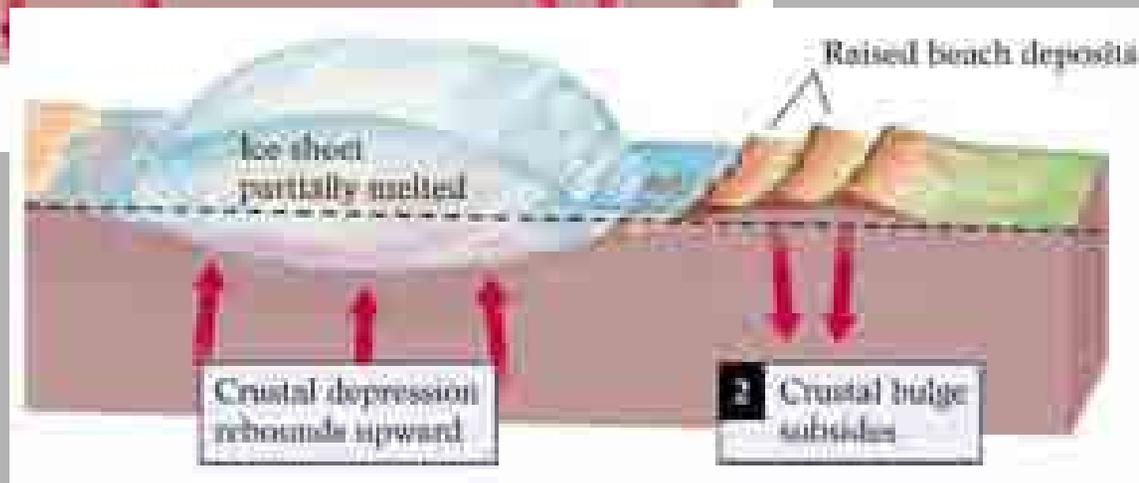
Chernicoff & Whitney (2002)

Effects of Glaciation

- **Groundwater distribution**
 - **Glacial outwash is the sediment deposited by rivers originating at the melting edge of a glacier. Many of these glacial outwash deposits now serve as important groundwater aquifers.**



Crustal rebound.



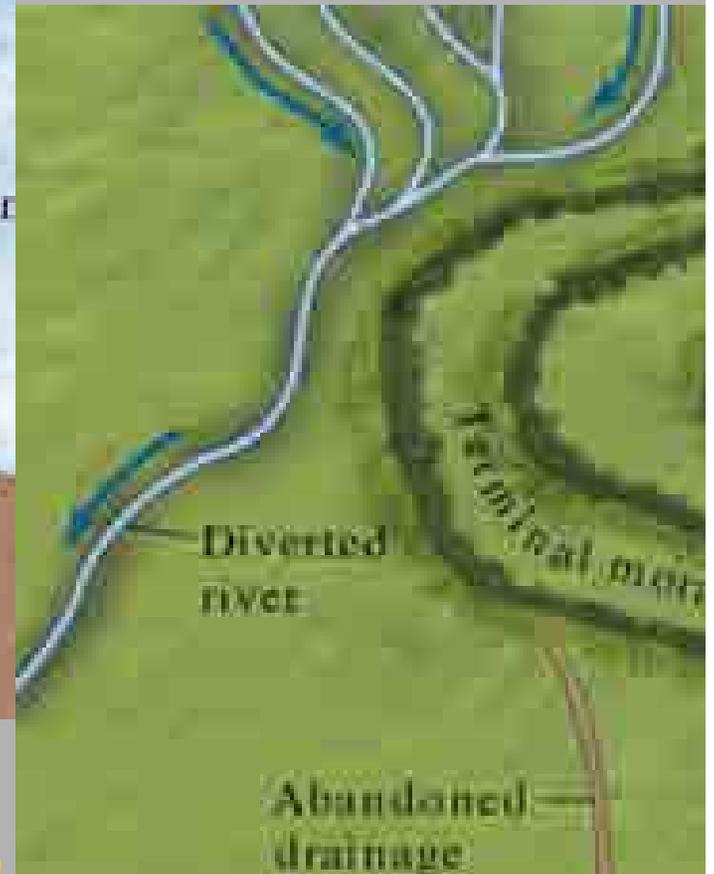
Drainage patterns



Marshak (2002)



Marshak (2002)



Marshak (2002)

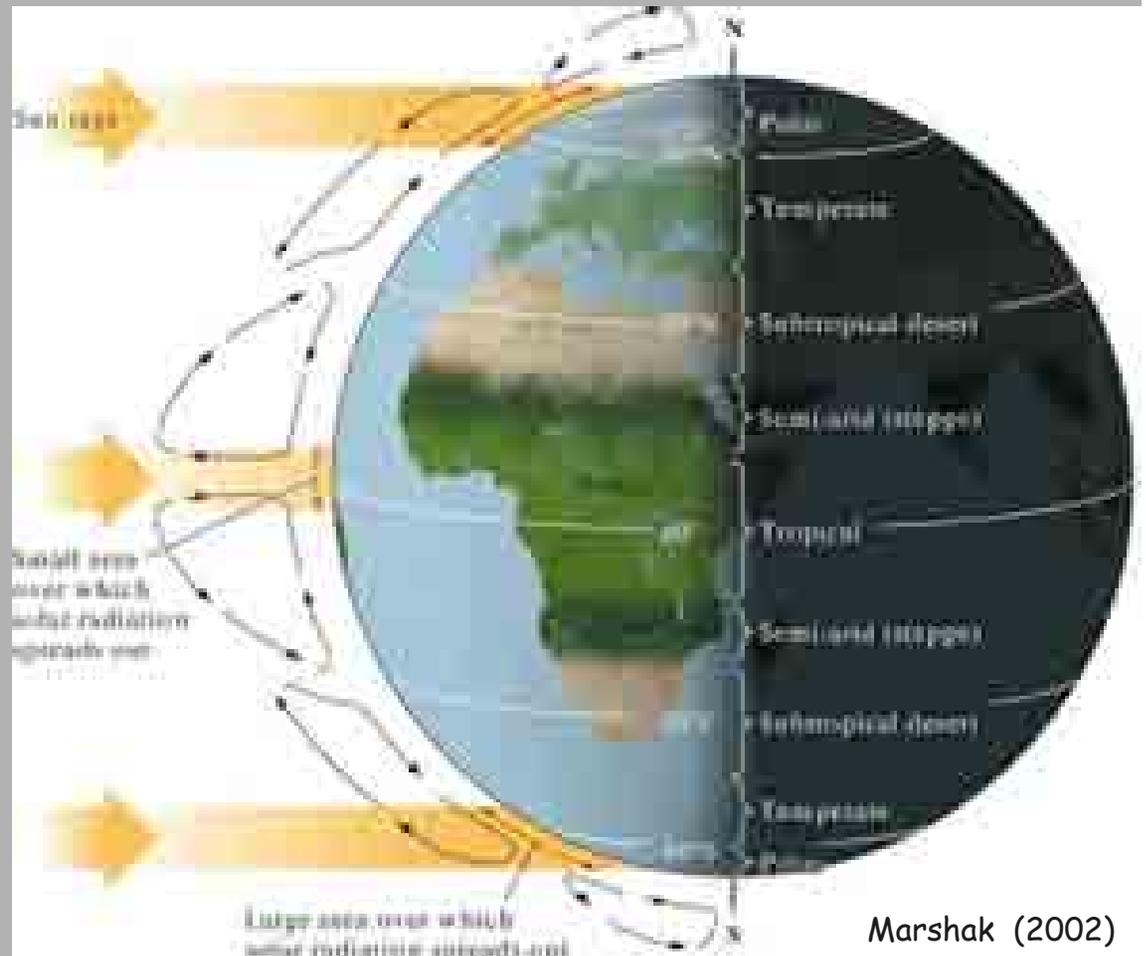
What Causes an Ice Age?

- **Five periods of glaciation (Ice Ages) separated by longer periods of mild climate are recognized in the geologic record. Such long-term climate changes probably resulted from changes in atmospheric and oceanic circulation patterns as well as changes in the geographic position of continents, both driven by plate tectonics.**
- **During the Pleistocene Ice Age, several periods of continental glaciation are recognized, each separated by a warmer interglacial period. These intermediate-term climate changes spanned tens to hundreds of thousands of years and may be explained by the Milankovitch Theory.**
- **Climatic events like the Little Ice Age take place on a scale of centuries and are considered short-term. Hypotheses favoring variations in solar energy and volcanism have been proposed.**

The Milankovitch Theory

- The theory draws on minor irregularities in the Earth's orbit and rotation to explain intermediate-term climate changes and thus the timing of glacial advances and contractions during ice ages.

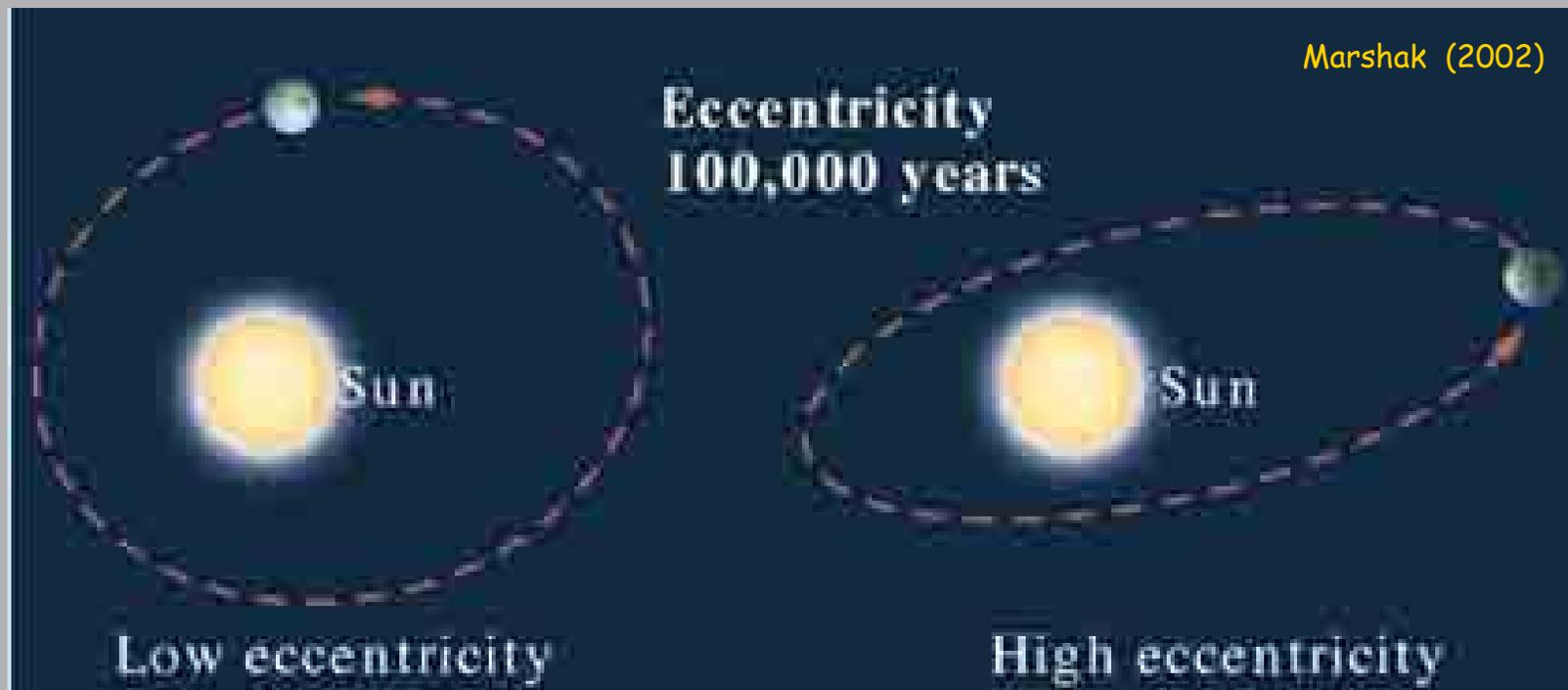
These orbital and rotational irregularities collectively cause the amount of solar heat received at any latitude to vary over time, perhaps triggering onset of glacial-interglacial episodes.



Marshak (2002)

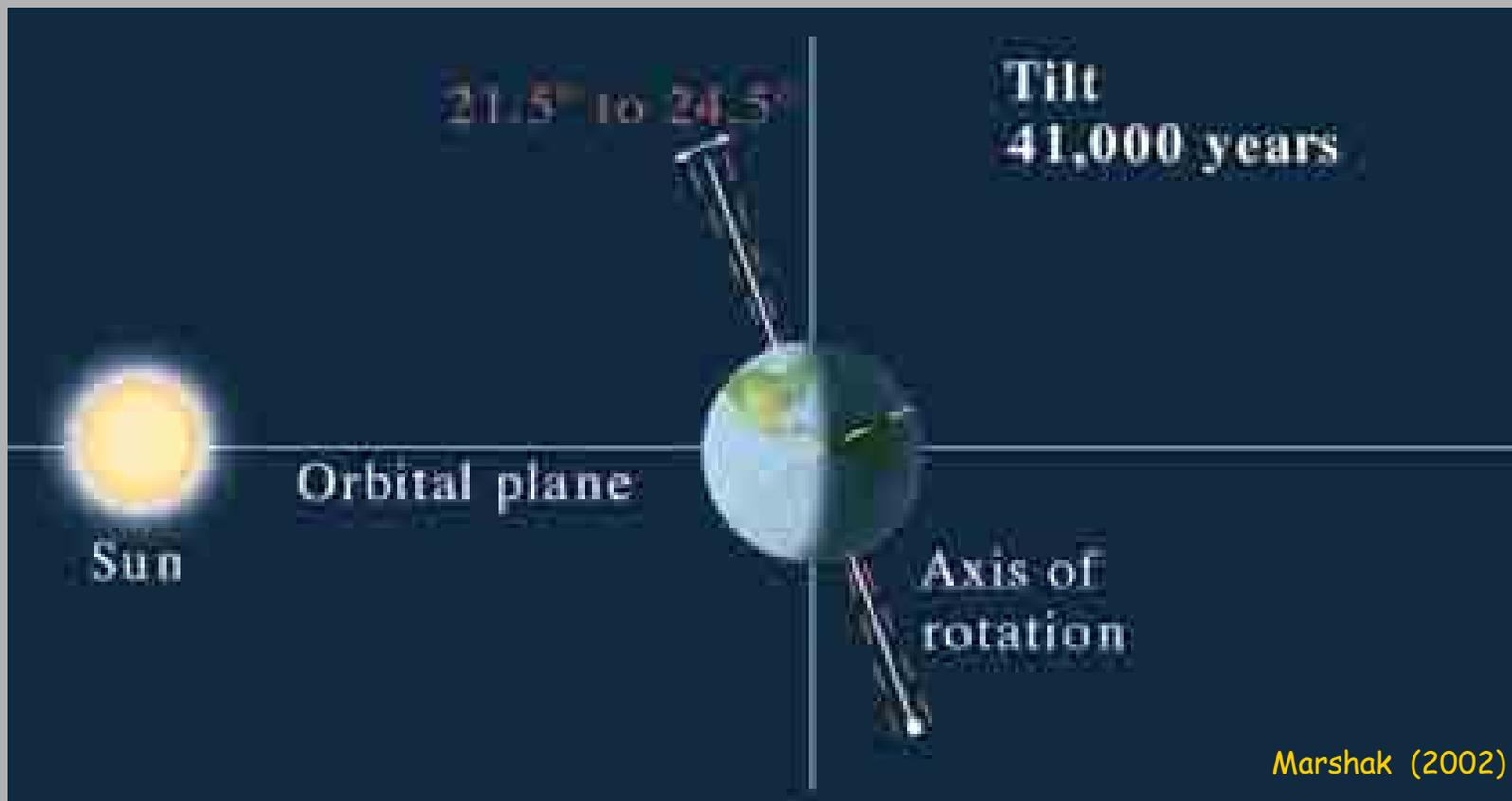
The Milankovitch Theory

- **Orbital eccentricity** refers to the degree to which Earth's solar orbit departs from a perfect circle. Earth's orbit reaches maximum eccentricity every 100,000 years. This corresponds closely to the 20 warm-cold cycles that occurred in the Pleistocene



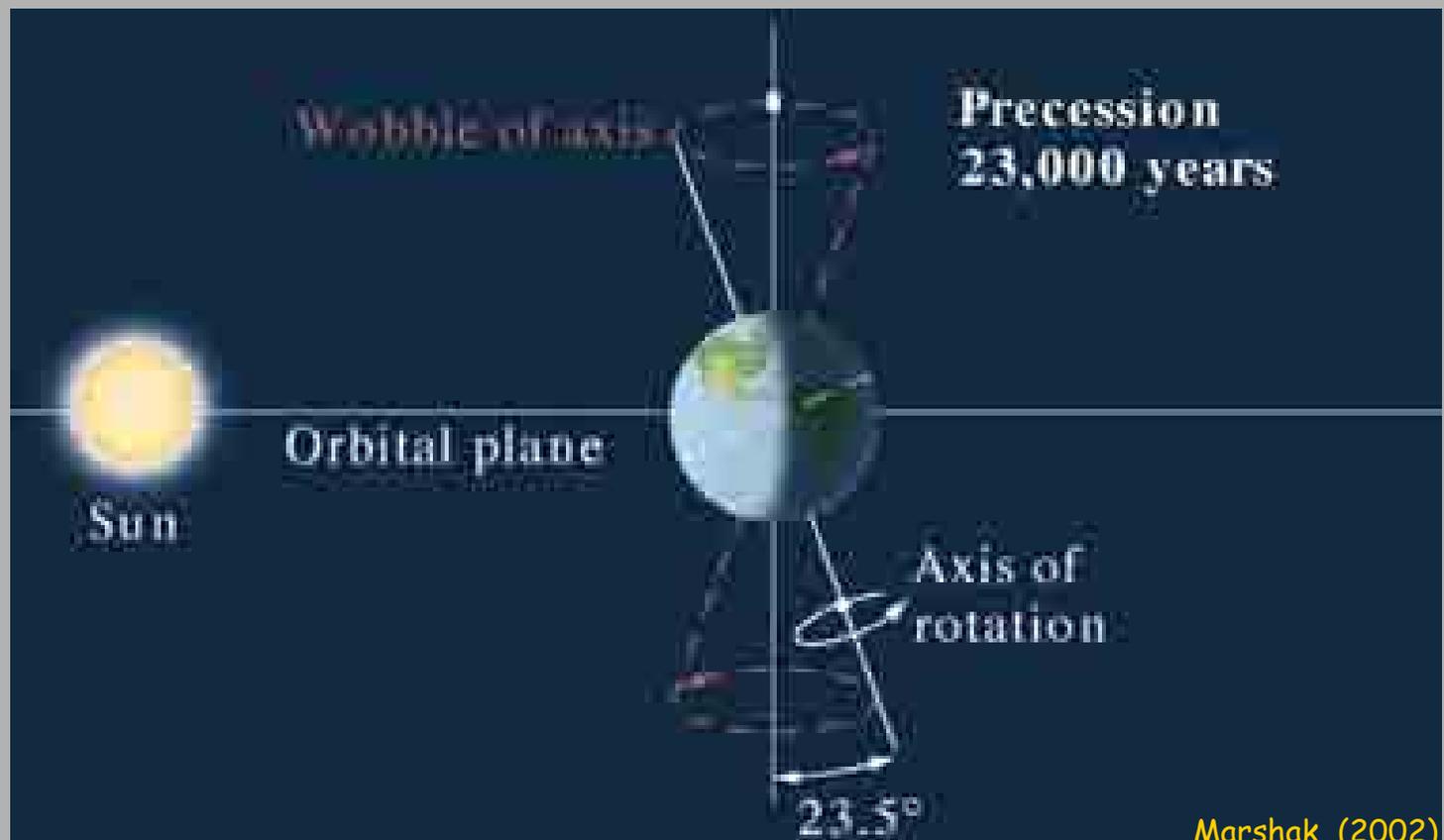
The Milankovitch Theory

- The inclination of Earth's rotational axis shifts about 1.5° on a 41,000 year cycle causing a rotational wobble.



The Milankovitch Theory

Precession concerns the effect resulting from movement of Earth's rotational axis as it traces out the path of a cone in space. This cycle spans 23,000 years and affects Earth's proximity to the Sun in summer and winter

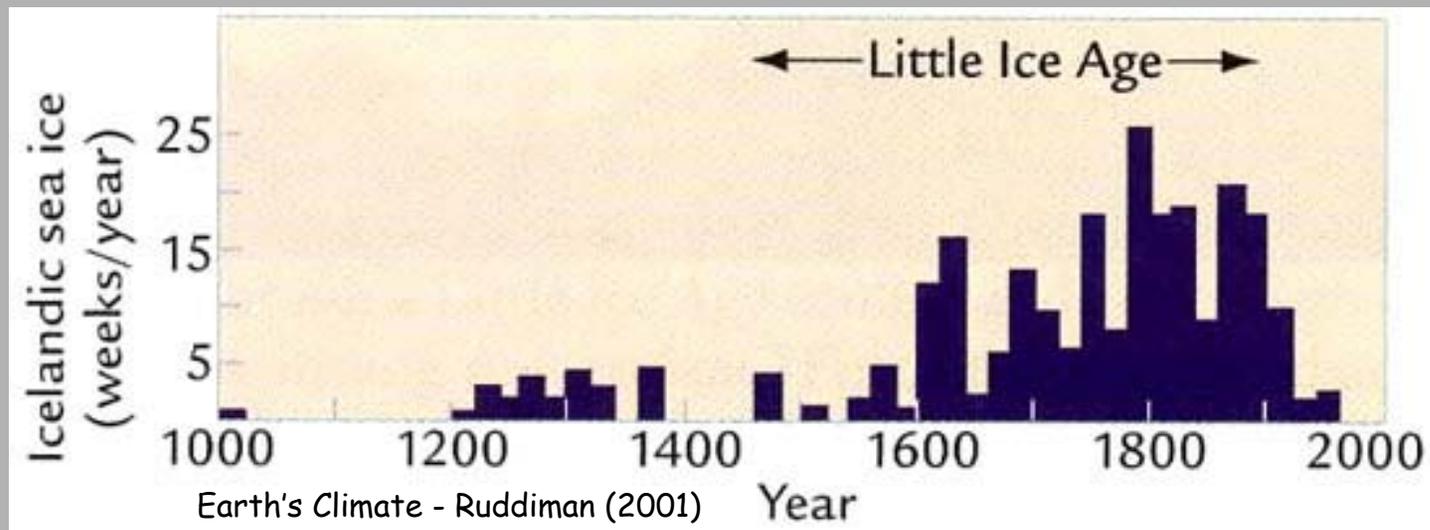


Global climate change

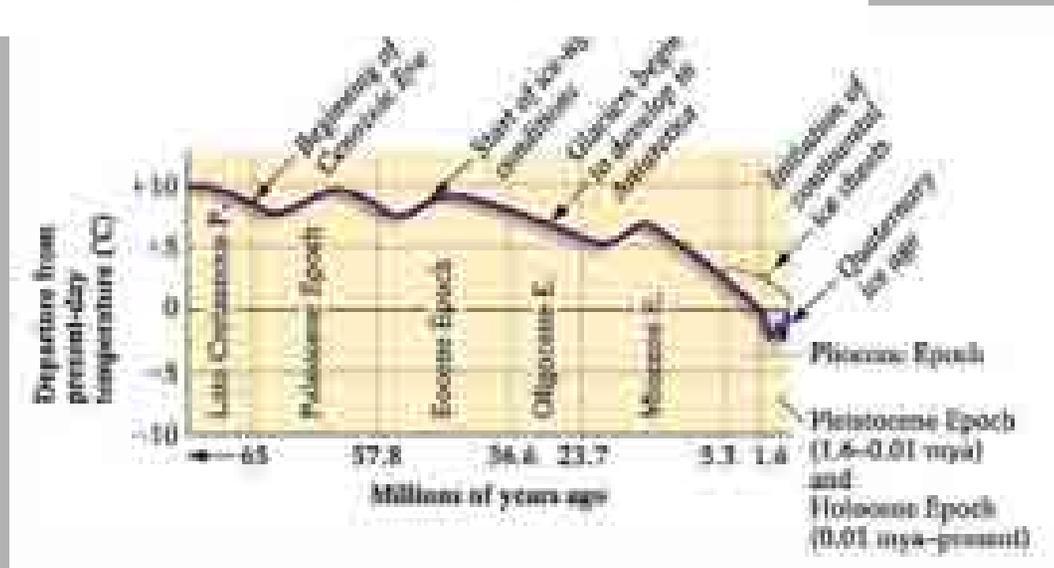
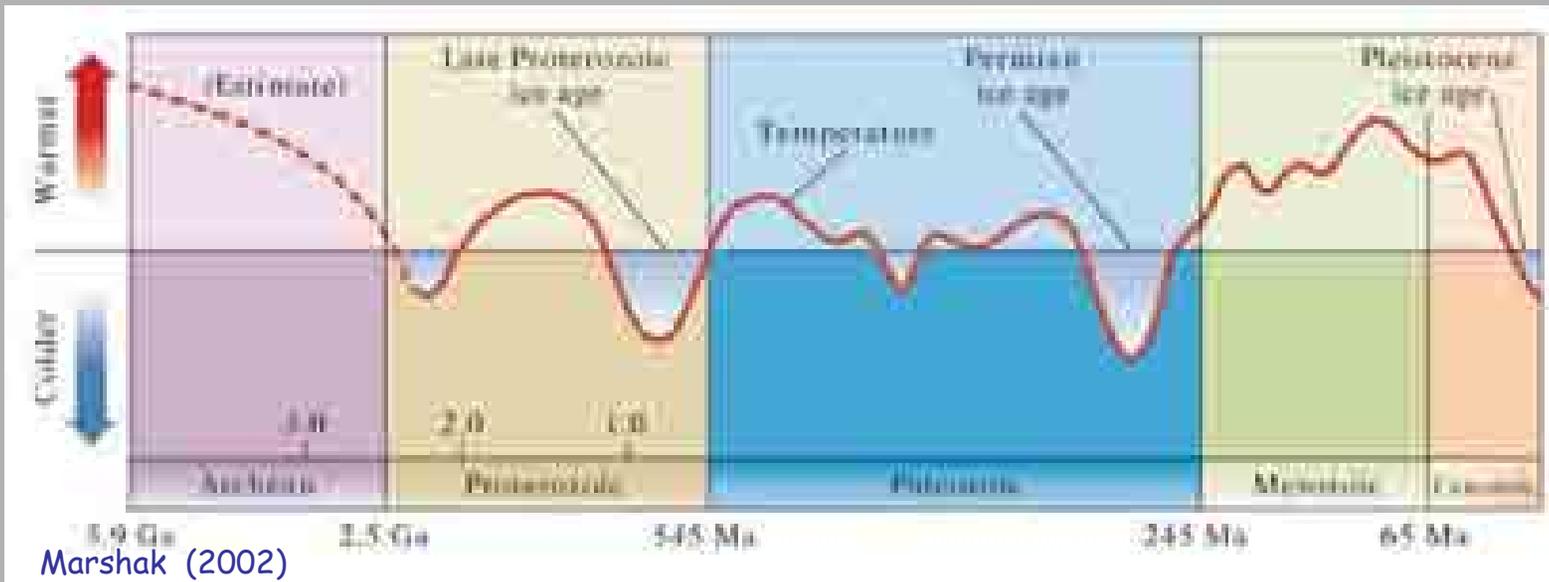
- **The cyclic pattern of the ice ages can be related to minor changes in the earth's rotation. Three factors influence the onset of ice ages**
 - **Obliquity of the earth's axis**
 - **Eccentricity of the earth's orbit**
 - **The precession of the earth's axis**
- **Each factor alone can cause a "little ice age" (1450-1850) when they act in concert a major glaciation can occur. However, the expected temperature changes from these events cannot account for the 4° to 10° drop seen in the Pleistocene**
- **There is geological evidence for 20 or more periods of deep cooling in the Pleistocene with intervening warm periods**

Global climate change

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Global climate change



Global climate change

- **Other possible factors include**
 - **Volcanic activity**
 - **Increased atmospheric dust**
 - **Changing ocean currents**



Pipkin and Trent (1997)