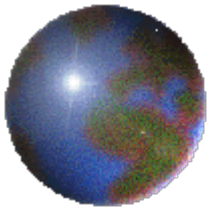
Introduction to Physical Geology



Chapter 17
Glaciers and Ice Ages

By Dr. Jia Hui

School of Earth Sciences and Engineering

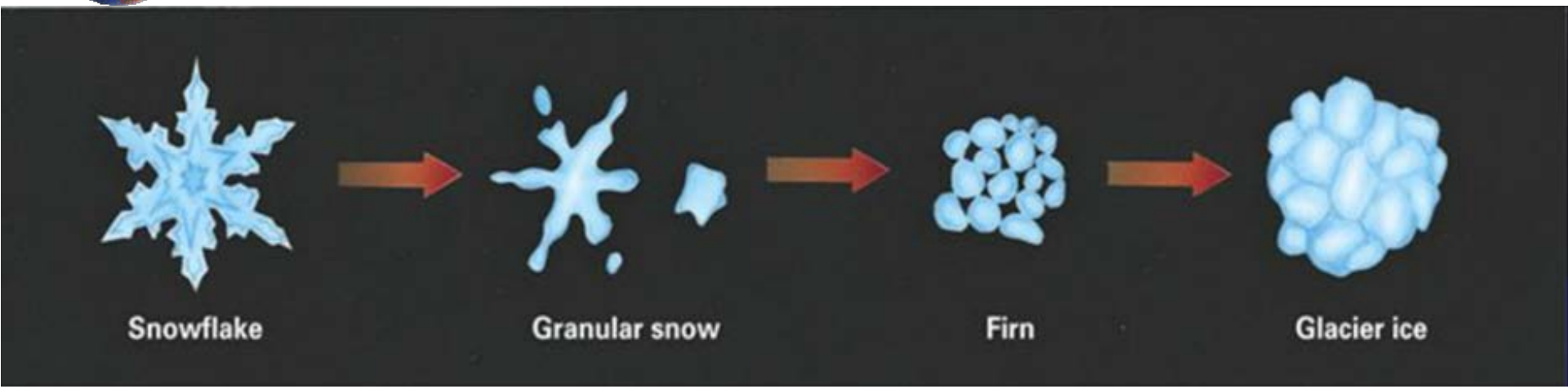
Xi'an Shiyou University

Content

17.1 What Is Glacier?

The Robson Glacier spills into Berg Lake on Mt. Robson, B.C., Canada.

17.1 What Is Glacier?



A **glacier** is a massive, long-lasting, moving mass of compacted snow and ice.

Formation of Glaciers: if snow survives one summer, it converts to rounded ice grains called firn, and can be compacted by burial to glacial ice.

Glaciers form only on land, wherever winter accumulation exceeds summer melt, and flow plastically by the pull of gravity.

- Glaciers form in two environments…as alpine glaciers (at all latitudes) on high, snowy mountains. The growth of an alpine glacier depends on both temperature and precipitation.

- To right, an alpine glacier flows in British Columbia, Canada.

- Glaciers also form (next slide)…

Some alpine glaciers flow great distances from the peaks into lowland valleys.

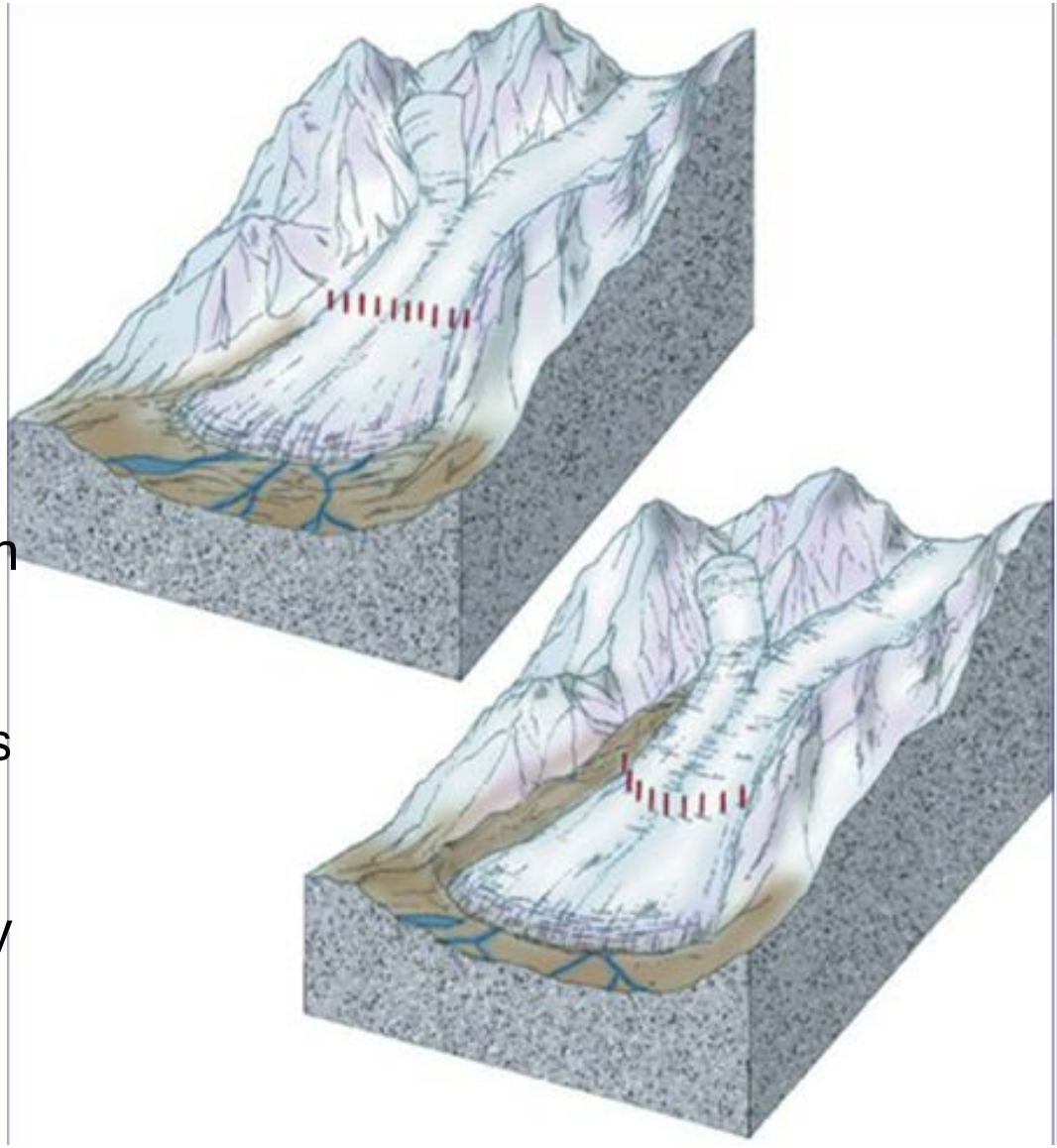
17.1 What Is Glacier?

As continental ice sheets (if over 50,000 square km) in polar regions. Today, two exist in Greenland and Antarctica. They contain 99% of the world's ice, and 75% of the Earth's freshwater. The Antarctic ice sheet covers 13 million square km and entire mountain ranges. Is there an ice sheet at the North Pole?

17.2 How Do Glaciers Move?

Movement depends on slope steepness, precipitation and air temperature (e.g., a few cm to a meter/day) and flow by *basal slip* (entire glacier can slide over bedrock when water accumulates) and *plastic flow*. Plastic flow shown to right. Why do poles in center move down slope faster than poles near the margin of the glacier?

Frictional resistance with the valley walls slows movement along the edges and glacial ice flows plastically.

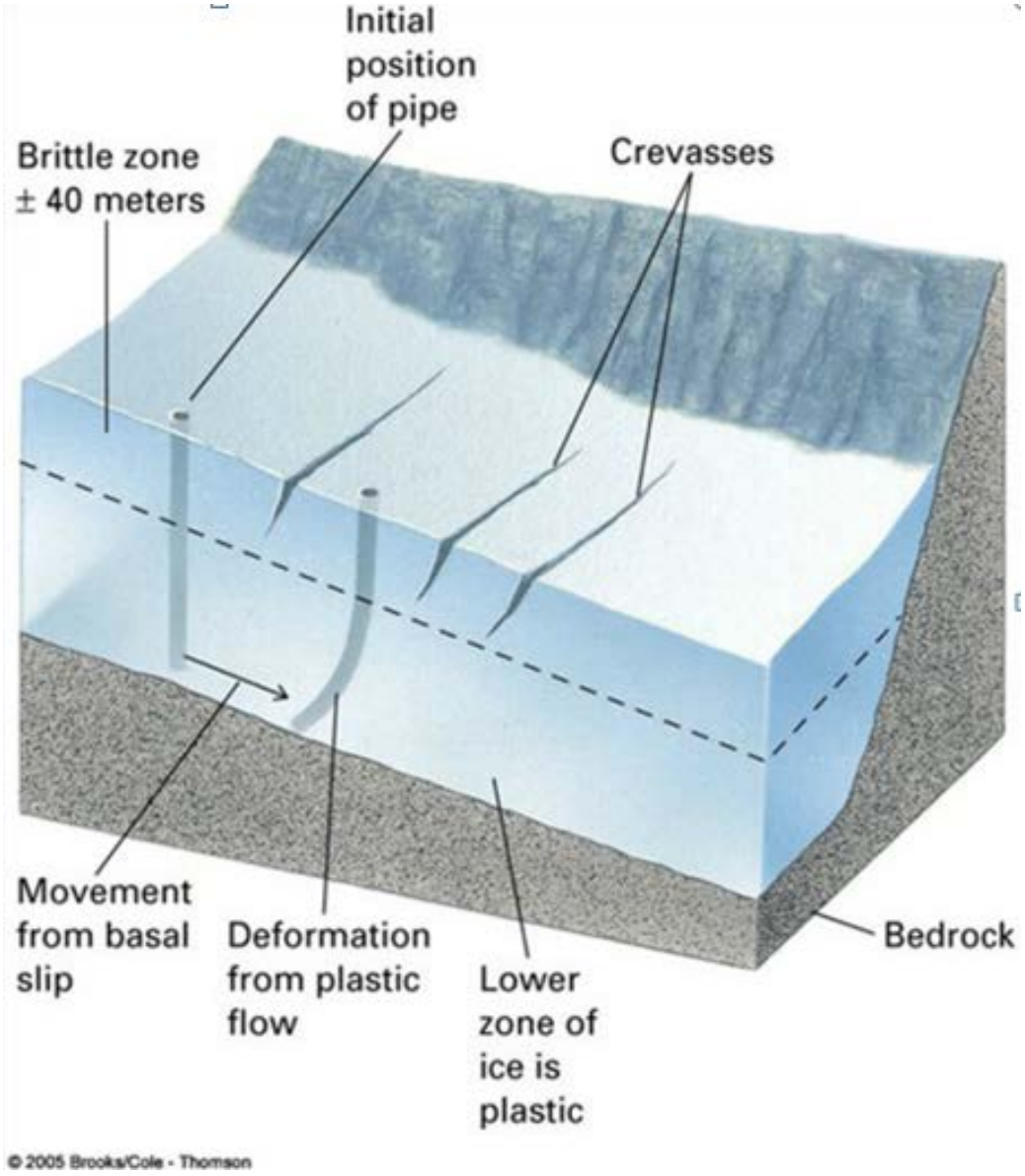


17.2 How Do Glaciers Move?

Also, this experiment shows the entire pipe, driven into bedrock, moved by basal slip, but the center of the glacier moved faster by plastic flow. In the upper 40 meters ice is now plastic but is brittle, and forms crevasses which open and close as the glacier moves.

The relative rates of basal slip and plastic flow depend on the steepness of the bedrock underlying the glacier and on the thickness of the ice.

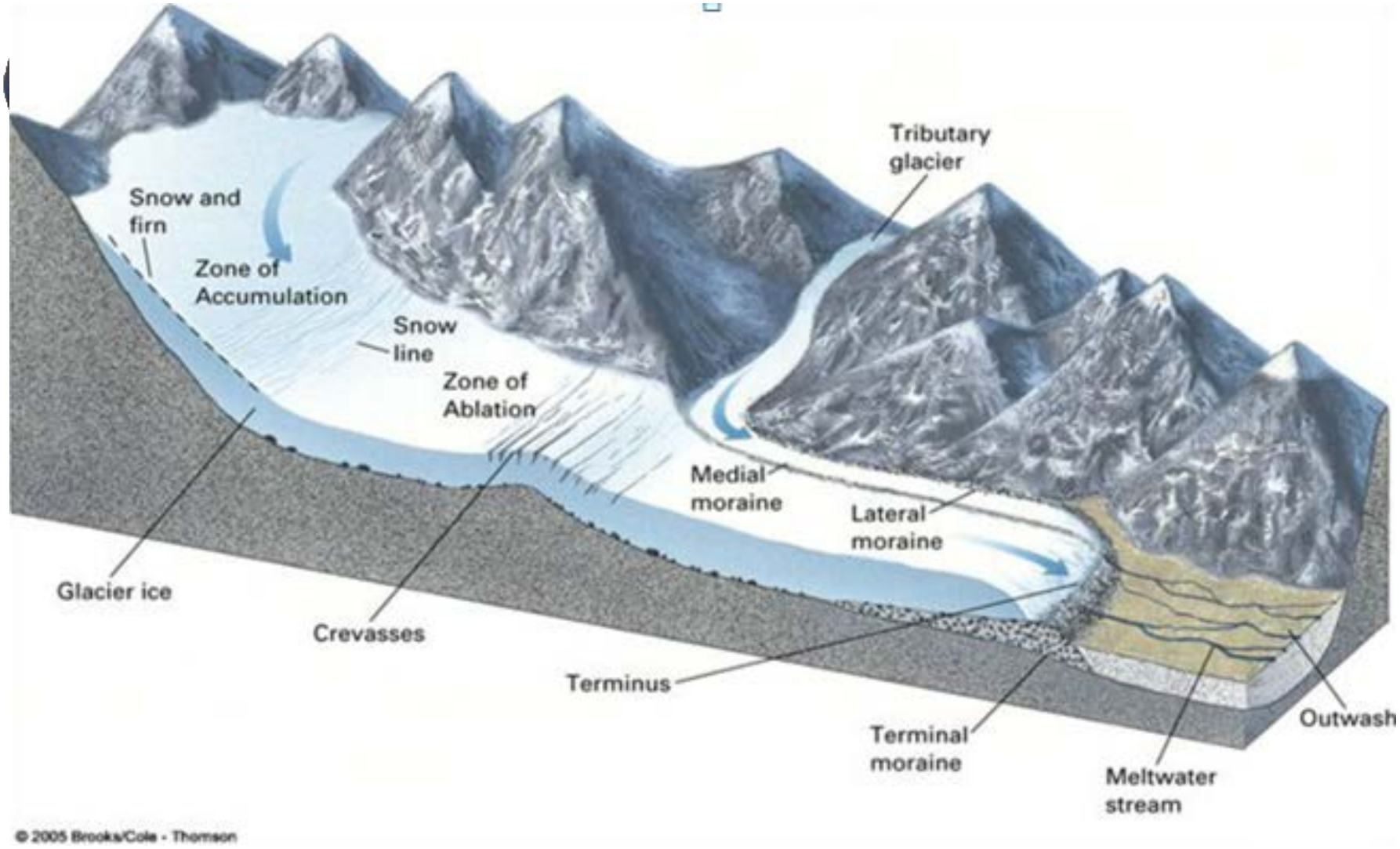
An **ice fall** is a section of a glacier consisting of crevasses and towering ice pinnacles.



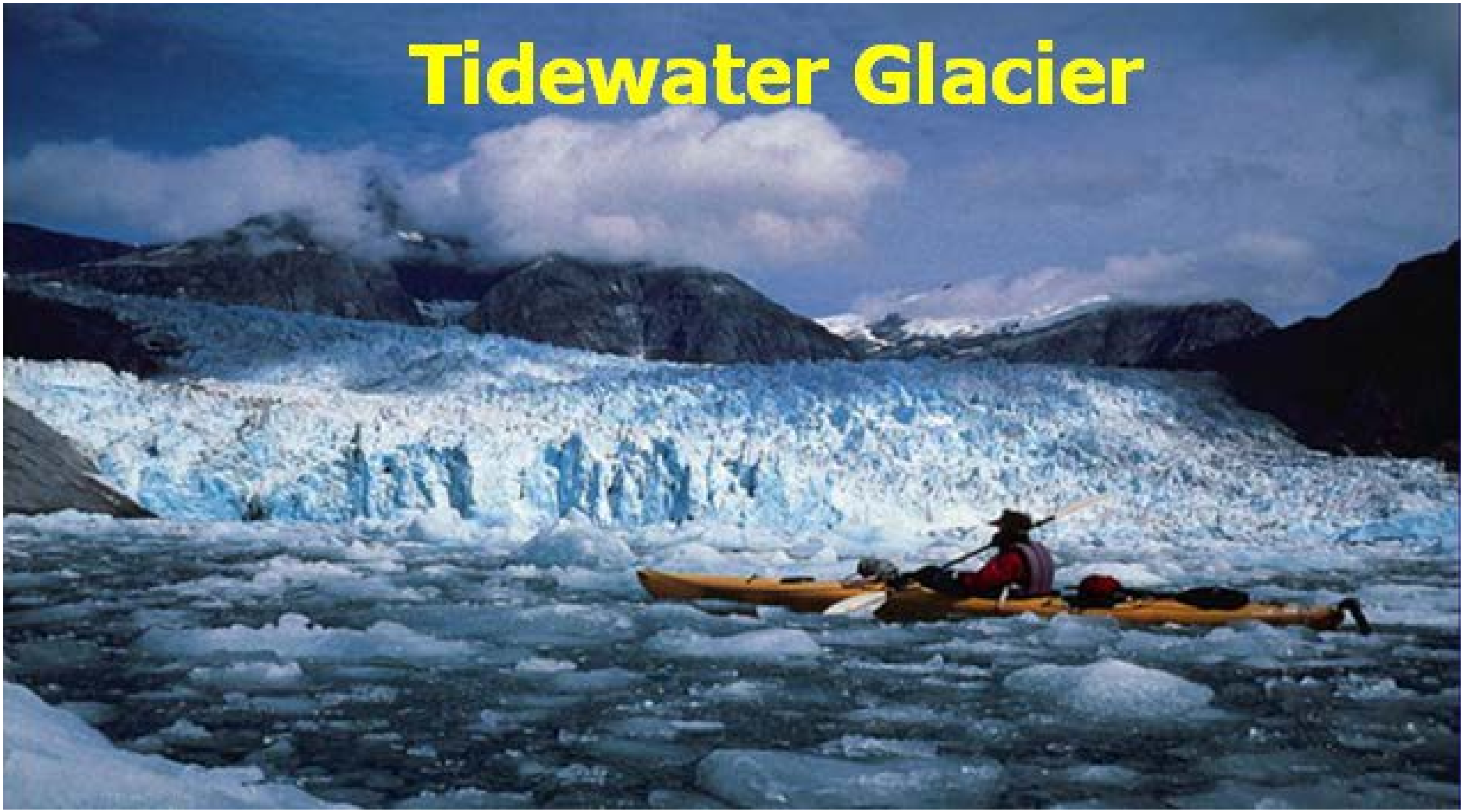
17.2 How Do Glaciers Move?

Crevasses in the Bugaboo Mountains of British Columbia, Canada.

When a glacier flows over uneven bedrock, the deeper plastic ice bends and flows over bumps, stretching the brittle upper layer of ice so that it cracks, forming crevasses.



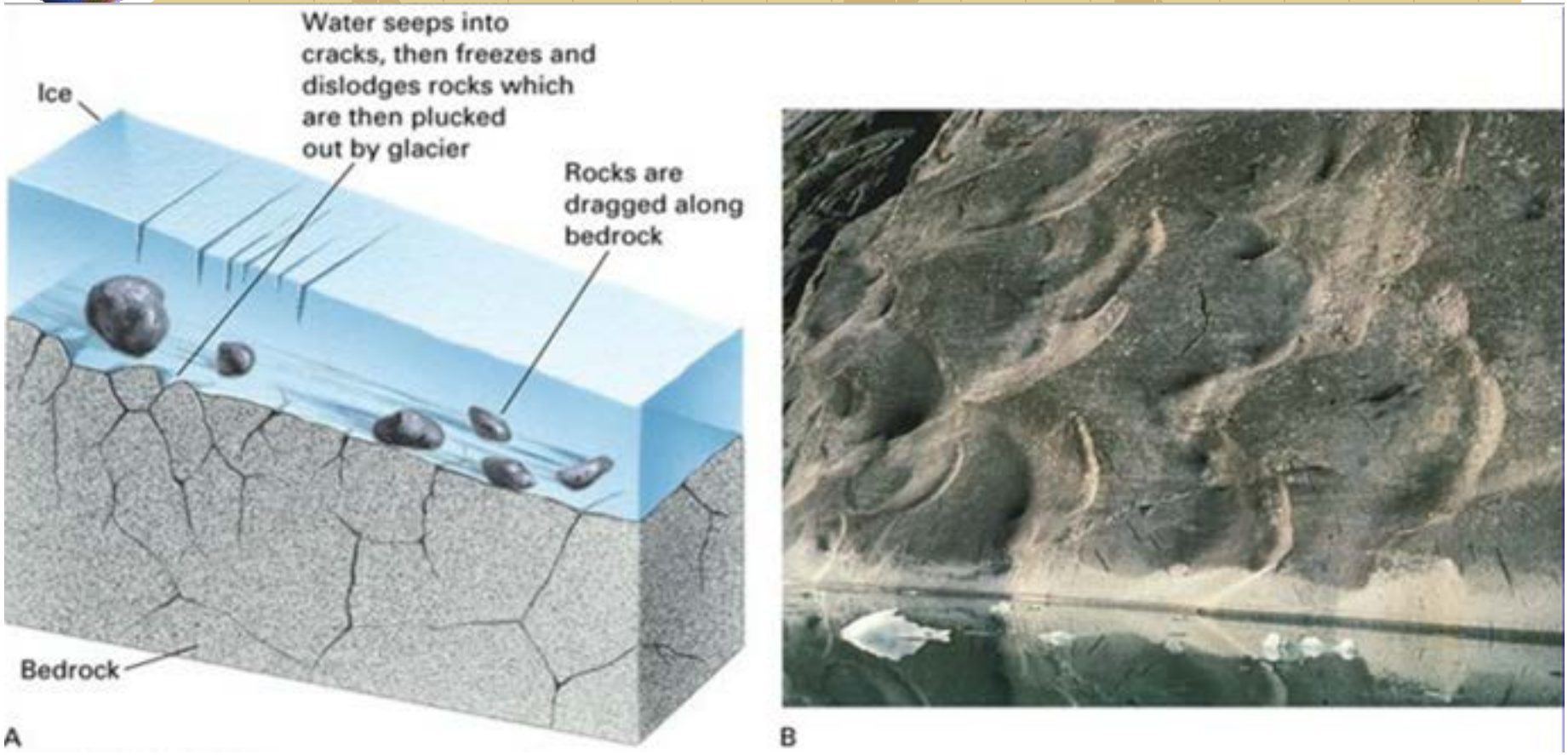
The Mass Balance of a Glacier: The Zone of Accumulation (where more snow falls in the winter than melts in the summer) is separated by the Zone of Ablation (where more snow melts in the summer than accumulates in the winter) by the snow line (boundary between permanent snow and seasonal snow). So, why is there ice in the Zone of Ablation? What determines the glaciers terminus?



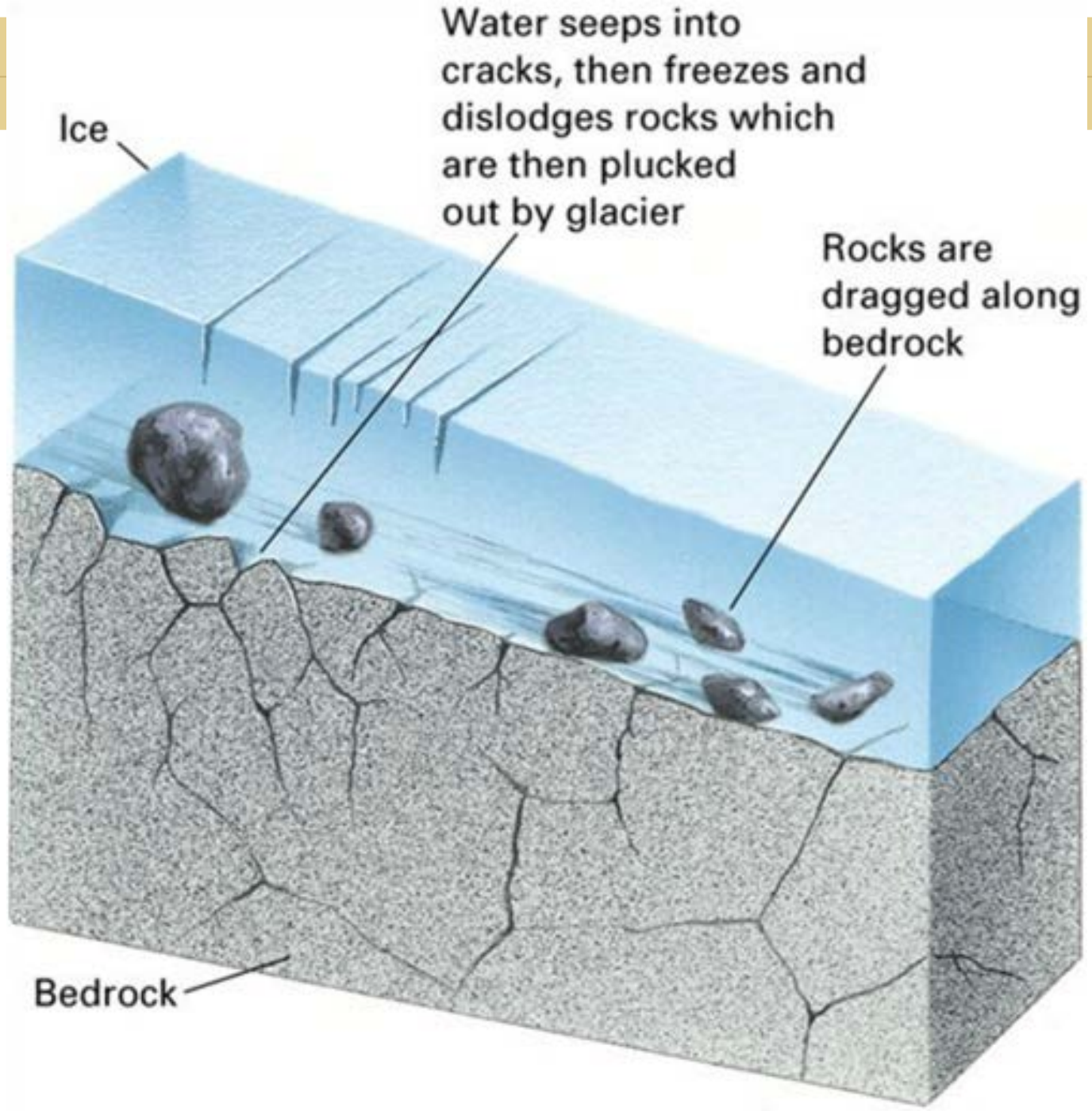
In equatorial and temperate regions, glaciers commonly terminate at an elevation of 3,000 meters or higher. But in cold, wet climates they can cxtend into the sea, where great chunks break off as icebergs.

Photo shows small ice bergs that calved from the Le Conte Glacier in Alaska.

17.3 Glacial Erosion



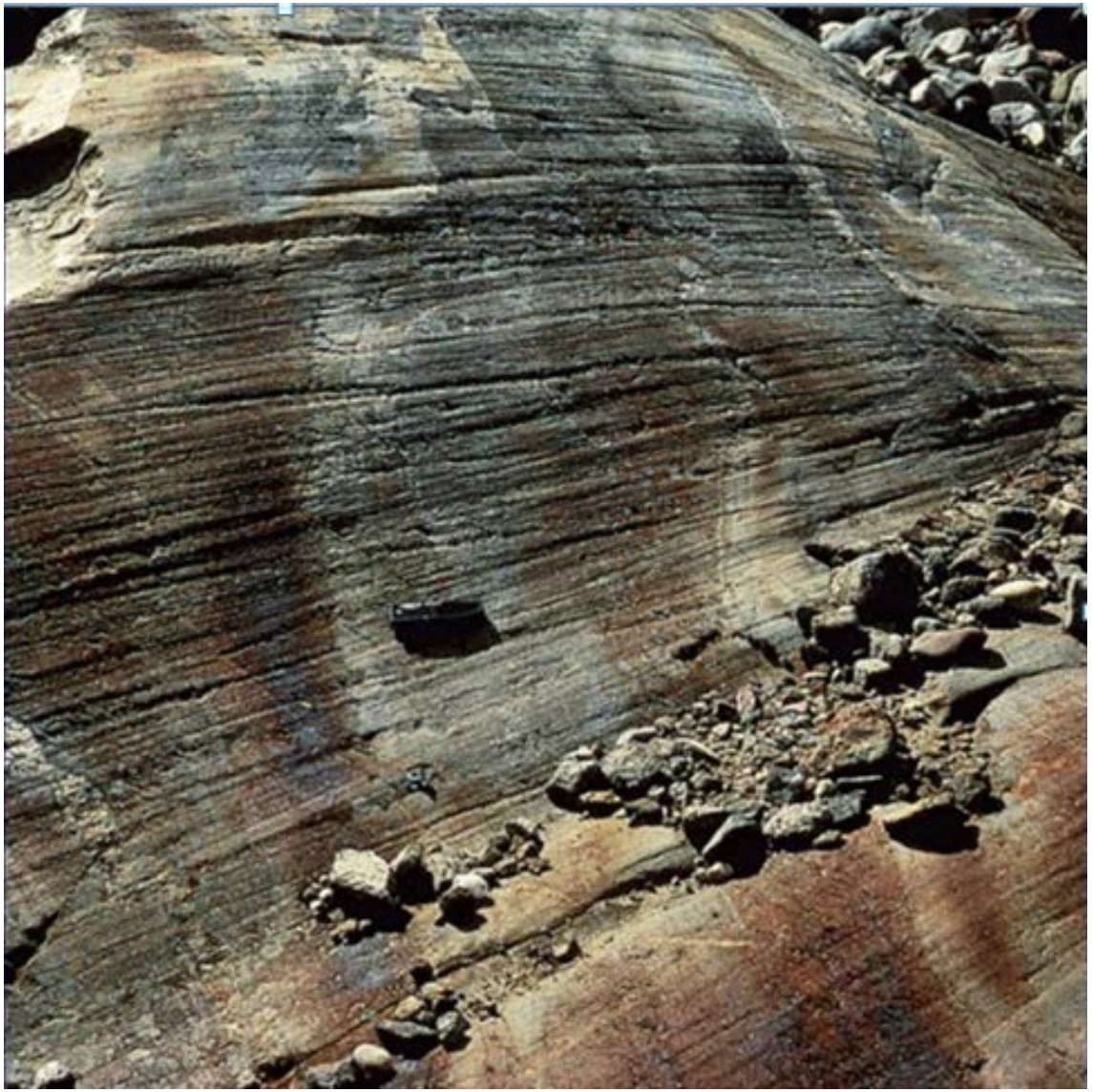
Glacial Erosion: a glacier plucks rocks from bedrock and then drags them along, abrading both the loose rocks and the bedrock. The crescent-shaped depressions in granite of Alaska were formed by glacial plucking.


Water seeps into cracks, then freezes and dislodges rocks which are then plucked out by glacier
Ice
Rocks are dragged along bedrock
Bedrock

17.3 Glacial Erosion

Glacier striations can form when stones embedded in the base of the glacier gouge the bedrock. Can the glacial icegouge the bedrock?

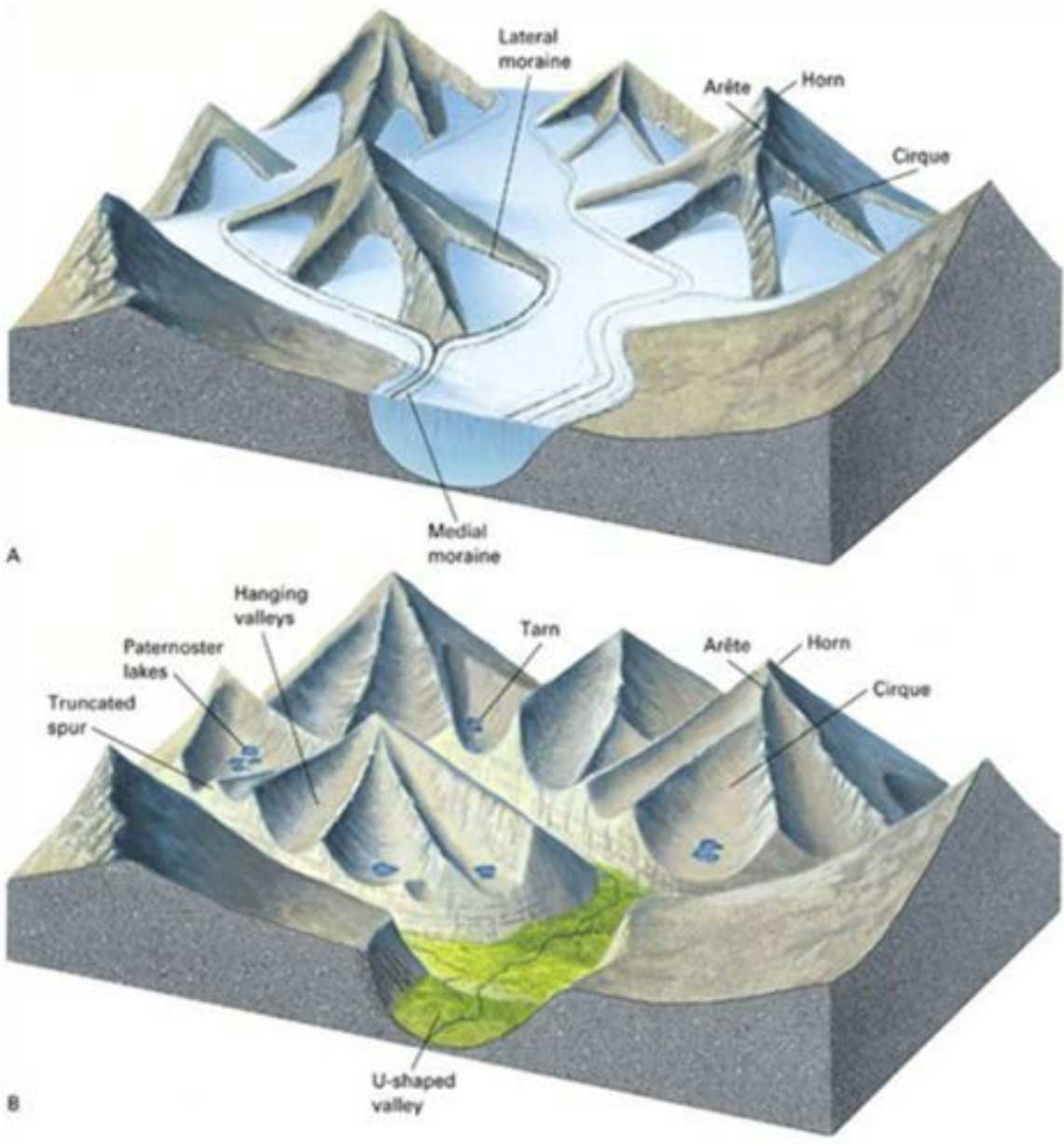
The striations show the direction of movement of the glacier.



17.4 Glacial landscapes

Discuss glacial landforms formed by alpine glacial erosion.

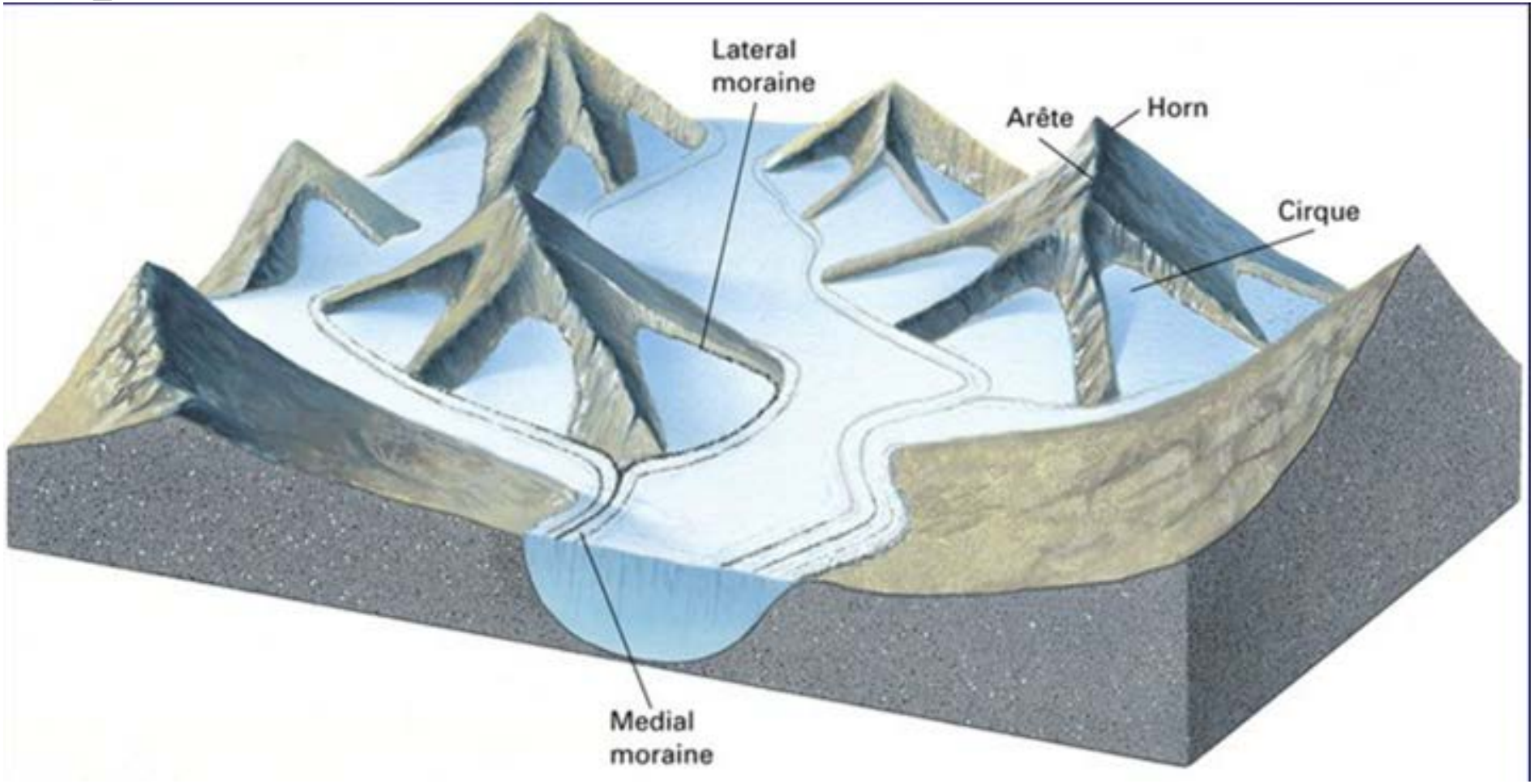
How could you tell a glacially carved valley from a stream carved valley?



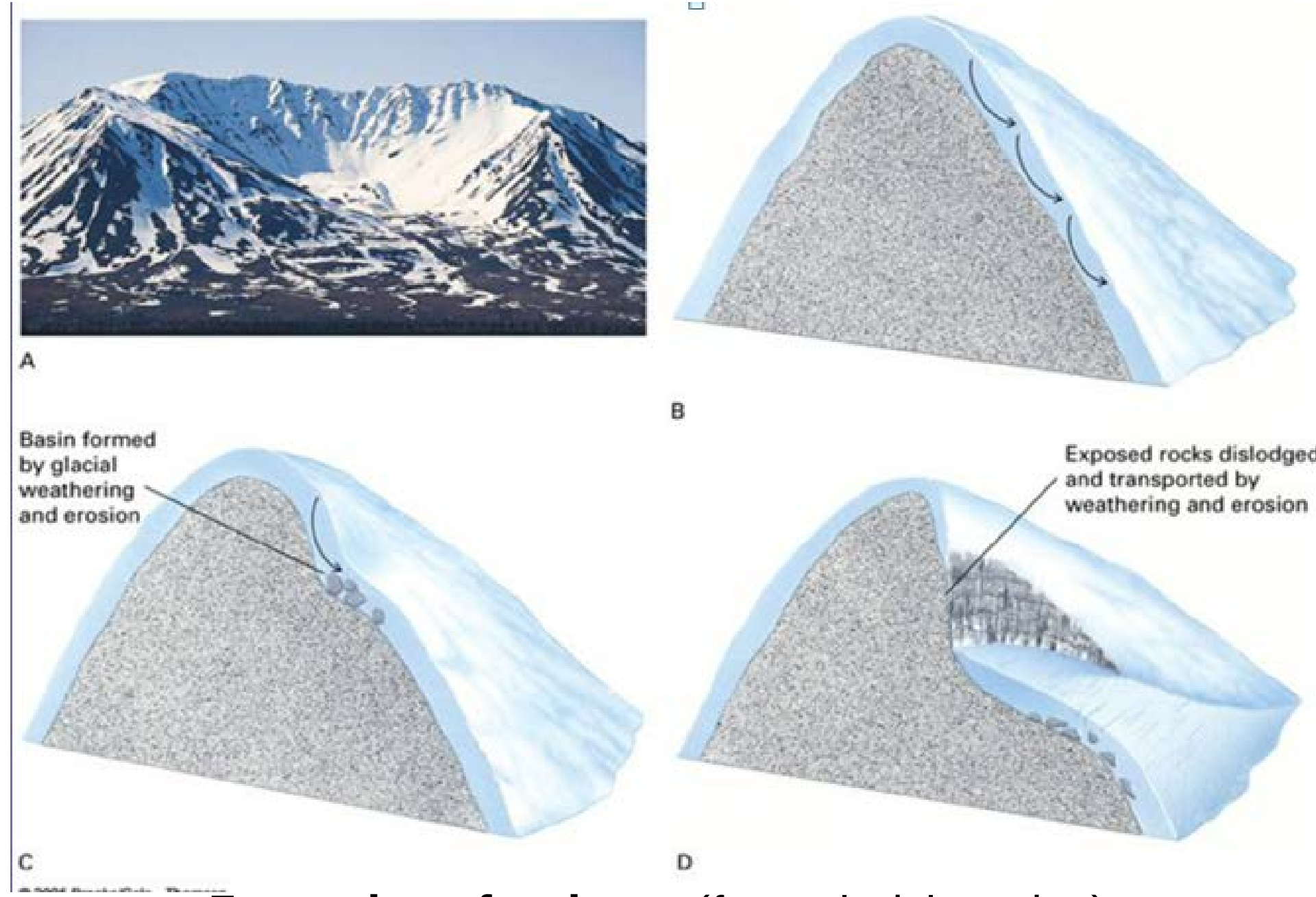
17.4 Glacial landscapes

U-shape valley (from glacial erosion) in the Purcell Mountains of British Columbia.

17.4 Glacial landscapes

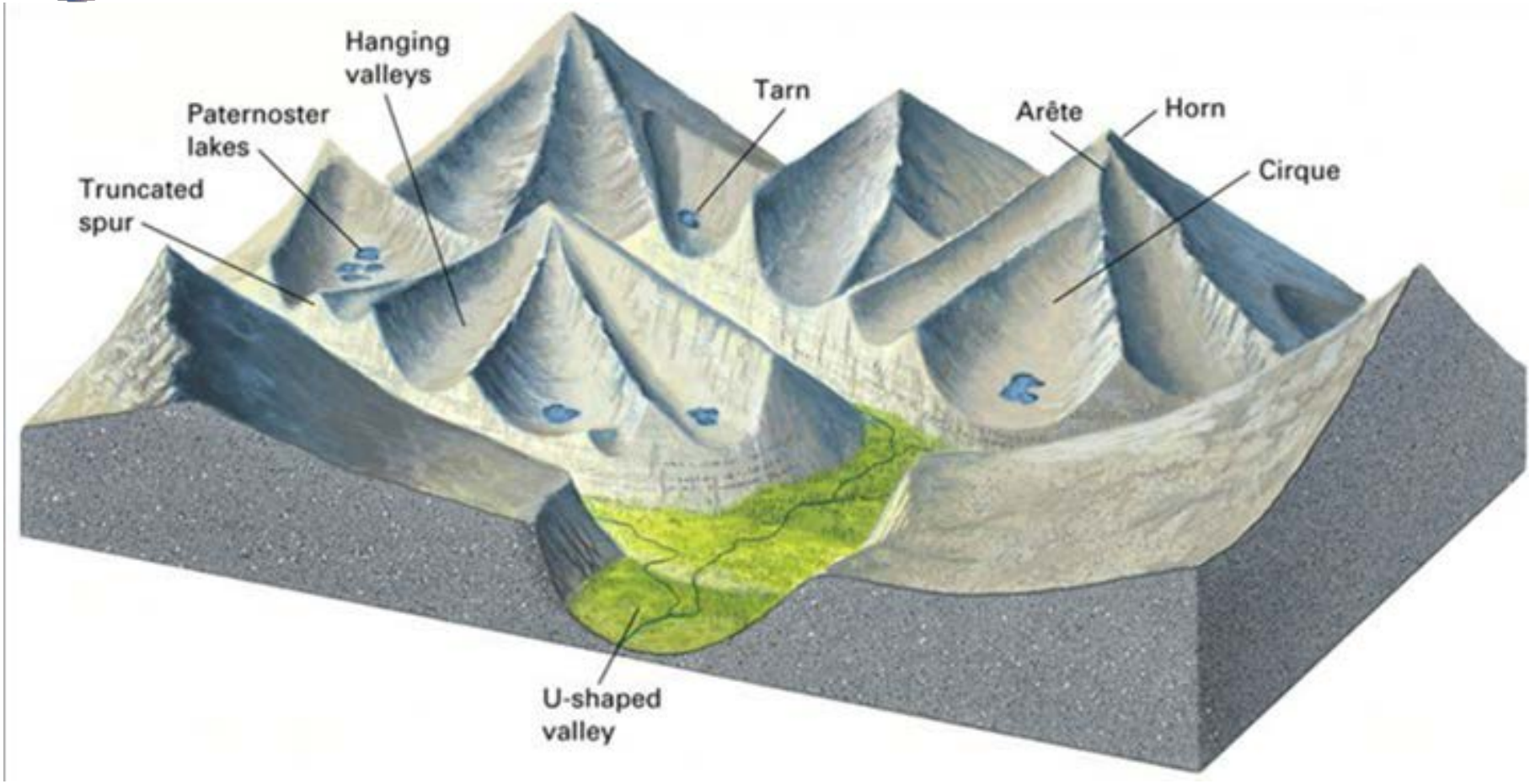


The ice plucks a small depression that grows slowly as the glacier flows . With time, the ***cirque*** walls become steeper and higher. The glacier carries the eroded rock from the cirque to lower parts of the valley . When the glacier finally melts, it leaves a steep walled, rounded cirque.



Formation of a cirque (from glacial erosion)

17.4 Glacial landscapes



One landform from glacial erosion is an **Arête**.
Two glaciers flowing along opposite sides of a mountain ridge may erode both sides of the ridge, forming a sharp, narrow **Arête** between adjacent valleys

17.4 Glacial landscapes

… And
paternoster lakes…
(from glacial erosion)

-----a series of lakes (depression from glacier eroding fills with water after the glacier melts)

17.4 Glacial landscapes

... And ***horns*** (such as the Matterhorn in the Swiss Alps from glacial erosion)

If glaciers erode three or more cirques into different sides of a peak, they may create a steep, pyramid-shaped rock summit called a ***horn***.

17.4 Glacial landscapes

… And **hanging valleys** (such as the famous waterfalls of Yosemite Valley in California from glacial erosion)

A small glacial valley lying high above the floor of the main valley is called a ***hanging valley*****.**

If the main valley glacier cuts off the lower portion of an arête, a triangular-shaped rock face called a ***truncated spur*** forms

17.4 Glacial landscapes

... And **fjords** (at high-latitude seacoasts, glacially carved inlet from glacial erosion)

This fjord is bound by 1,000meter cliffs in Baffin Island, Canada.

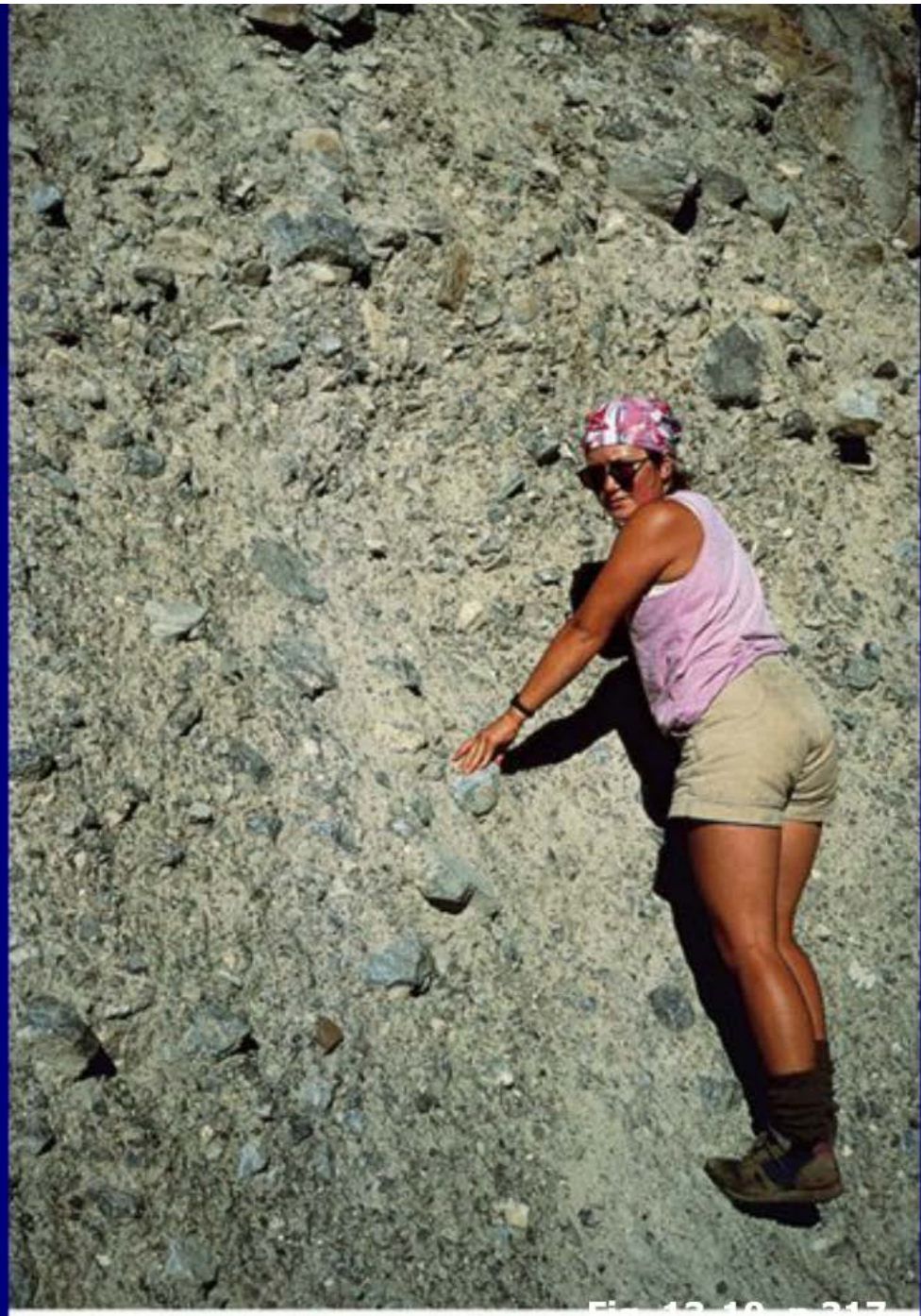
- Erosional landforms from continental glaciers can be massive because the glacier isn't confined to a valley, and is larger and thicker, covering vast regions and entire mountain ranges.

- To right is Lake Ontario and the Finger lakes in New York.

- **Now Glacial Deposits**: glacial ***drift*** is all rock or sediment transported and deposited by a glacier. There are two types: ***till*** (deposited directly by glacial ice) and ***stratified drift*** (first carried by a glacier, then transported and deposited by a stream).

- Till (to right) is unsorted and un-stratified sediment. What does this mean? In photo, large cobbles are mixed with smaller sediment.

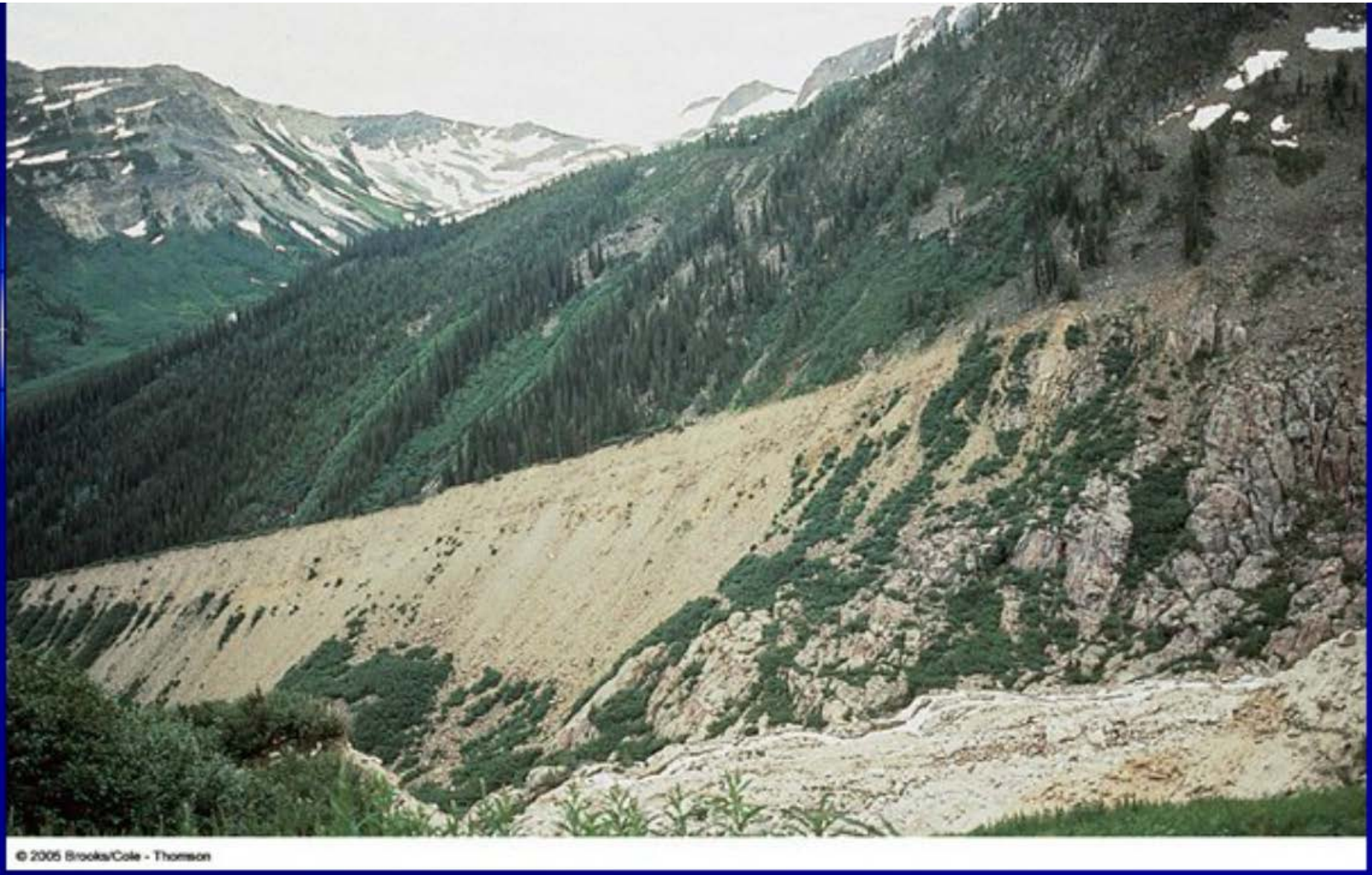
- What is the significance of the rounded cobbles? What is an erratic?



- Moraines, such as the end moraine to right, are landforms composed of till.

- What is the difference between end, terminal, recessional, ground, lateral and medial moraines? (see Figure 13.6).
  - Sediment accumulates at the terminus to form a ridge called an ***end moraine***.
  - ***Terminal moraine*** is an end moraine that forms when a glacier is at its greatest advance.
  - ***Recessional moraine*** forms when the glacier stabilizes again during its retreat.
  - When ice melts, till is deposited in a relatively thin layer over a broad area, forming a ***ground moraine***.

- Moraines can be huge. Above is a terminal moraine in New York State, marking the southernmost extent of glaciers in that region during the Pleistocene glaciation that reached its maximum extent about 18,000 years ago. End moraines and ground moraines are characteristic of both alpine and continental glaciers.



- A lateral moraine lies against the valley wall in the Bugaboo Mountains, B.C., Canada.

Sediment near the glacial margins forms a ***lateral moraine.***

- Where are the medial moraines (to right) and how did they form?

If two glaciers converge, the lateral moraines along the edges of the two glaciers merge into the middle of the larger glacier. This till forms a visible dark stripe on the surface of the ice called a ***medial moraine.***

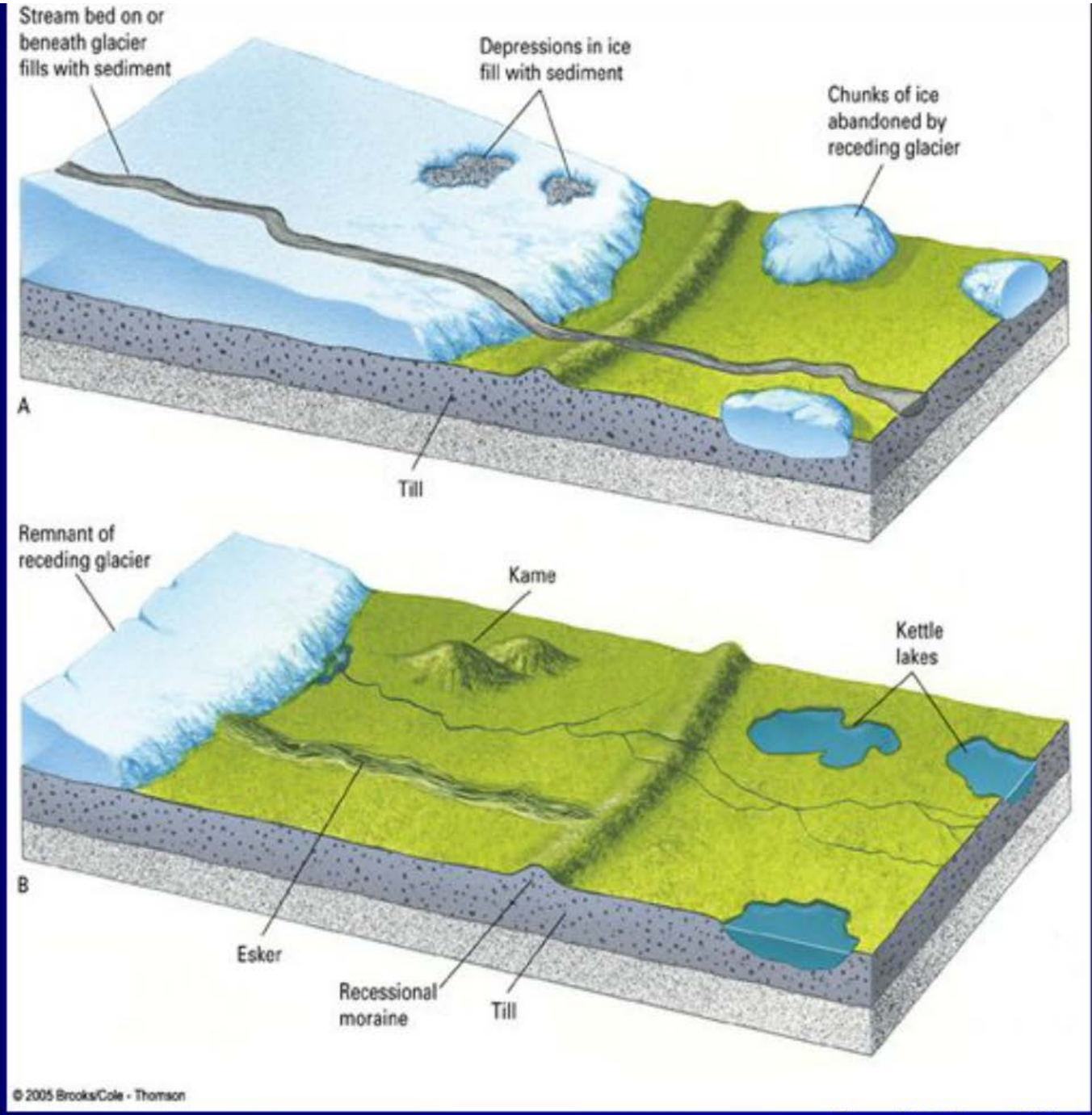
- Drumlins, elongate hills of till and sometimes bedrock, cover parts of the northern U.S. They are typically 1-2 km long and 15-50 meters apart. Glacier movement direction can be determined because glaciers generally erode a steep-sided face as it advances and deposits sediment on the downslope side to form a long, pointed slope.

- Landforms Composed of Stratified Drift: to right is glacial outwash (stream deposits beyond the glacial terminus). Can get valley trains (braided streams in a valley) or outwash plains (deposits spread out into larger valley or plain).

Outwash plains are also characteristic of continental glaciers.

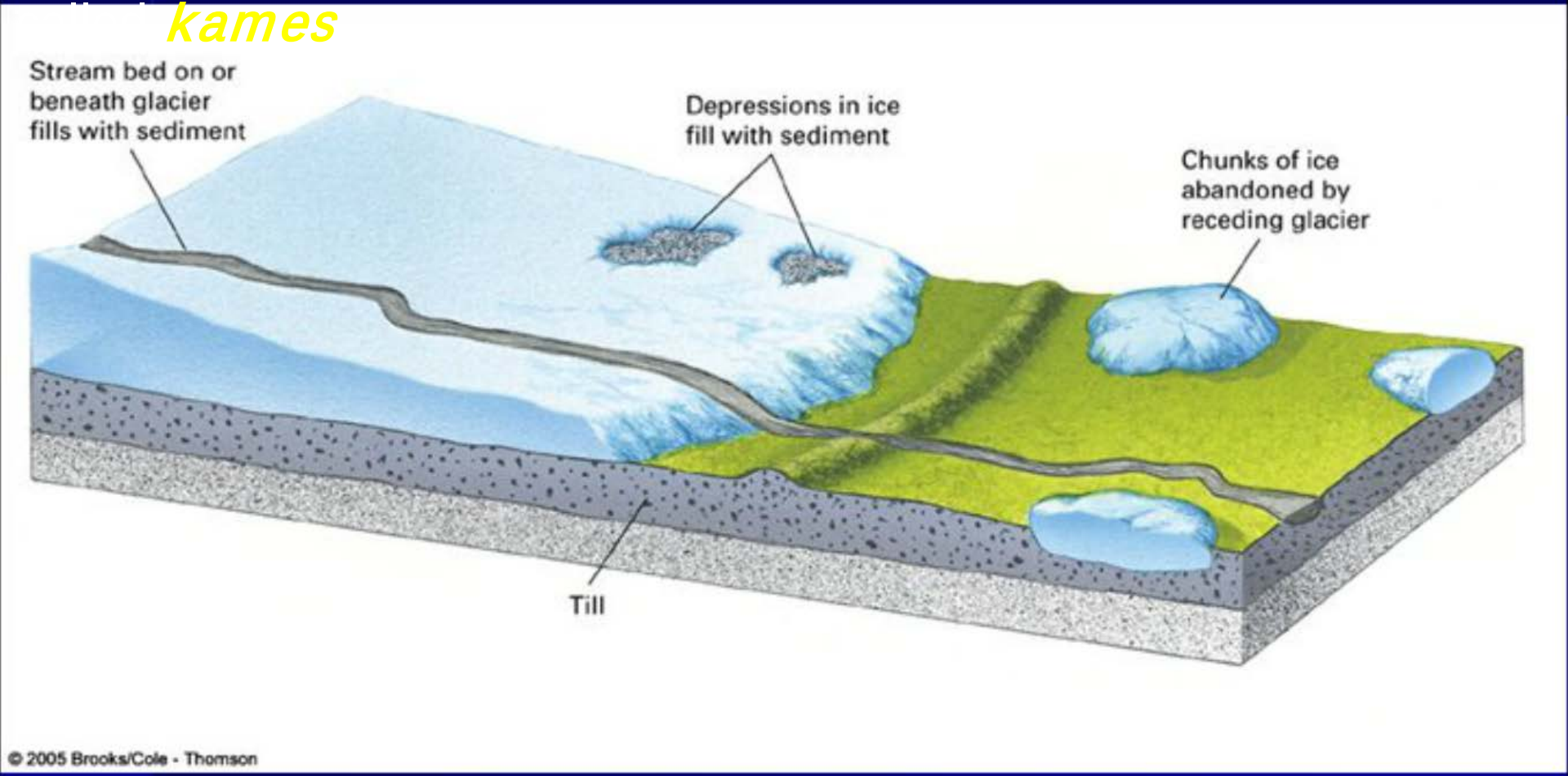
- How do Kames and Eskers form?
- How could you distinguish a Kame or Esker deposit from till?
- How does a kettle lake form?

- They show sorting and sedimentary bedding, which distinguishes them from unsorted and unstratified till.
- And the individual cobbles or grains are usually rounded.



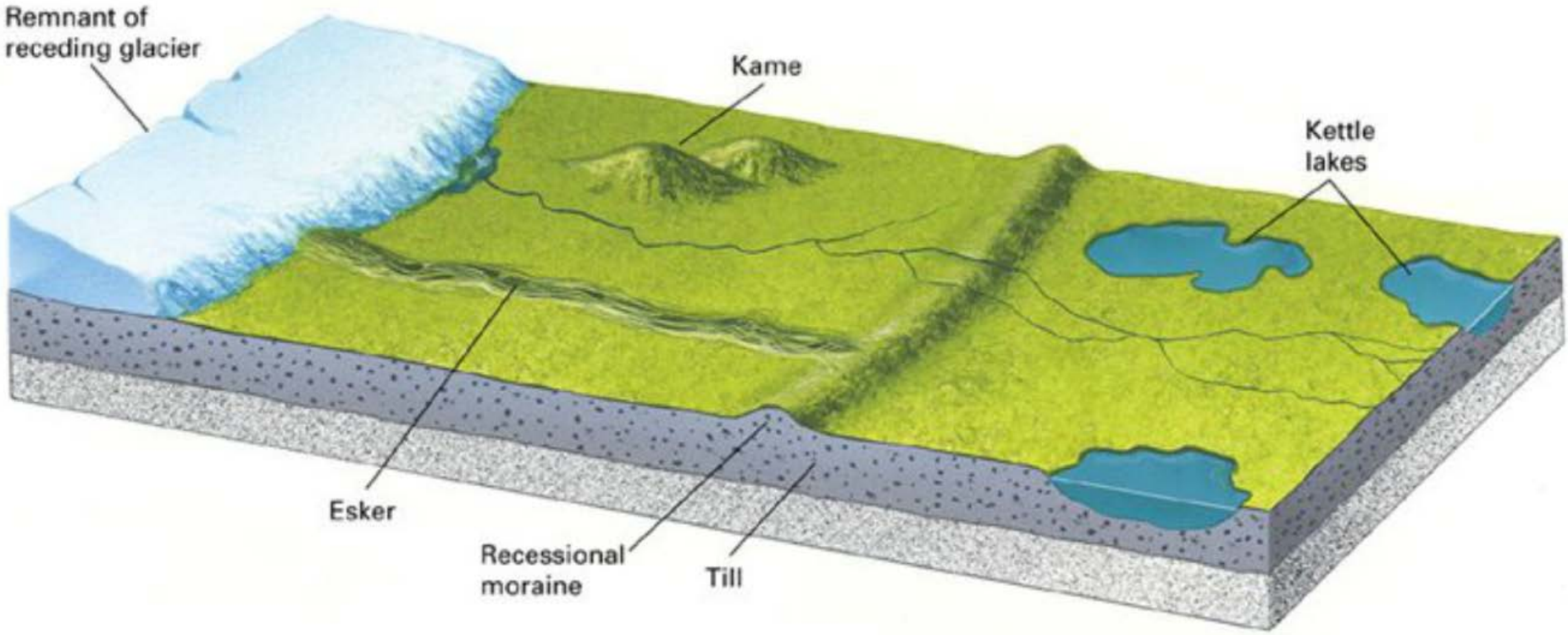
- This esker in Canada is a sinuous ridge of sand and gravel deposited in a bed of a stream that flowed beneath a continental glacier about 20,000 years ago.

Streams plunge into crevasses and run beneath the glacier over bedrock or drift, commonly deposit small mounds of sediment, called ***kames***



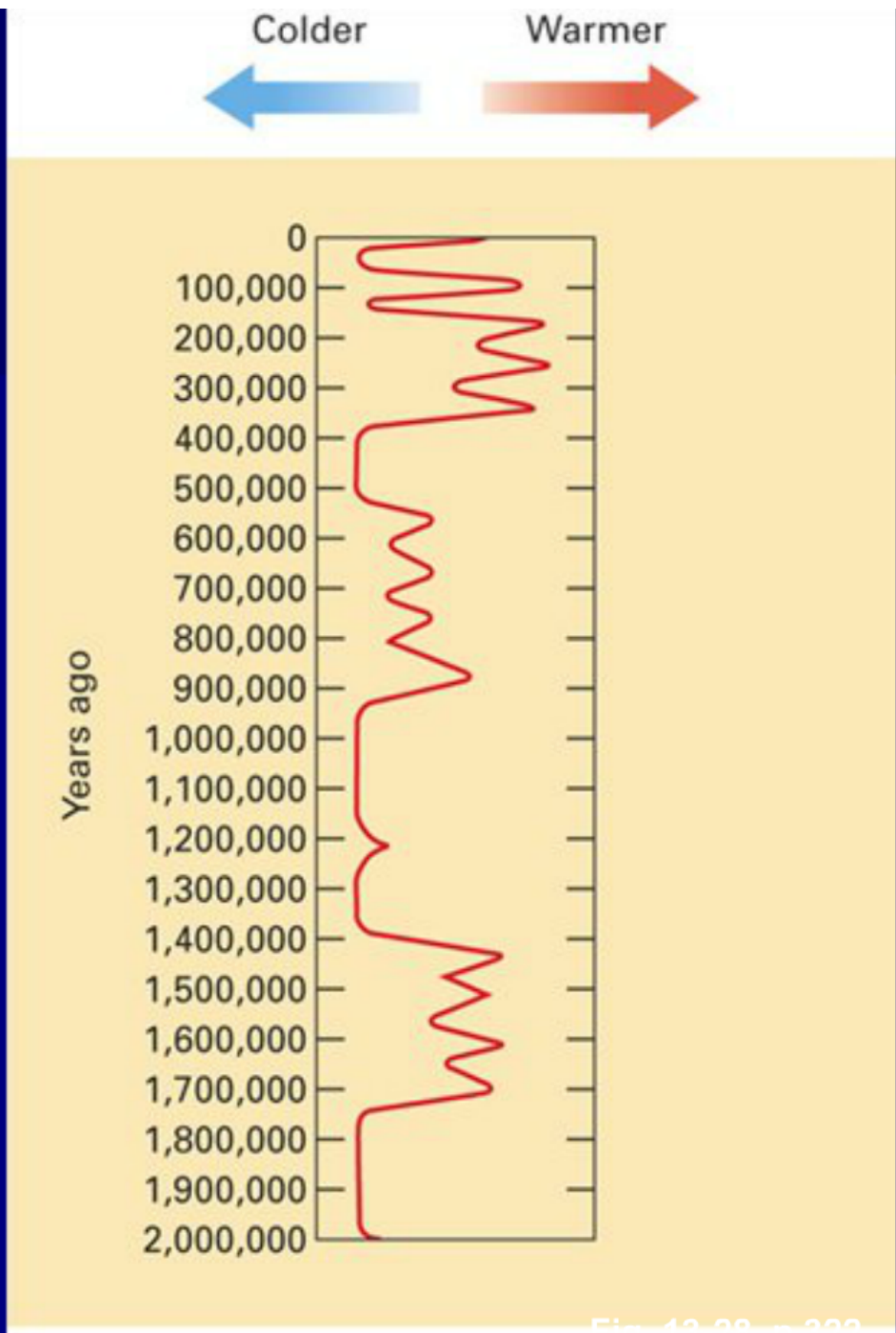
Large blocks of ice may be left behind in a moraine or an outwash plain as a glacier recedes. When it melts, it leaves a depression called a ***kettle***.

17.5 Glacial Deposits



- The Pleistocene Ice Age:

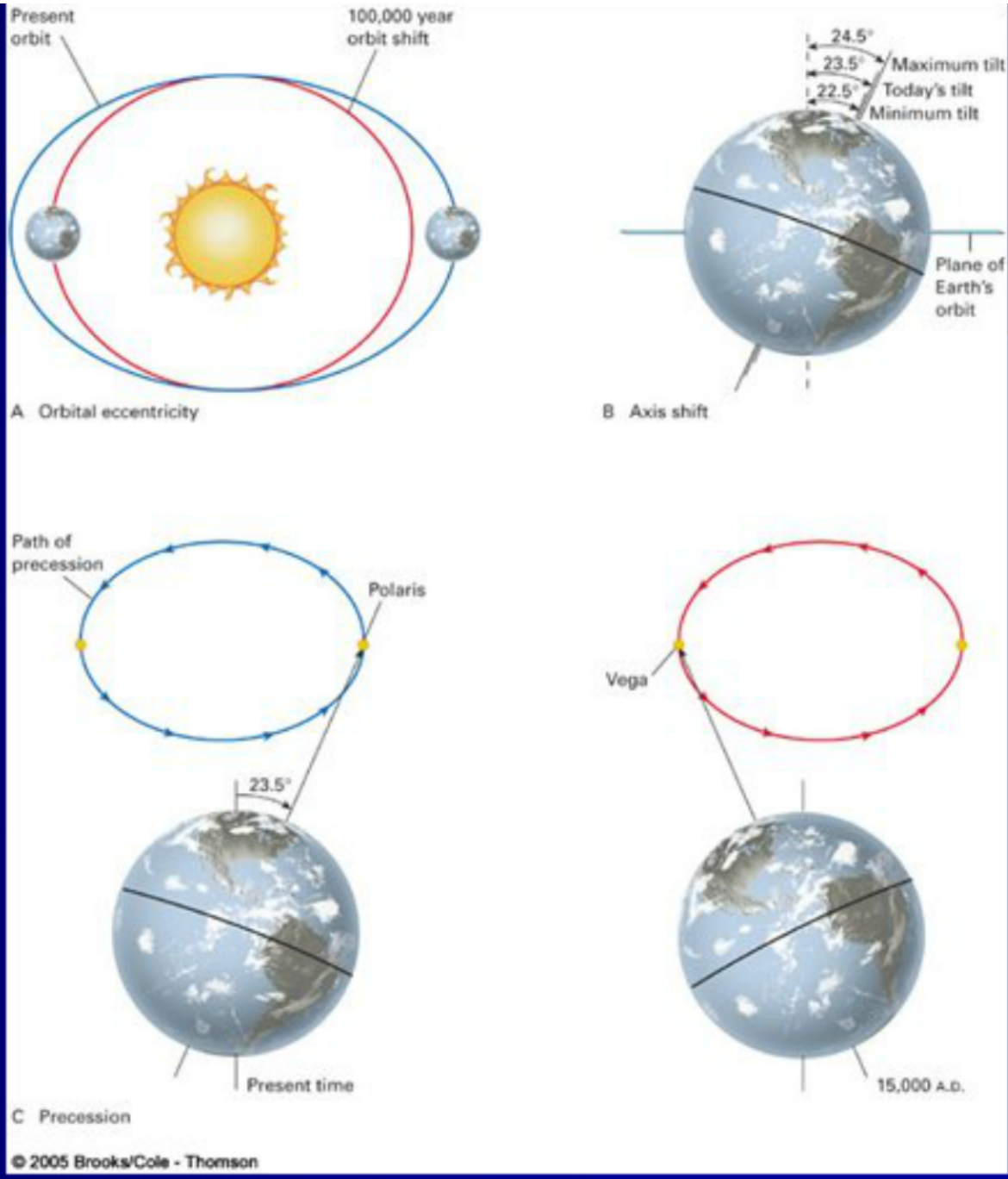
- Glacial and other geologic evidence shows at least 6 major ice ages occurred over the last 1 billion years, each lasted from 2-10 million years. The most recent took place mostly in the Pleistocene Epoch. It began about 2 million years ago, where climate has fluctuated and continental glaciers grew and melted away several times. Today, we are probably in an interglacial period of this ice age.

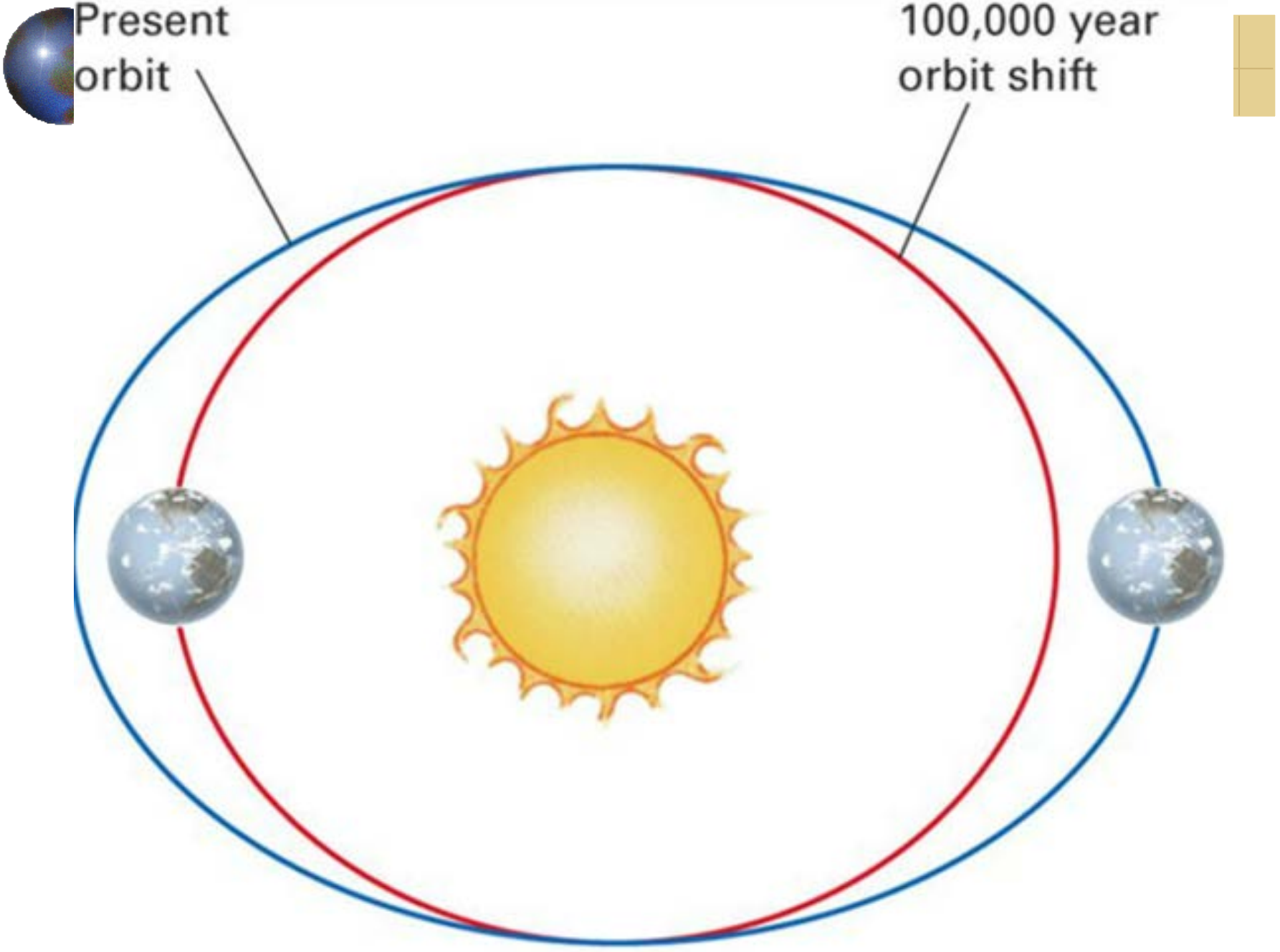


- Causes of the Pleistocene Ice Age and Glacial Cycles?

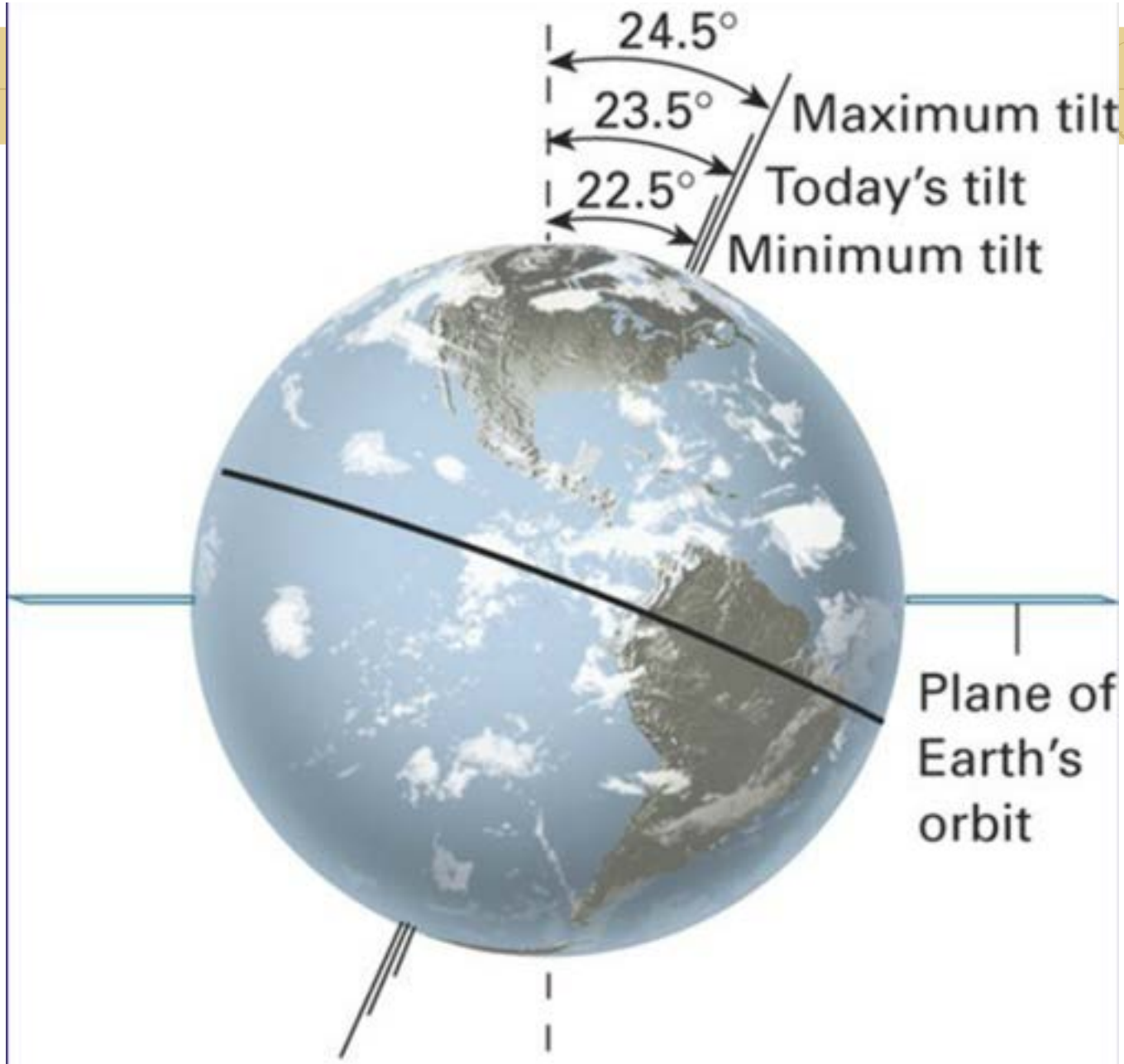
- An increase in volcanic activity may have triggered the onset of the Pleistocene Ice Age. But what causes the repeated cycles of growth and melting of glaciers over the past 2 million years?

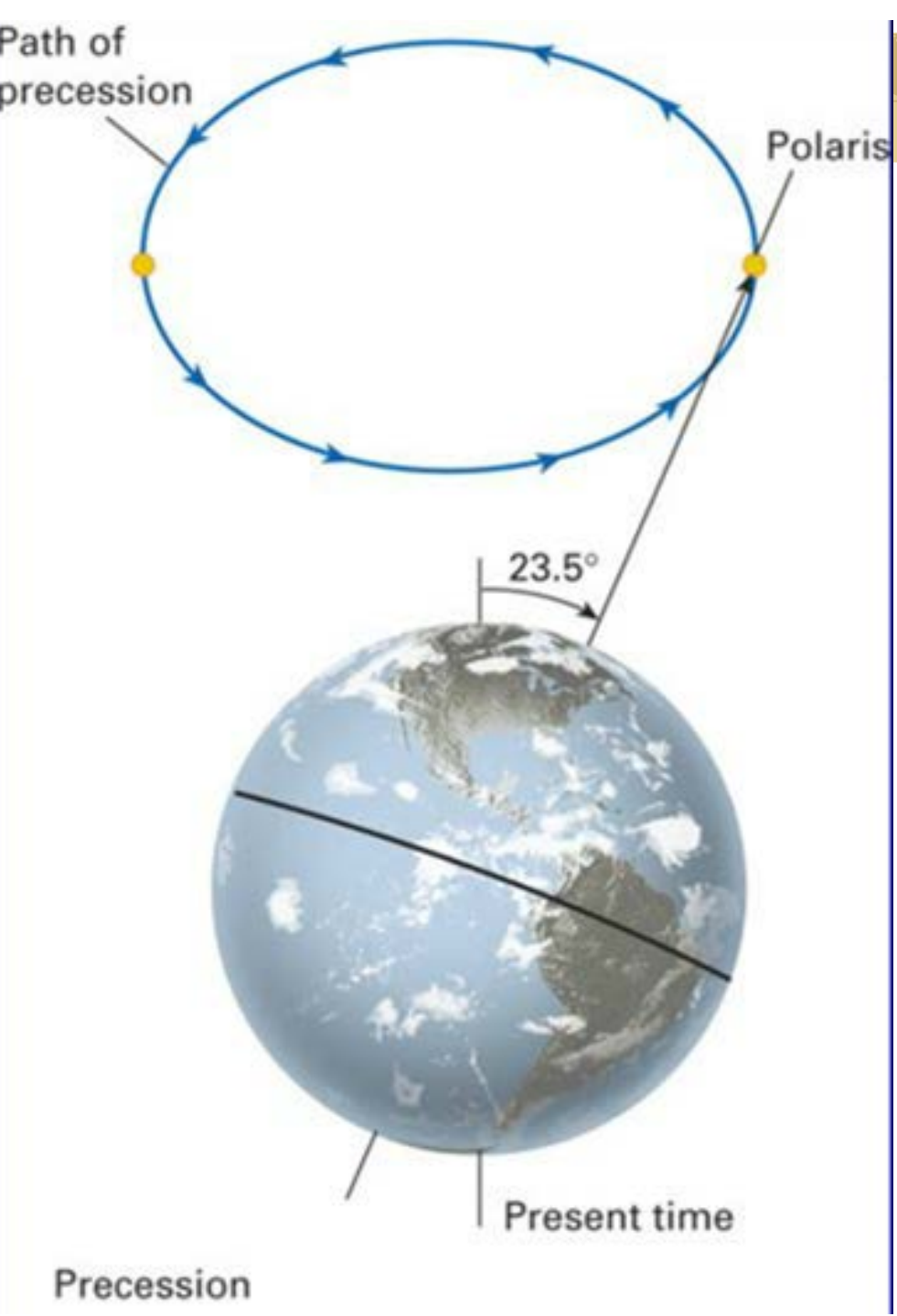
- Scientists have found that slight variations in Earth's orbit and orientation coincide with glacial expansion and shrinking: *eccentricity* (100k year cycle), *axis tilt* (41k year cycle) and *precession* (26k year cycle). These cycles can effect other earth systems and cause major climate change.



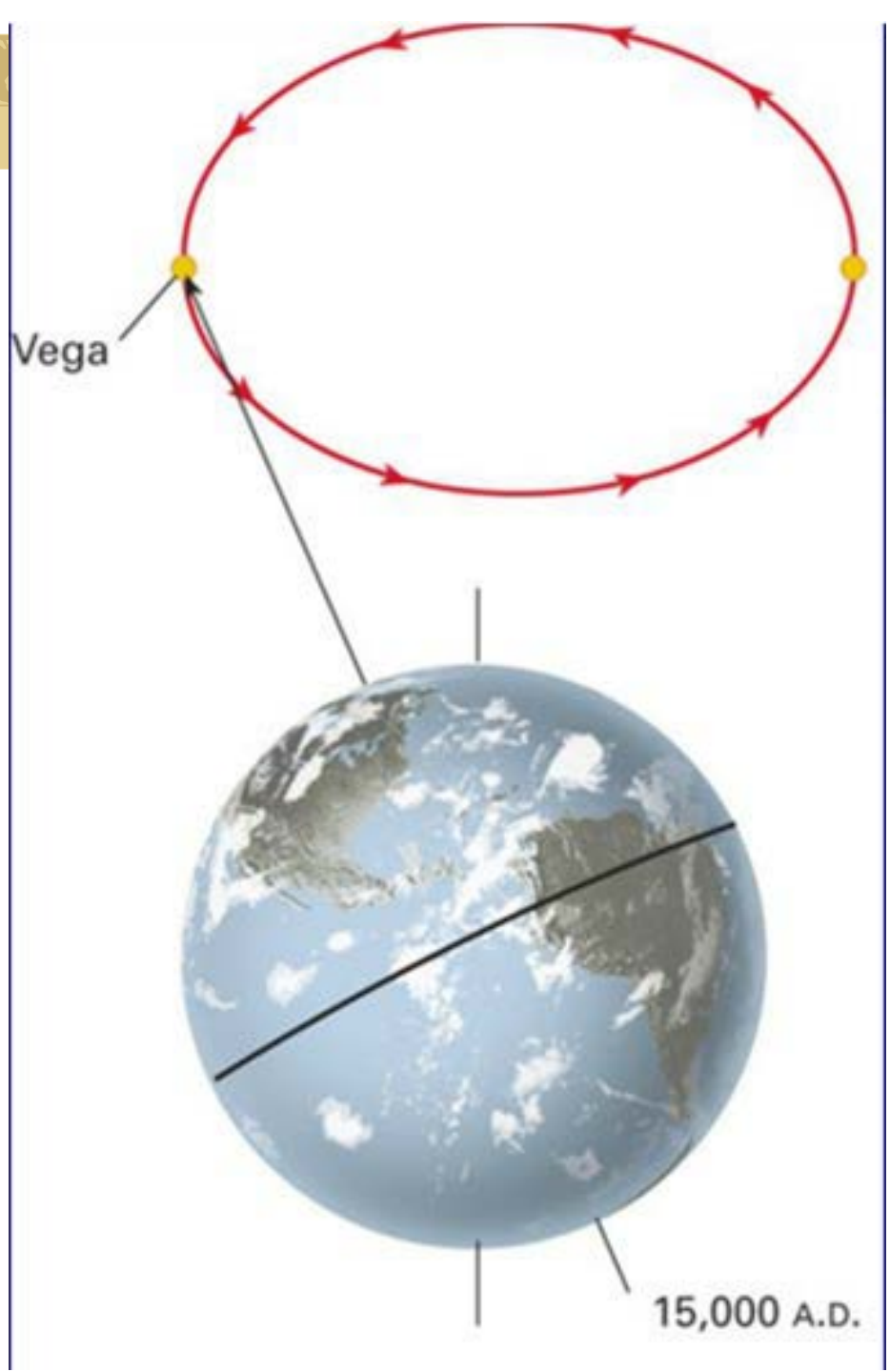


Orbital eccentricity


24.5°
23.5°
22.5°
Maximum tilt
Today's tilt
Minimum tilt
Plane of Earth's orbit
Axis shift
© 2005 Brooks/Cole - Thomson

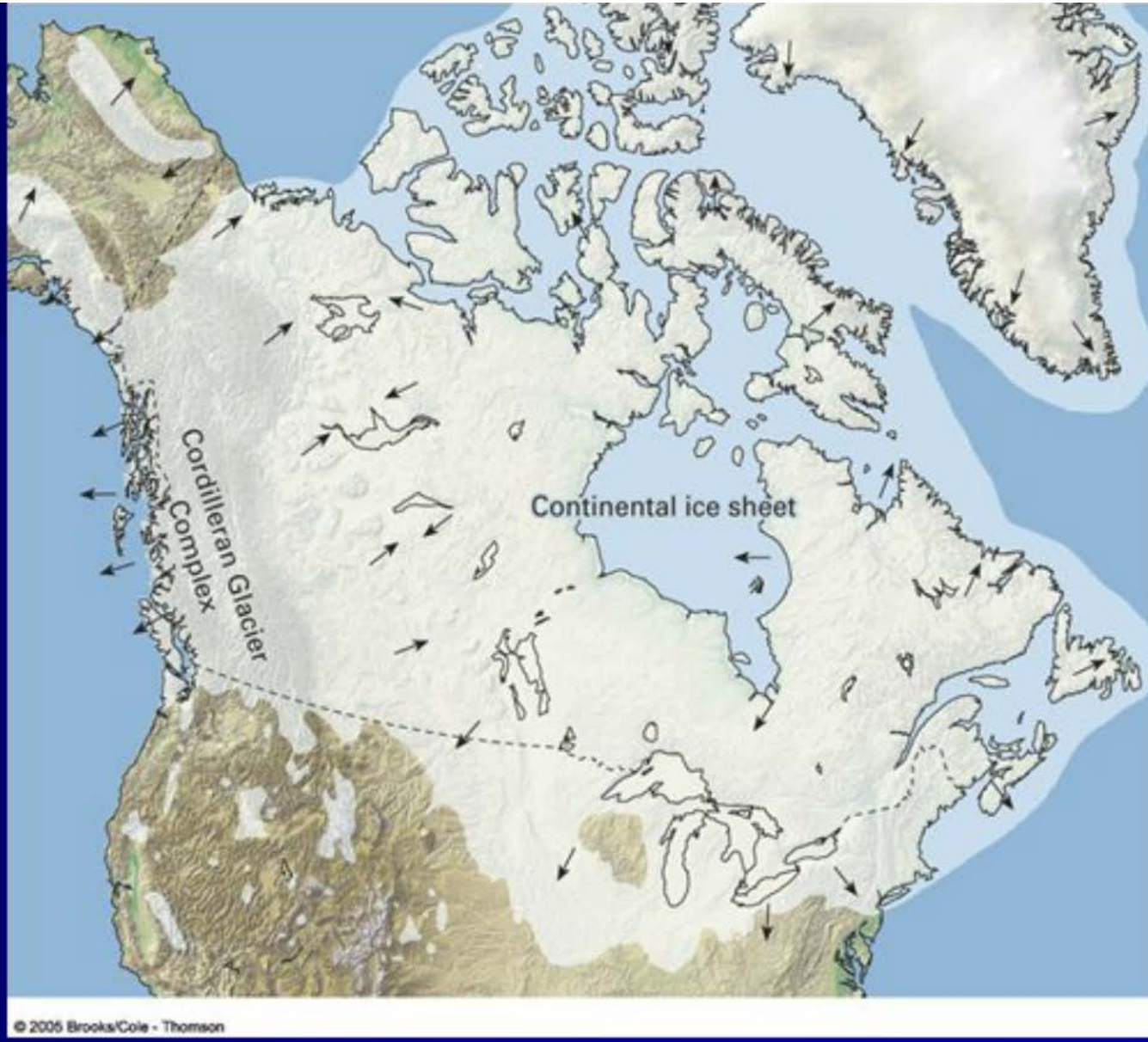


Precession

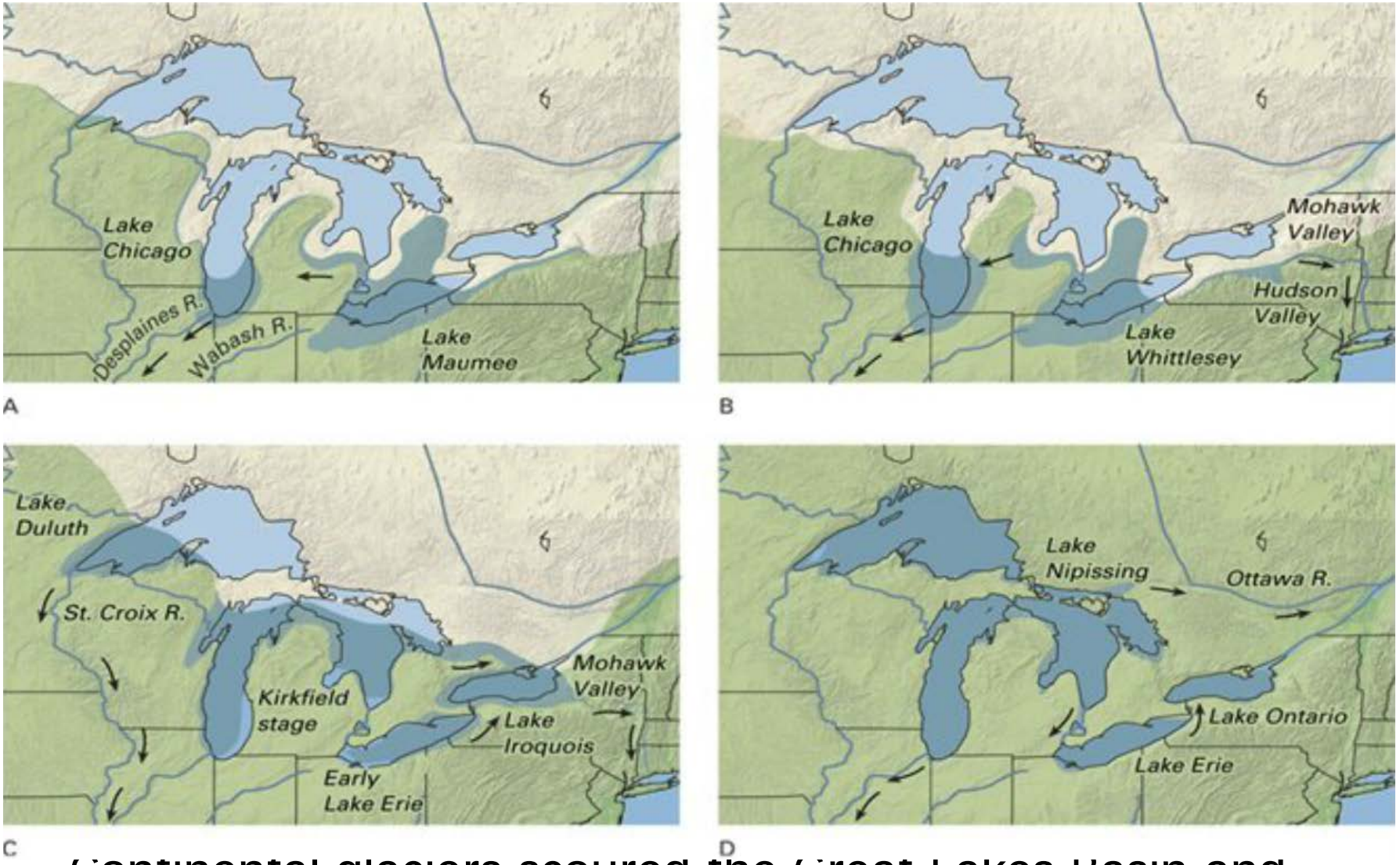


- Effects of Pleistocene Continental Glaciers: to right…maximum extent of the continental glaciers in North America during the latest glacial advance about 18,000 years ago. The arrows show direction of ice flow.

When glaciers grow, they accumulate water that would otherwise be in the oceans, and sea level falls.



17.6 Ice ages



Continental glaciers scoured the Great Lakes Basin and altered its drainage pattern several times.

17.6 Ice ages

17.6 Ice ages

17.6 Ice ages


Lake
Duluth
St. Croix R.
Kirkfield
stage
Mohawk
Valley
Lake
Iroquois
Early
Lake Erie

17.6 Ice ages

Snowball Earth

- Between 800-550 million years ago, evidence shows that Earth may have been covered several times in a 1 km thick shell of ice. Evidence comes from **tillites**: glacial deposits cemented into hard rock and found on almost all continents (remember, continents have drifted throughout time; some glacial deposits formed on continents near the equator). Instead of covering only 1/3 of the continents, as modern ice ages do, they were global in scale. In your reading, you will see examples of hypothesis' that involve threshold and feedback mechanisms of all four spheres…

- **Earth's Disappearing Glaciers**: scientists point out that atmospheric carbon dioxide has increased about 50 percent over the past century. Human caused?? Glaciers and Ice Sheets are melting (above is Boulder Glacier in Montana, 1932; see next slide), which could have profound effects on our planet; sea level rises and fresh water flowing into the ocean may eventually alter ocean currents and global climate.

17.6 Ice ages

Boulder Glacier (area!) 1988... Completely gone...

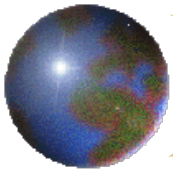


TABLE 13.1 Selected Examples of Ice Melt around the World

Name	Location	Measured Loss
Arctic Sea Ice	Arctic Ocean	Has shrunk by 6 percent since 1978, with a 14 percent loss of thicker, year-round ice. Has thinned by 40 percent in less than 30 years.
Greenland Ice Sheet	Greenland	Has thinned by more than a meter a year on its southern and eastern edges since 1993.
Columbia Glacier	Alaska	Has retreated nearly 13 kilometers since 1982. In 1999, retreat rate increased from 25 meters per day to 35 meters per day.
Glacier National Park	Rocky Mtns., U.S.	Since 1850, the number of glaciers has dropped from 150 to fewer than 50. Remaining glaciers could disappear completely in 30 years.
Antarctic Sea Ice	Southern Ocean	Ice to the west of the Antarctic Peninsula decreased by some 20 percent between 1973 and 1993, and continues to decline.
Pine Island Glacier	West Antarctica	Grounding line (where glacier hits ocean and floats) retreated 1.2 kilometers a year between 1992 and 1996. Ice thinned at a rate of 3.5 meters per year.
Larsen B Ice Shelf	Antarctic Peninsula	Calved a 200 km^2 iceberg in early 1998. Lost an additional 1,714 km^2 during the 1998–1999 season, and 300 km^2 so far during the 1999–2000 season.
Tasman Glacier	New Zealand	Terminus has retreated 3 kilometers since 1971, and main front has retreated 1.5 kilometers since 1982. Has thinned by up to 200 meters on average since the 1971–1982 period. Icebergs began to break off in 1991, accelerating the collapse.
Meren, Carstenz, and Northwall Firn Glaciers	Irian Jaya, Indonesia	Rate of retreat increased to 45 meters a year in 1995, up from only 30 meters a year in 1936. Glacial area shrank by some 84 percent between 1936 and 1995. Meren Glacier is now close to disappearing altogether.
Dokriani Bamak Glacier	Himalayas, India	Retreated by 20 meters in 1998, compared with an average retreat of 16.5 meters over the previous 5 years. Has retreated a total of 805 meters since 1990.
Ducsuogang Peak	Ulan Ula Mtns., China	Glaciers have shrunk by some 60 percent since the early 1970s.
Tien Shan Mountains	Central Asia	Twenty-two percent of glacial ice volume has disappeared in the past 40 years.
Caucasus Mountains	Russia	Glacial volume has declined by 50 percent in the past century.
Alps	Western Europe	Glacial area has shrunk by 35 to 40 percent and volume has declined by more than 50 percent since 1850. Glaciers could be reduced to only a small fraction of their present mass within decades.
Mt. Kenya	Kenya	Largest glacier has lost 92 percent of its mass since the late 1800s.
Speke Glacier	Uganda	Retreated by more than 150 meters between 1977 and 1990, compared with only 35–45 meters between 1958 and 1977.
Upsala Glacier	Argentina	Has retreated 60 meters a year on average over the last 60 years, and rate is accelerating.
Quelccaya Glacier	Andes, Peru	Rate of retreat increased to 30 meters a year in the 1990s, up from only 3 meters a year between the 1970s and 1990.

Worldwatch Institute, www.worldwatch.org/alerts/000306.html