Fundamentals of Earth Sciences (ESO 213A)

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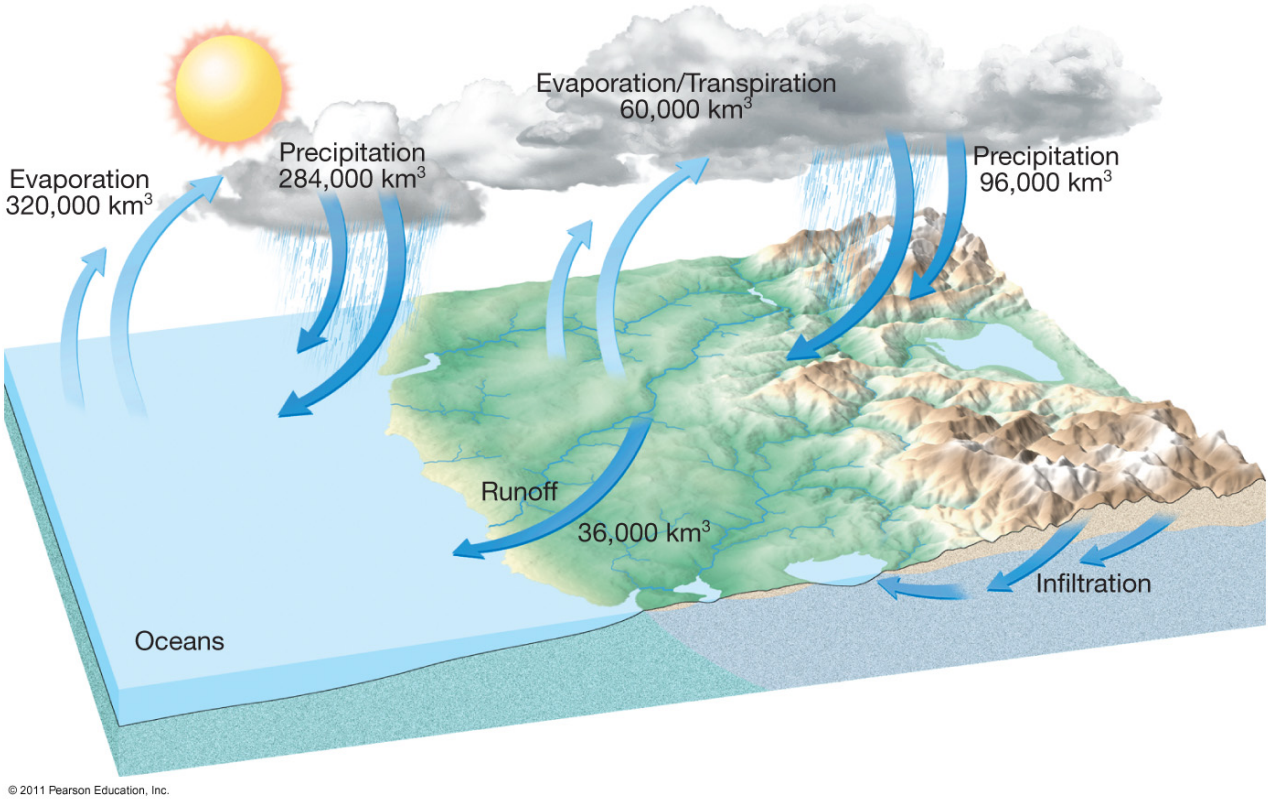
Hydrological Cycles (Glaciers)

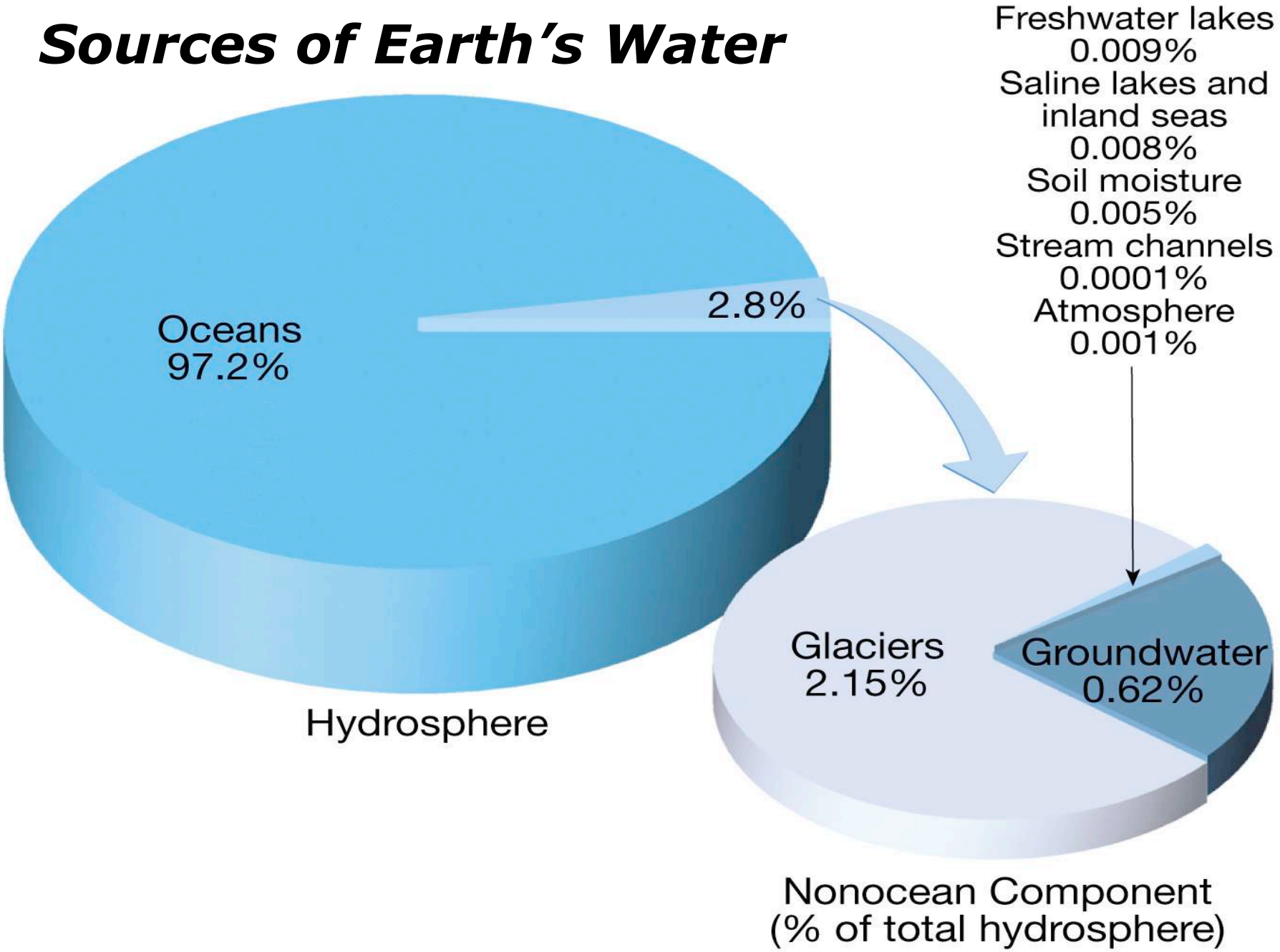
Previous class: Landslides

Hydrologic Cycle

- The hydrologic cycle is a summary of the circulation of Earth's water supply among different spheres: hydrosphere, atmosphere, geosphere, biosphere
- Processes involved in the hydrologic cycle are:
  - Precipitation
  - Evaporation
  - Infiltration
  - Runoff
  - Transpiration



Sources of Earth's Water



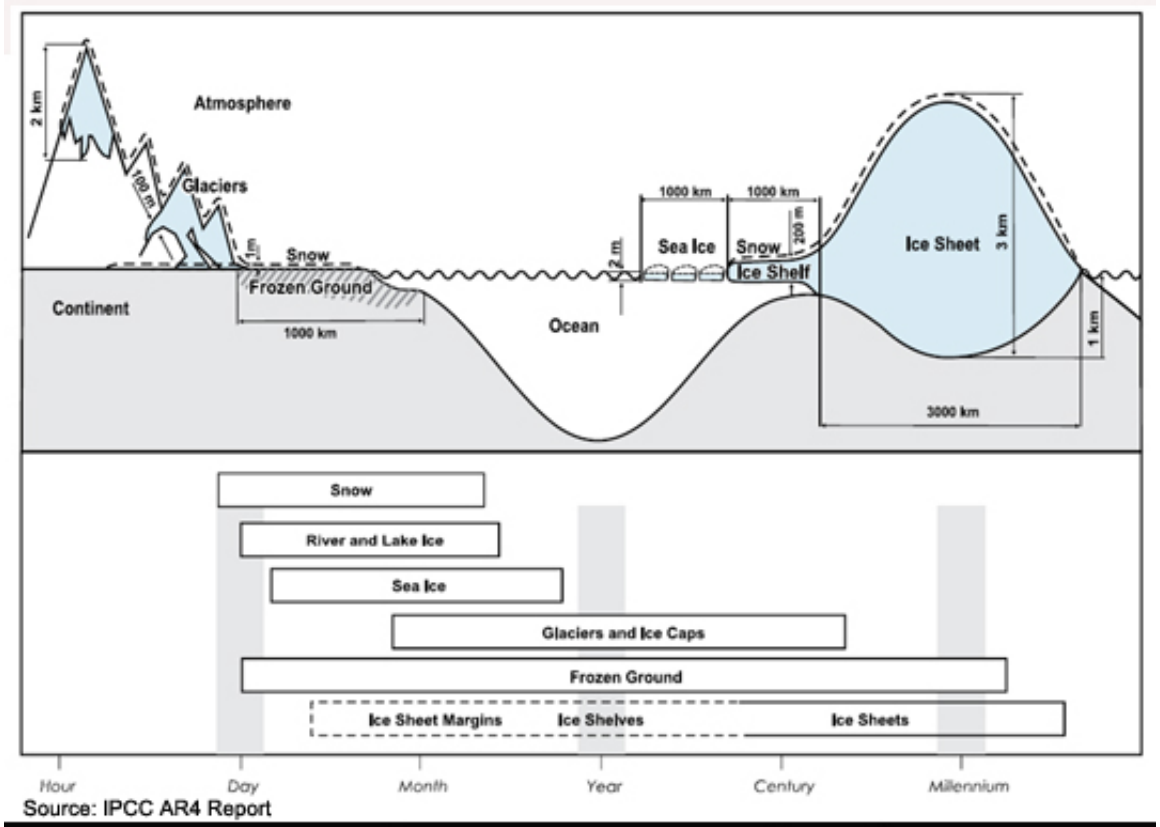
Cryosphere

Some places on Earth are so cold that water is a solid—ice or snow. Such places where water is in its solid form, where low temperatures freeze water and turn it into ice. The word "cryosphere" comes from the Greek word for cold, "kryos

Components

The main components of the cryosphere are :-

- Glaciers & ice caps.
- Snow.
- River and lake ice.
- Sea ice.
- Ice shelves.
- Ice sheets.
- Frozen Ground.



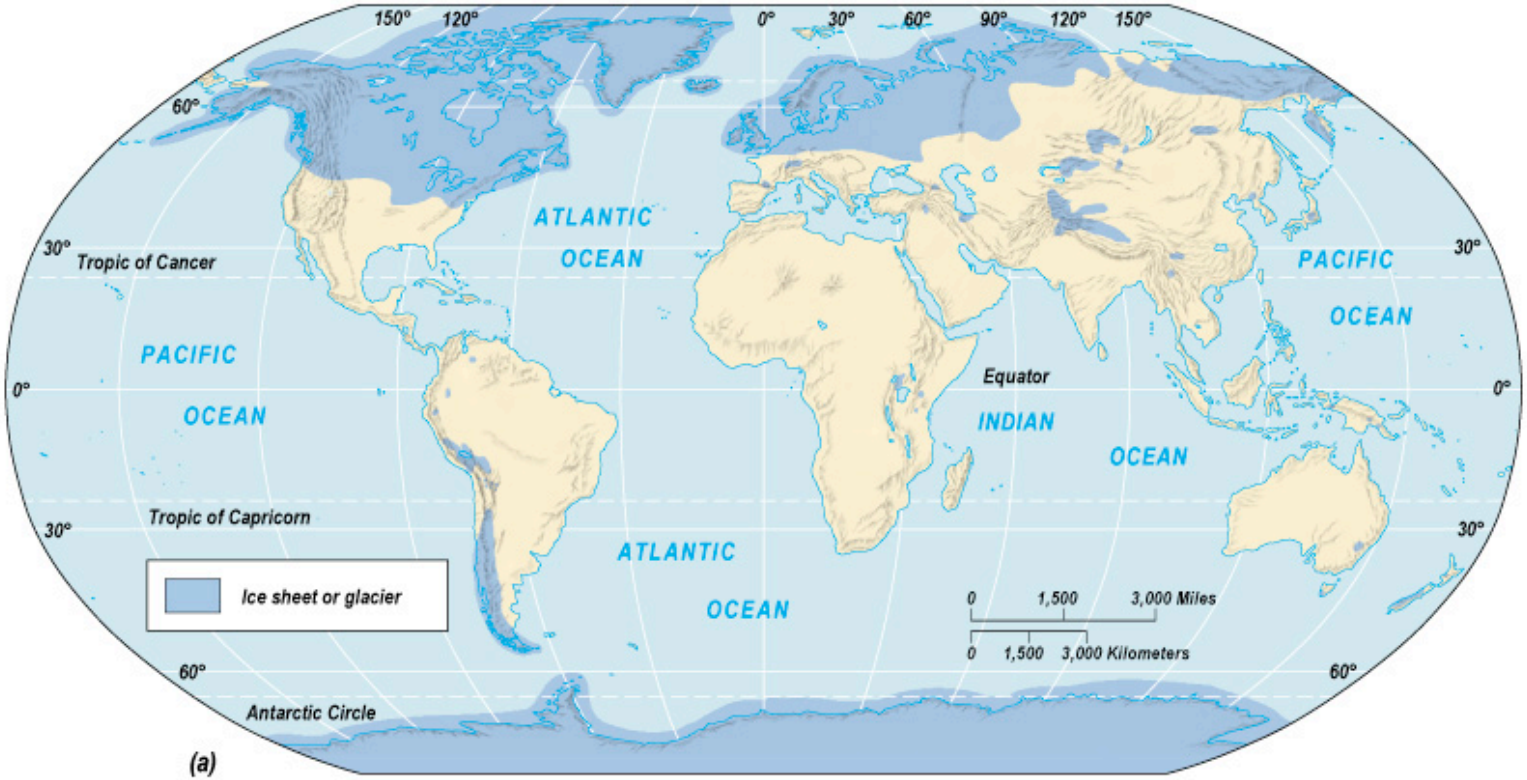
COMPONENTS OF THE CRYOSPHERE AND THEIR TIME SCALES

Glaciers

Glaciers are parts of two basic cycles:

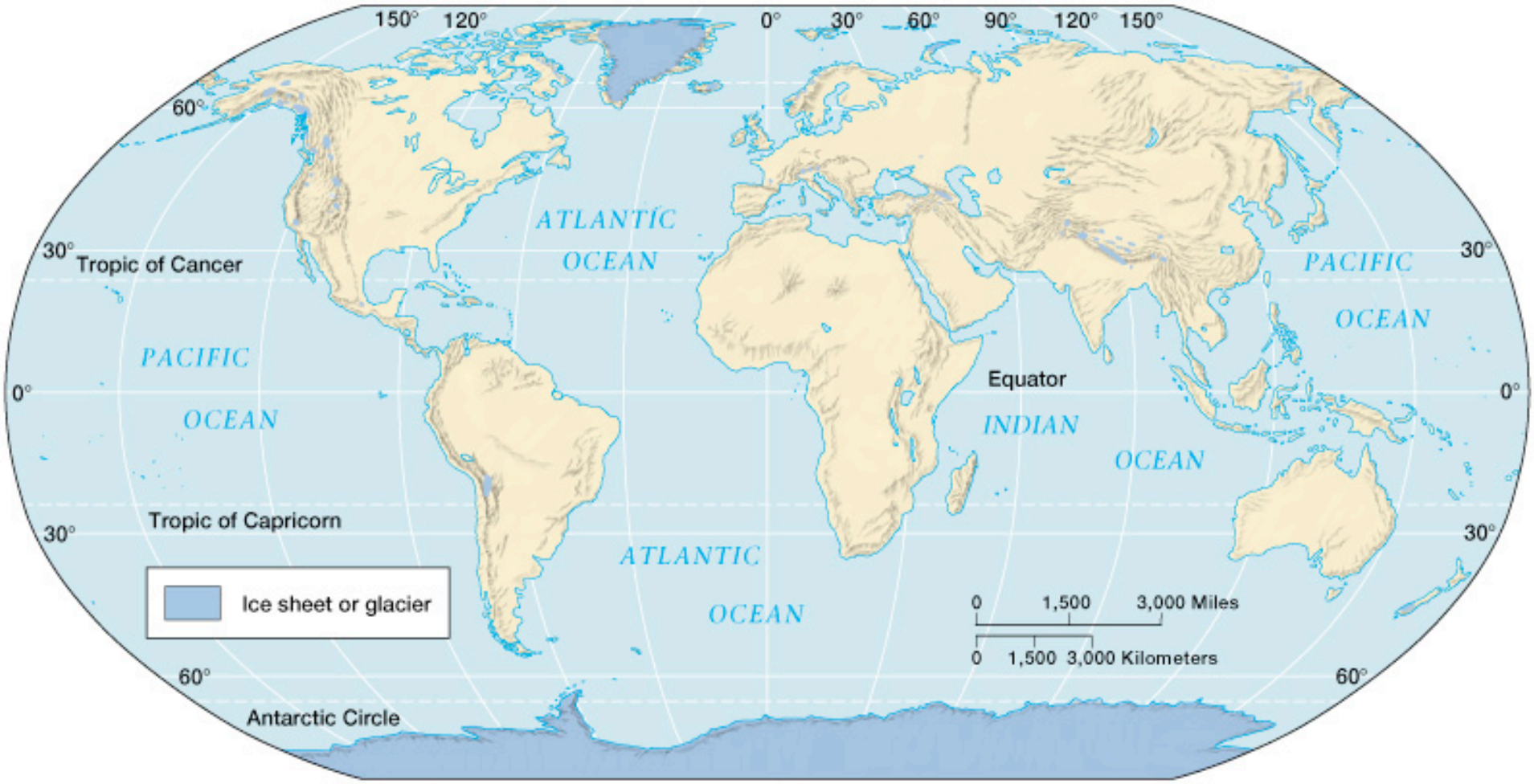
1. Hydrologic cycle
2. Rock cycle

A glacier is a thick mass of ice that originates on land from the accumulation, compaction, and recrystallization of snow.



Maximum Extent of Pleistocene Glaciation - 1/3 of land surface

Most recent glacial maximum peaked 18,000 years ago and is considered to have ended 10,000 B.P.



Current Extent of Glaciation -
about 10% of land surface

Glaciers

Types of glaciers

Valley (alpine) glaciers

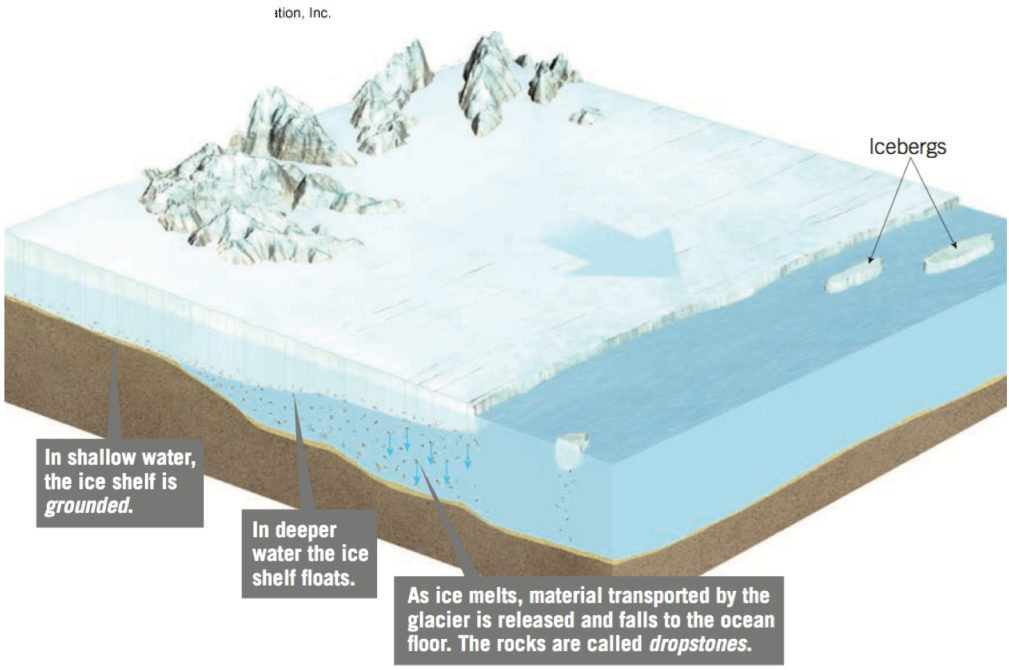
- Exist in mountainous areas
- Flow down a valley from an accumulation center at its head

Ice sheets

- Exist on a larger scale than valley glaciers
- Forms due to low annual solar radiation
- Two major ice sheets on Earth are over Greenland and Antarctica.
- Often called *continental ice sheets*
- Ice flows out in all directions from one or more snow accumulation centers.

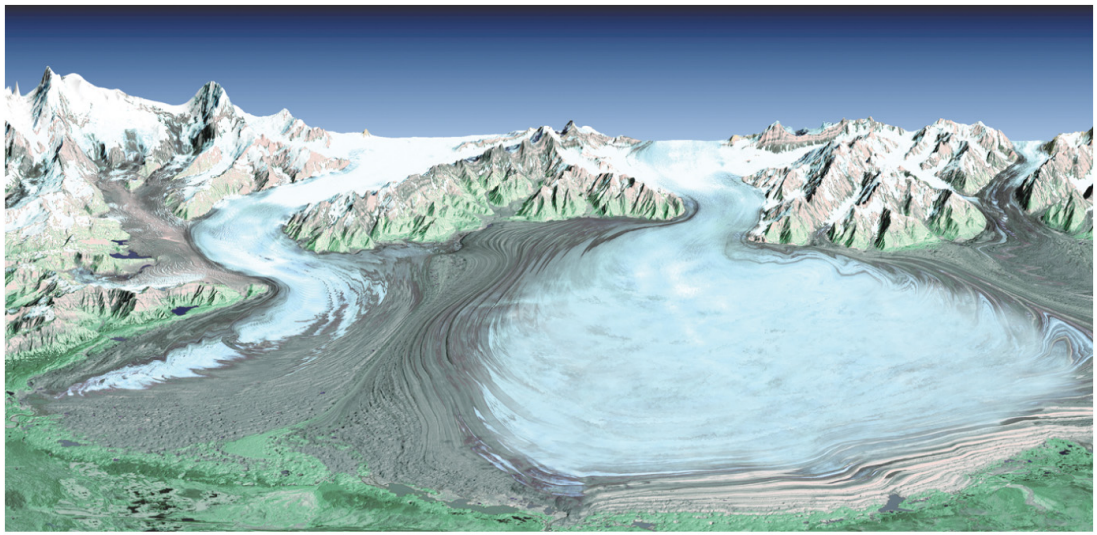
Glaciers

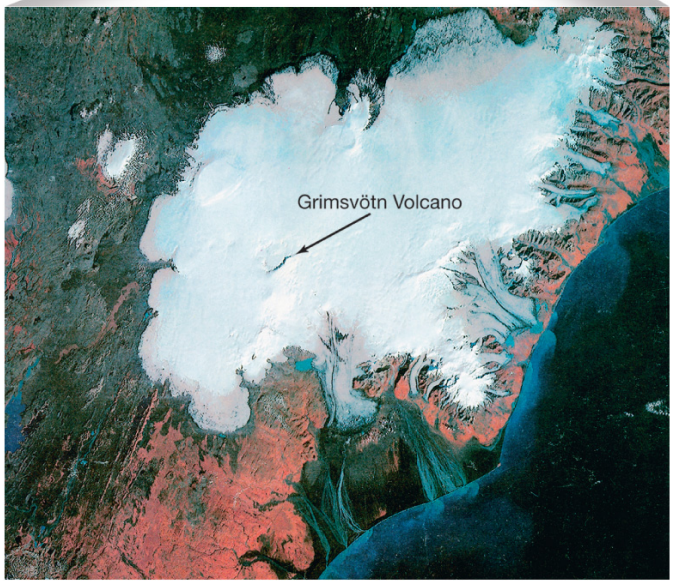
- Ice sheets continued
  - Along portions of the Antarctic coast, glacial ice flows into the adjacent ocean, creating features called *ice shelves*
  - Ross, Filchner, Larson B
  - Some are unstable and break apart → *icebergs*



Glaciers

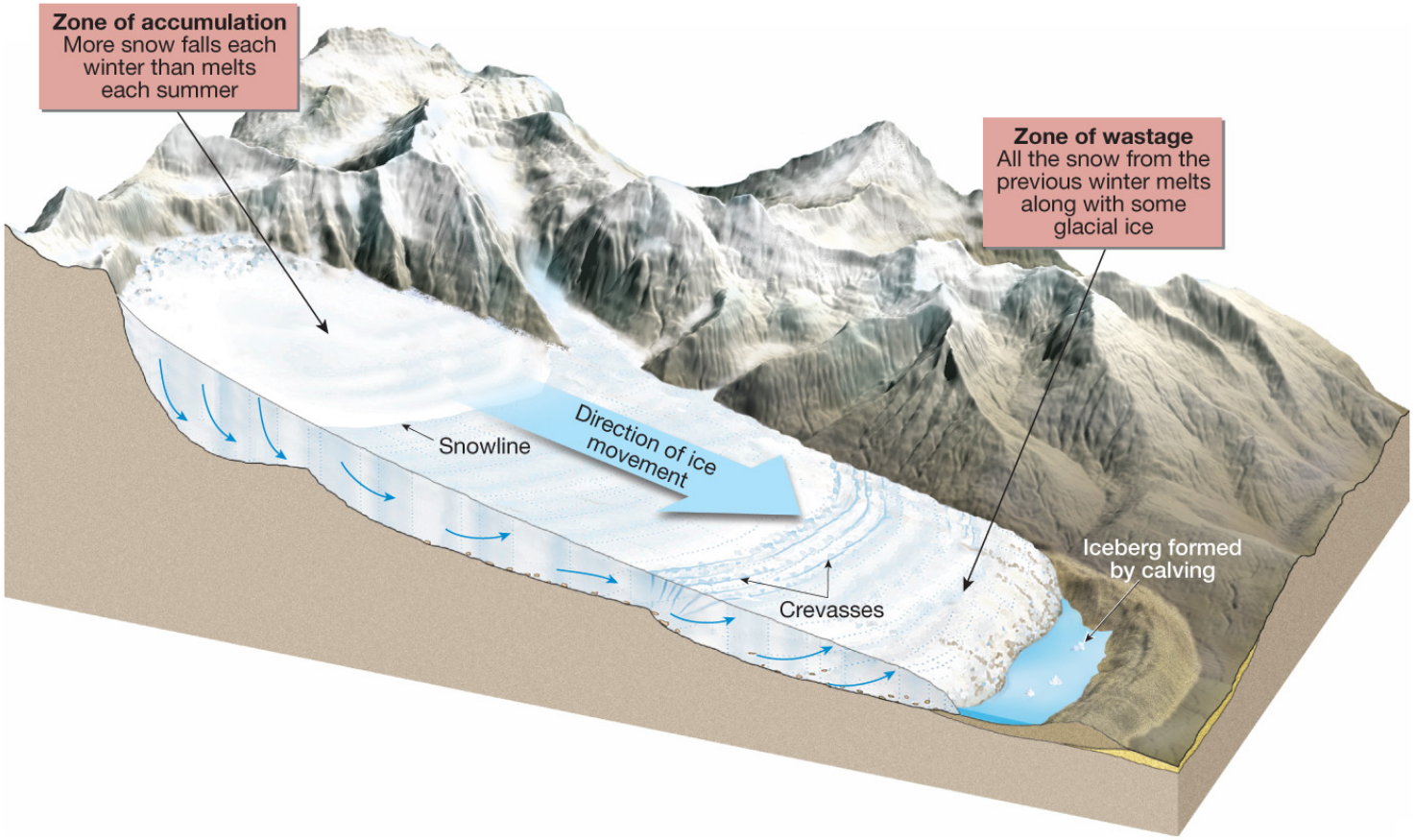
- Other types of glaciers
  - Ice caps – similar, but much smaller, than ice sheets
  - Piedmont glaciers – form when one or more alpine glaciers emerge from the confining walls of mountain valleys





Formation of Glacial Ice

- Glaciers form in areas where more snow falls in winter than melts during the summer (very high latitudes and altitudes)
- The elevation above which snow remains throughout the year is called *snowline*



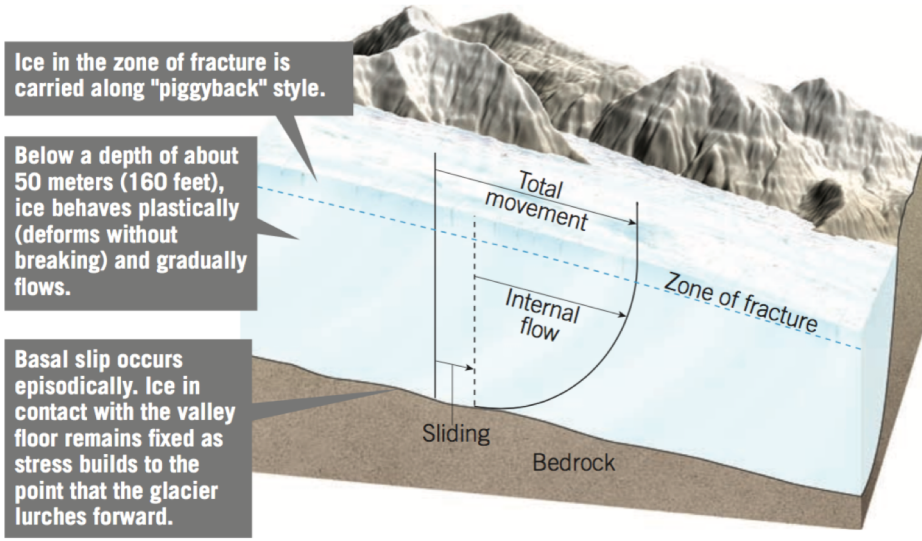
Formation of Glacial Ice

- Steps in the formation of glacial ice
  - Air infiltrates *snow*
  - Snowflakes become smaller, thicker, and more spherical
  - Air is forced out
  - Snow is recrystallized into a much denser mass of small grains called *firn*
  - Once the thickness of the ice and snow exceeds 50 meters, firn fuses into a solid mass of interlocking ice crystals—*glacial ice*

Movement of Glacial Ice

Movement is referred to as flow

- Two basic types
  1. Plastic flow
     - » Occurs within the ice
     - » Under pressure (equivalent to weight of ~ 50 m of ice), ice behaves as a plastic material
  2. Basal slip
     - » Entire ice mass slipping along the ground
     - » Most glaciers are thought to move by this sliding process
- Zone of fracture
  - – Occurs in the uppermost 50 meters
  - – Tension causes crevasses to form in brittle ice



Movement of Glacial Ice

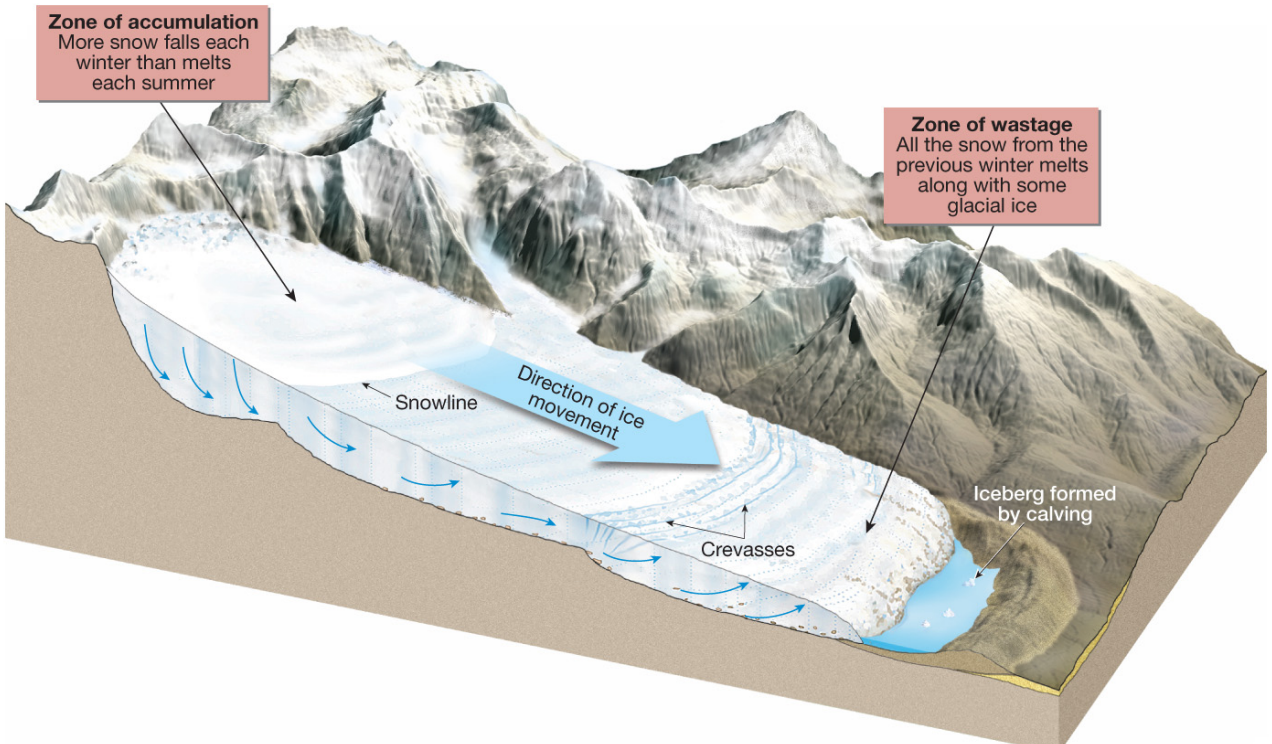
- Rates of glacial movement
  - Unlike streamflow, glacial movement is not obvious
  - Average velocities vary considerably from one glacier to another
  - Rates of up to several meters per day
  - Some glaciers exhibit periods of extremely rapid movements called surges (flow rates are as much as 100 times the normal rate)

Movement of Glacial Ice

Glacial Zones

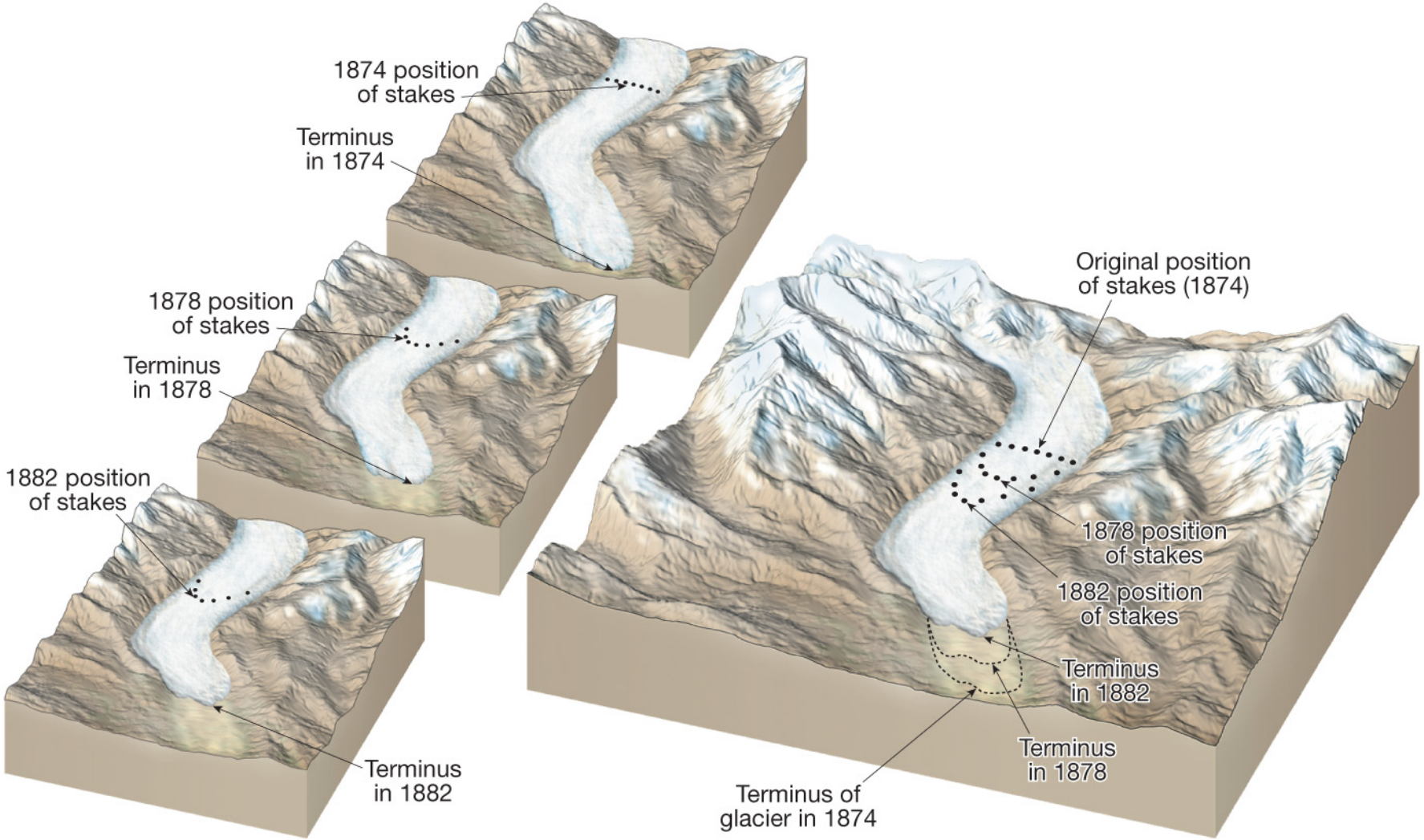
- The *zone of accumulation* is the area where a glacier forms
- The outer limits = snowline
- Elevation of the snowline varies greatly (from sea level in polar regions to 5000 m near equator)
- The *zone of wastage* is the area where there is a net loss of ice due to:
  - Melting
  - Calving—the breaking off of large pieces of ice (icebergs where the glacier has reached the sea)

The Glacial Budget



Movement of Glacial Ice

- Budget of a glacier
  - **Whether the margins of a glacier is advancing, retreating, or remaining stationary depends on the *glacial budget* = balance, or lack of balance, between accumulation at the upper end and loss at the lower end**
    - If accumulation exceeds loss (ablation), the glacial front advances
    - If ablation increases and/or accumulation decreases, the ice front will retreat

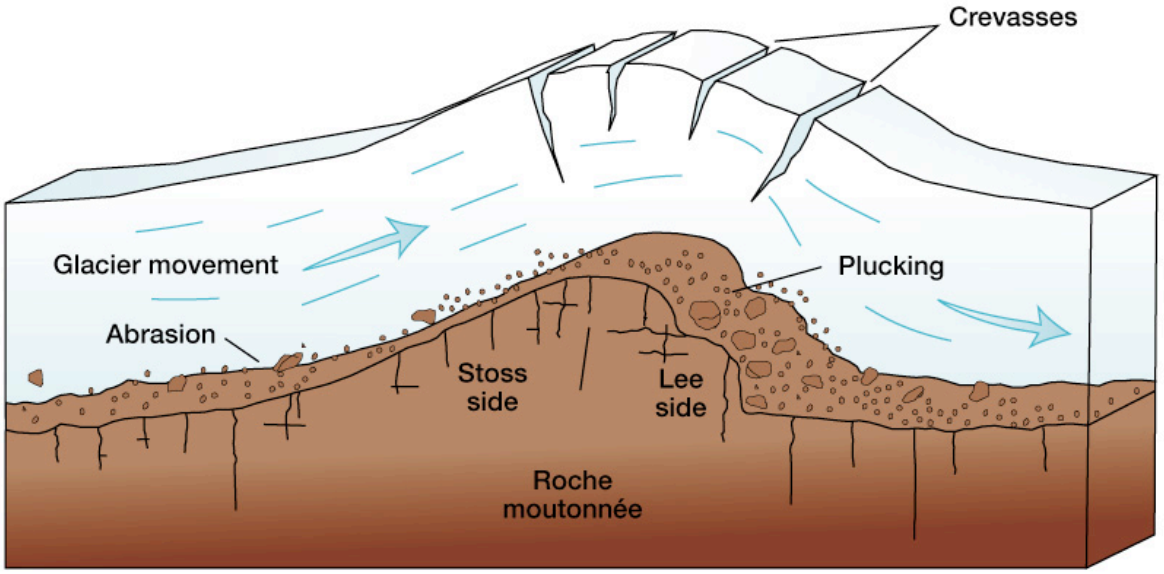


Glacial Erosion

- Glaciers are capable of great erosion and sediment transport;
- Can carry huge blocks – *glacial erratics* (sometimes as far as 500 – 1000 km from their source area)

Glacial Erosion

- Glaciers erode the land primarily in two ways:
  1. Plucking - lifting of rocks and incorporation into ice
  2. Abrasion - rocks within the ice acting like sandpaper to smooth and polish the surface below
  - Glacial abrasion produces:
    - Rock flours (pulverized rock)
    - Glacial striations (scratches and grooves in the bedrock, in case of large rock fragments)
    - Highly polished surface (in case of finer particles)



Glacial Erosion

A.

Glacial striations

B.

Glacially polished granite

Differential erosion by ice is largely controlled by four factors:

(1) rate of glacial movement;
(2) thickness of the ice;
(3) shape, abundance, and hardness of the rock fragments contained in the ice at the base of the glacier; and
(4) the erodibility of the surface beneath the glacier.

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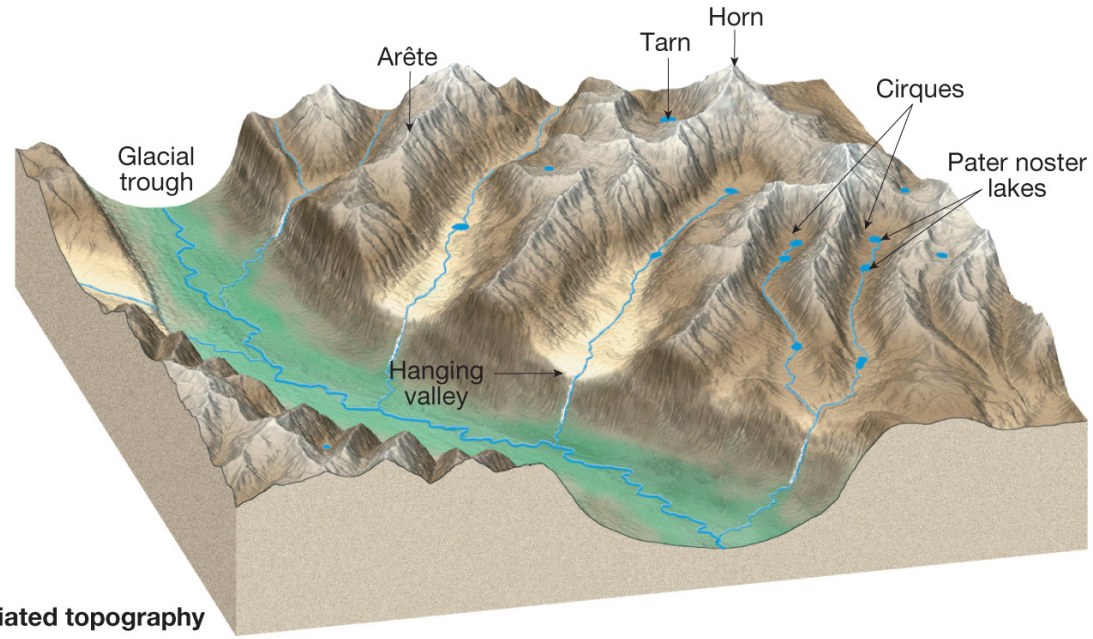
Landforms Created by Glacial Erosion

Glaciated Valleys

Glacial troughs – mountain valleys transformed during glaciation (wider, deeper, U-shaped)

Hanging valleys – after glaciation, valleys of tributary glaciers are left standing above the main glacial trough

U-Shaped Glacial Trough, Norway



C. Glaciated topography

Landforms Created by Glacial Erosion

Glaciated Valleys

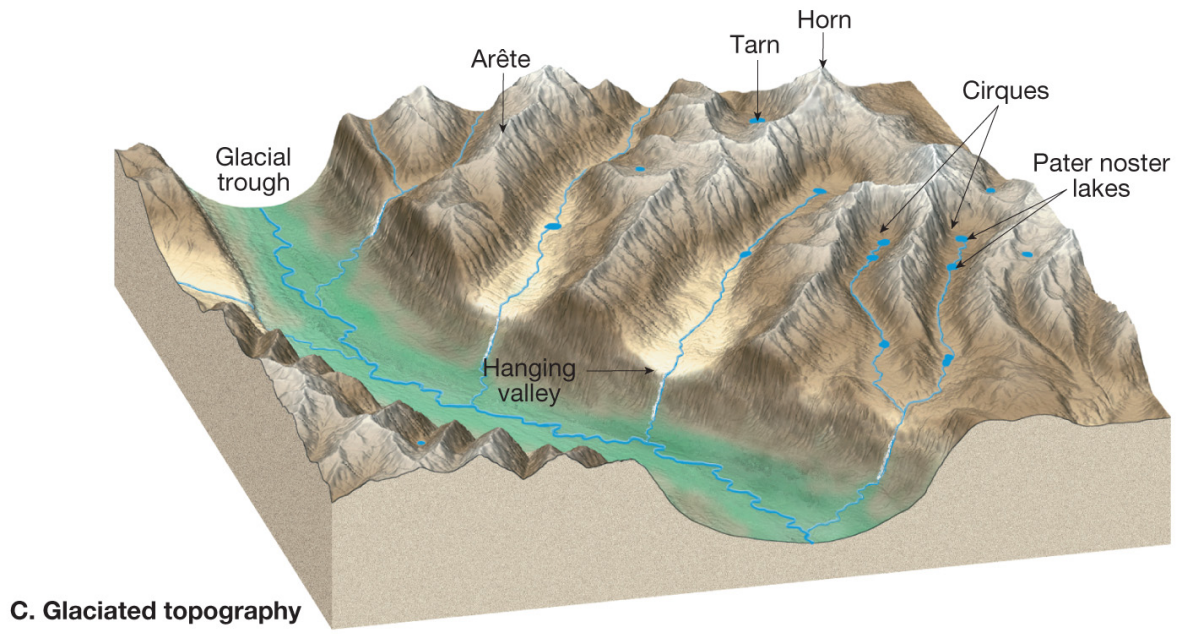
Pater noster lakes – in a glacial trough

Cirques – at the head of a glacial valley, bowl-shaped depressions

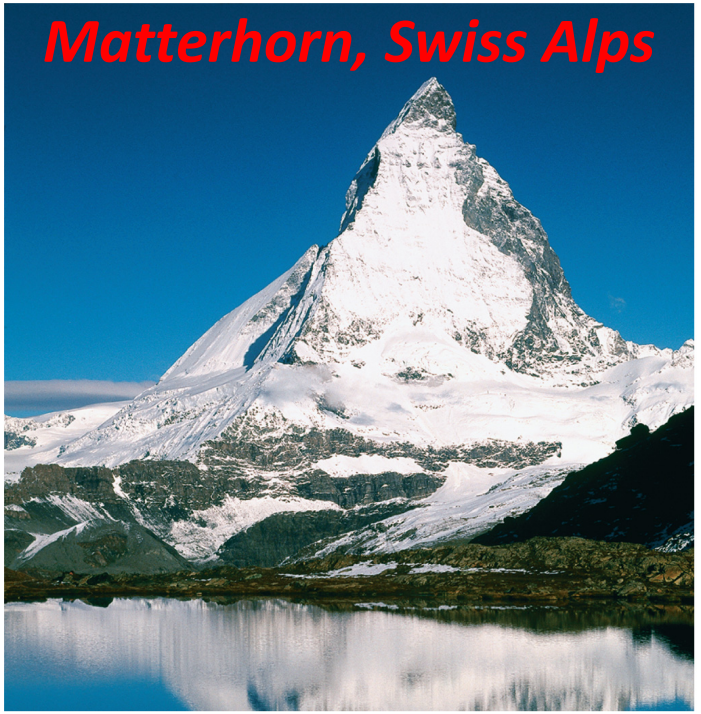
Tarns – small lake in the cirque basin

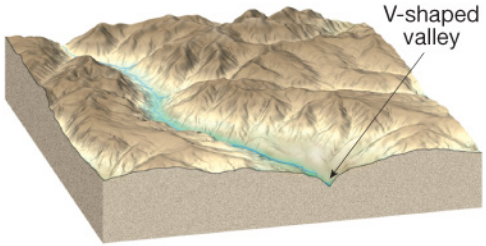
Arêtes – sharp-edged ridges

Horns – sharp pyramid-like peaks

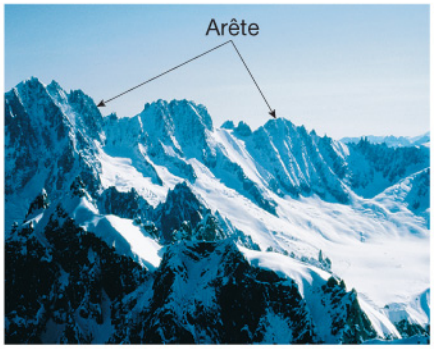


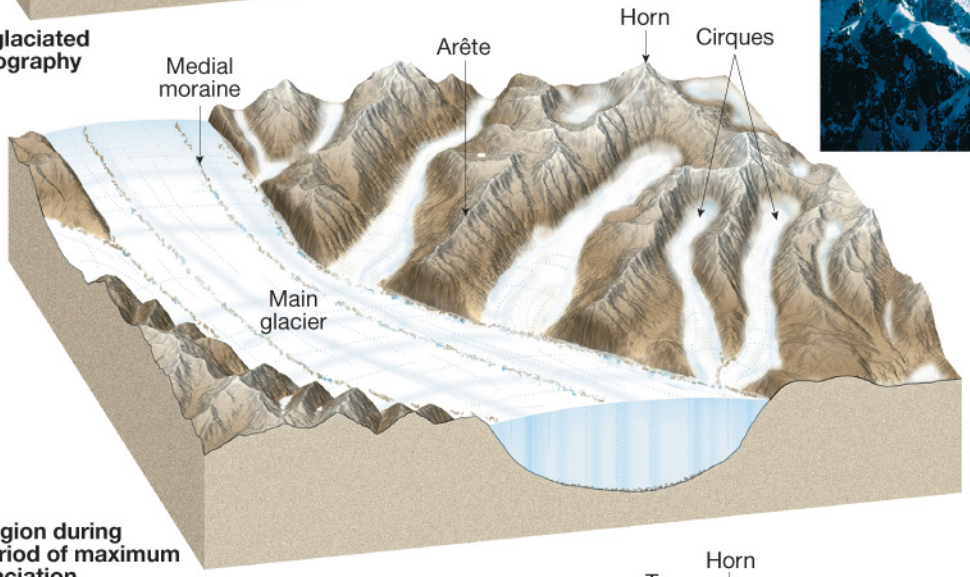
C. Glaciated topography



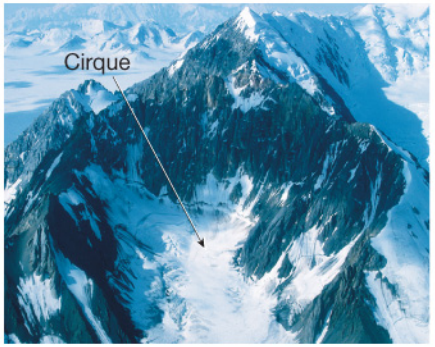


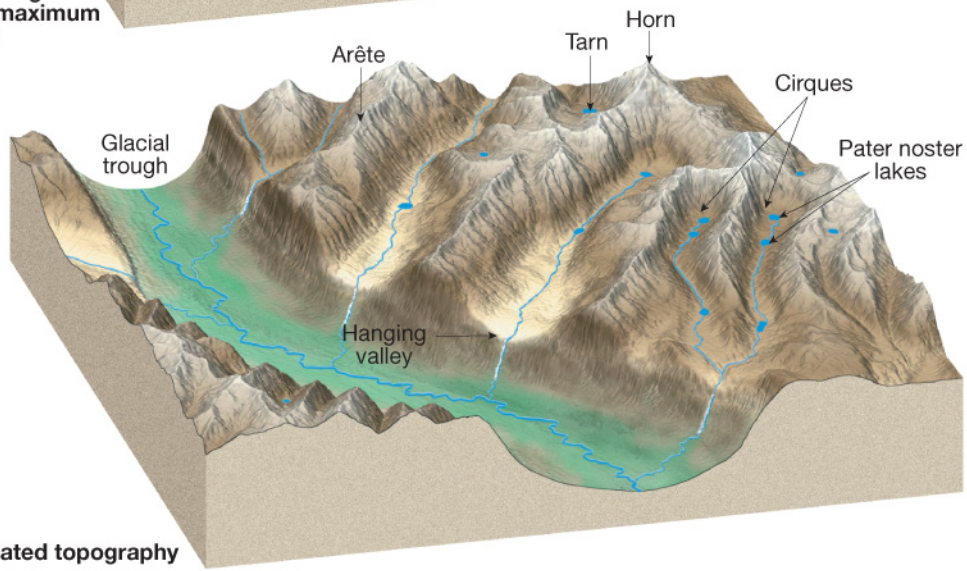
A. Unglaciated topography





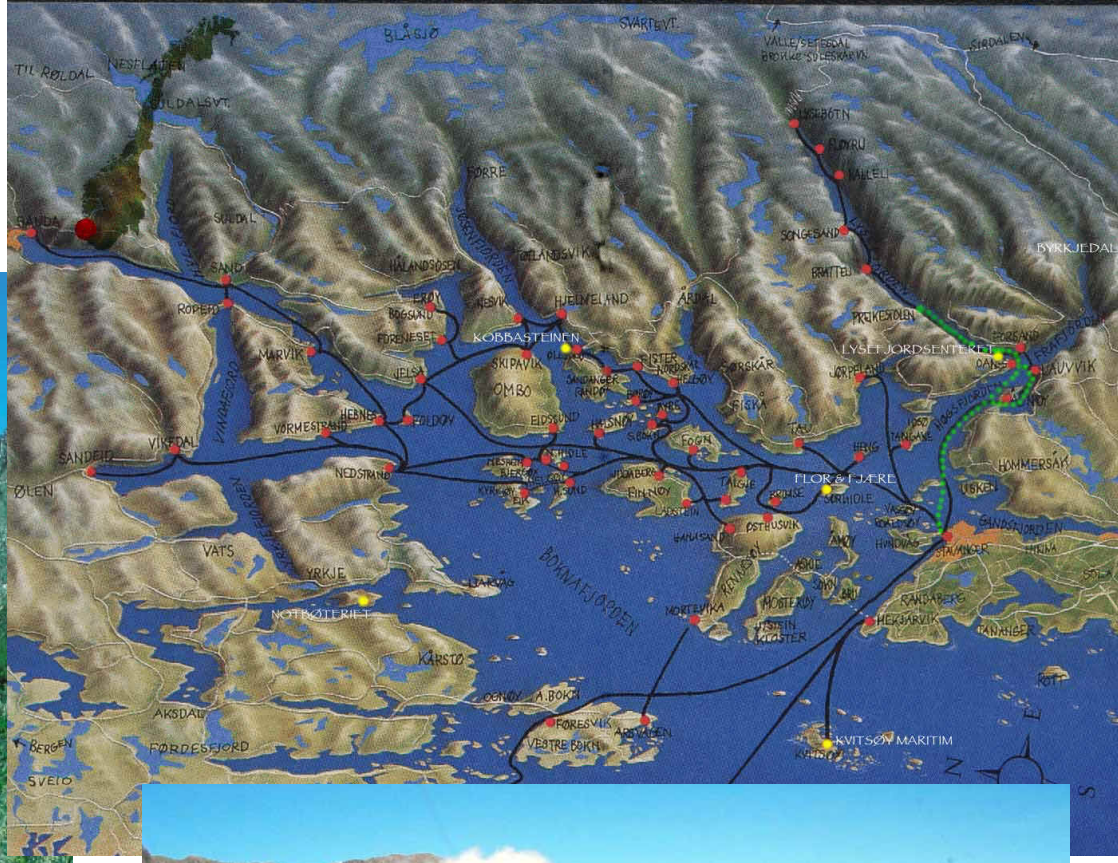
B. Region during period of maximum glaciation





C. Glaciated topography

Fjords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RANDA
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KOBBASTEINEN
SKIPAVIK
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MARVIK
VIKEDAL
SANDEID
ØLEN
NEDSTRAND
VATS
YRKJE
NOTRØTERIET
KÅRSTØ
AKSDAL
FØRDESFJORD
BERGEN
SVEIO
BØKNAFJORDEN
FLOR & FJÆRE
HUMMERSAK
STAVANGER
SANDNESKJEN
KVITSØY MARITIM
LYSET JORDSENTERET
BYRKJEDAL

Glacial Deposits

- *Glacial drift* refers to all sediments of glacial origin
- Different from sediments laid down by other erosional agents: *consist of mechanically-weathered rock debris that underwent little or no chemical weathering prior to deposition*
    - Types of glacial drift
        - Till—material that is deposited directly by the ice (unstratified, unsorted)
        - Stratified drift—sediments laid down by glacial meltwater

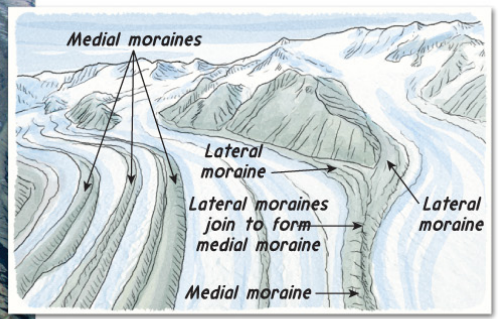
Glacial Till Is Typically Unstratified and Unsorted

• ***Glacial erratics*** are enormous boulders transported and deposited by glaciers, often far from their source region.

Landforms made of till

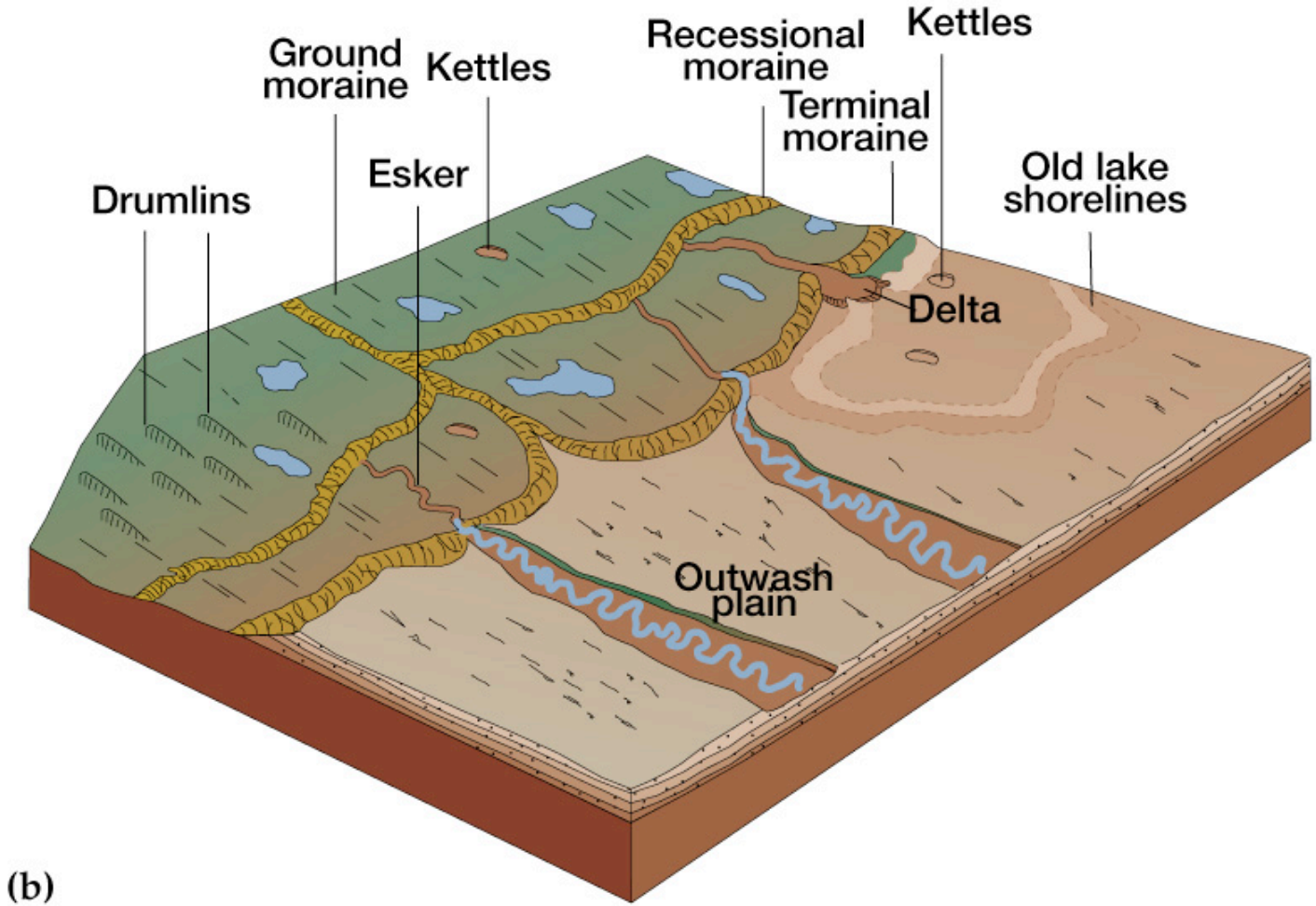
Glacial Deposits

- *Moraines*
  - Layers or ridges of till
- Moraines produced by alpine glaciers
  - Lateral moraine – ridges of till paralleling the sides of the valley
  - Medial moraine – created when two alpine glaciers coalesce to form a single ice stream
  - Layers or ridges of till
- Other types of moraines (valley glaciers; ice sheets)
  - End moraine – forms at the terminus of a glacier; equilibrium between ablation and ice accumulation
  - Terminal moraine – outermost end moraine; marks the limit of the glacial advance

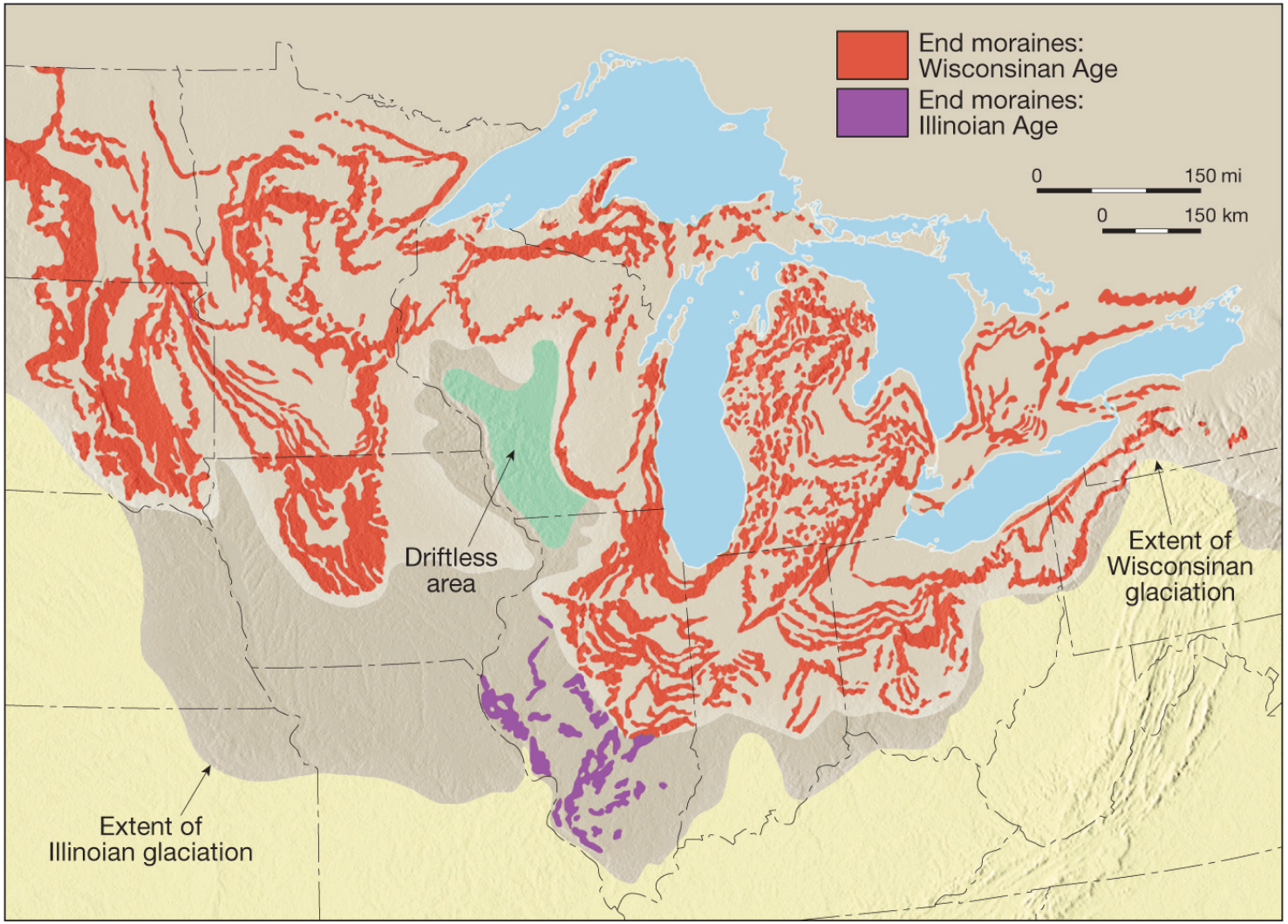


Geologist's Sketch

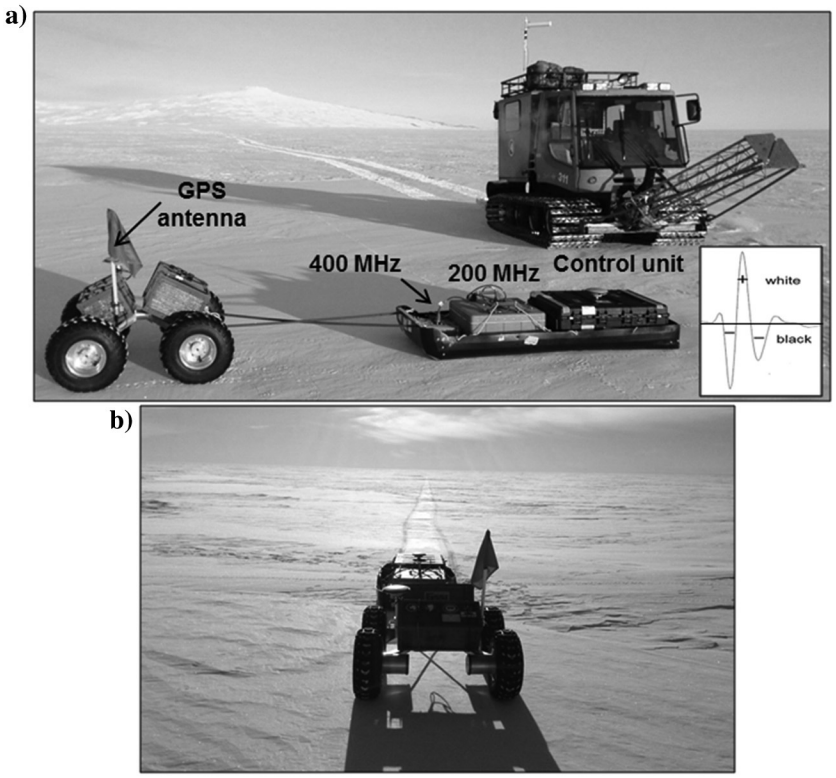
Continental Glaciers or Ice Sheets

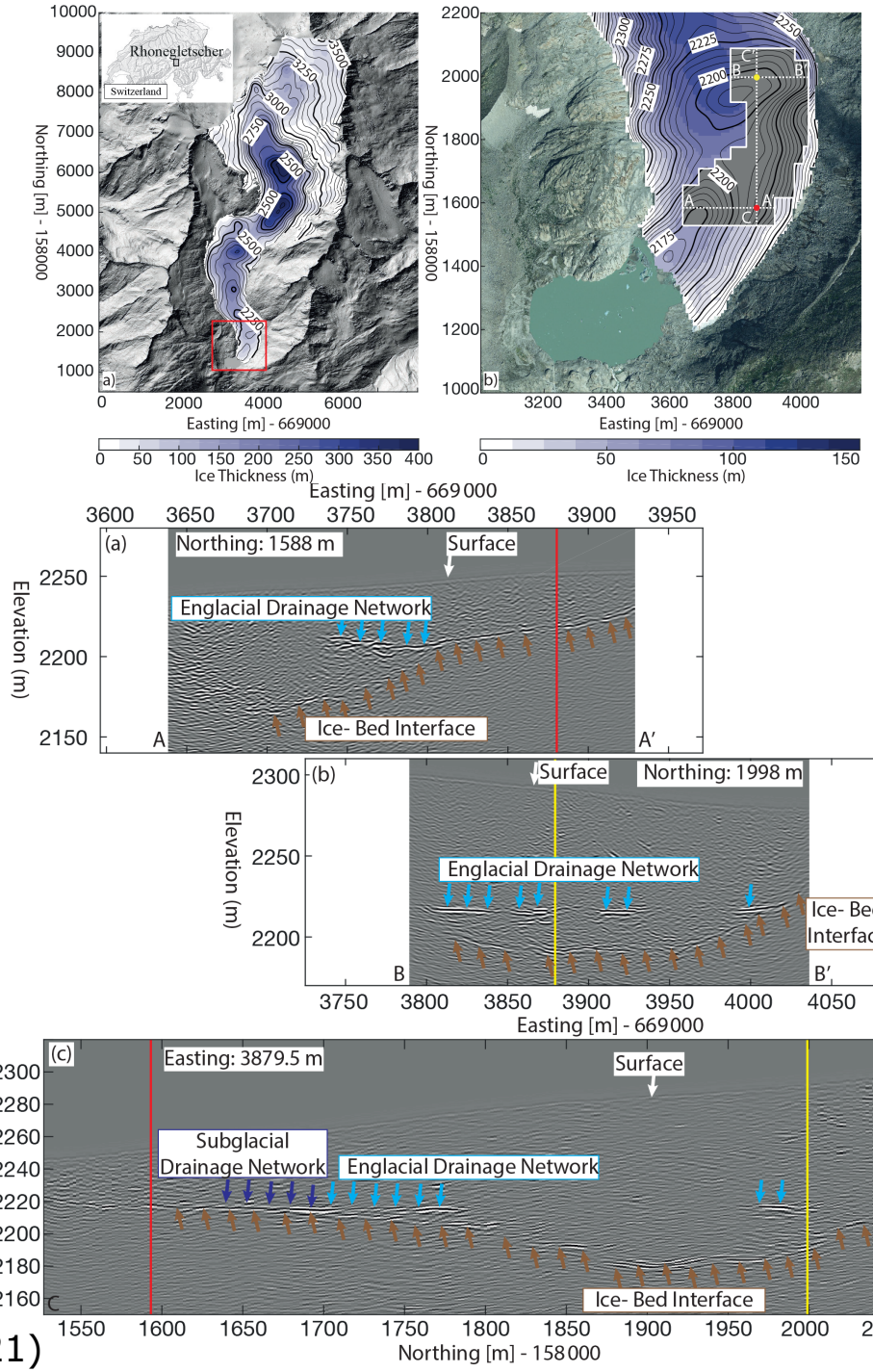


End Moraines of the Great Lakes Region



GPR studies

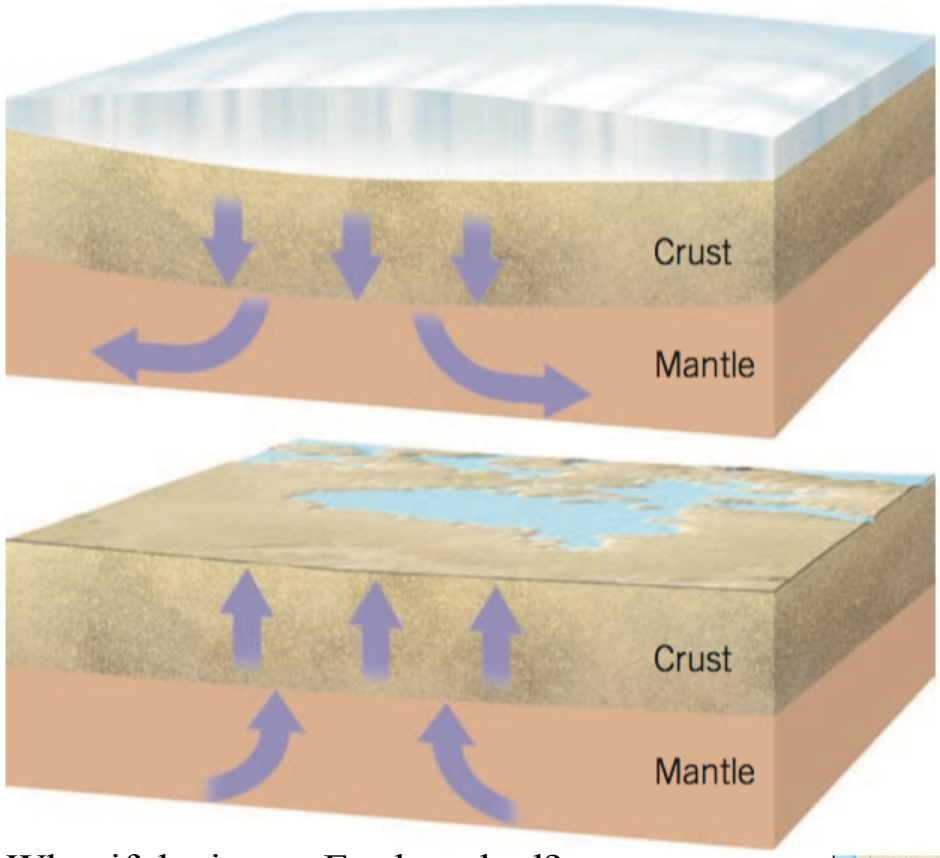




(a) GPR inline profile (perpendicular to ice flow direction): the glacier surface, drainage network, and basal interface are marked, and the red line represents the crossing point for profile (c). (b) GPR inline profile (perpendicular to ice flow direction): the yellow line represents the crossing point for profile (c). (c) GPR crossline profile (parallel to ice flow direction).

Church et al., (2021)

In northern Canada and Scandinavia, where the greatest accumulation of glacial ice occurred, the added weight caused downwarping of the crust.



Sea Level Changes Over the Past 20,000 Years

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What if the ice on Earth melted?

- Slightly more than 2% of the world's water is tied up in glaciers.
- Antarctic ice sheet
  - 80 % of the world's ice
  - 65 % of Earth's fresh water
  - Covers almost one and a half times the area of the United States
  - If melted, sea level would rise 60 to 70 meters.

Indian glaciers: Drang-Drung Glacier (Ladhak)

Indian glaciers

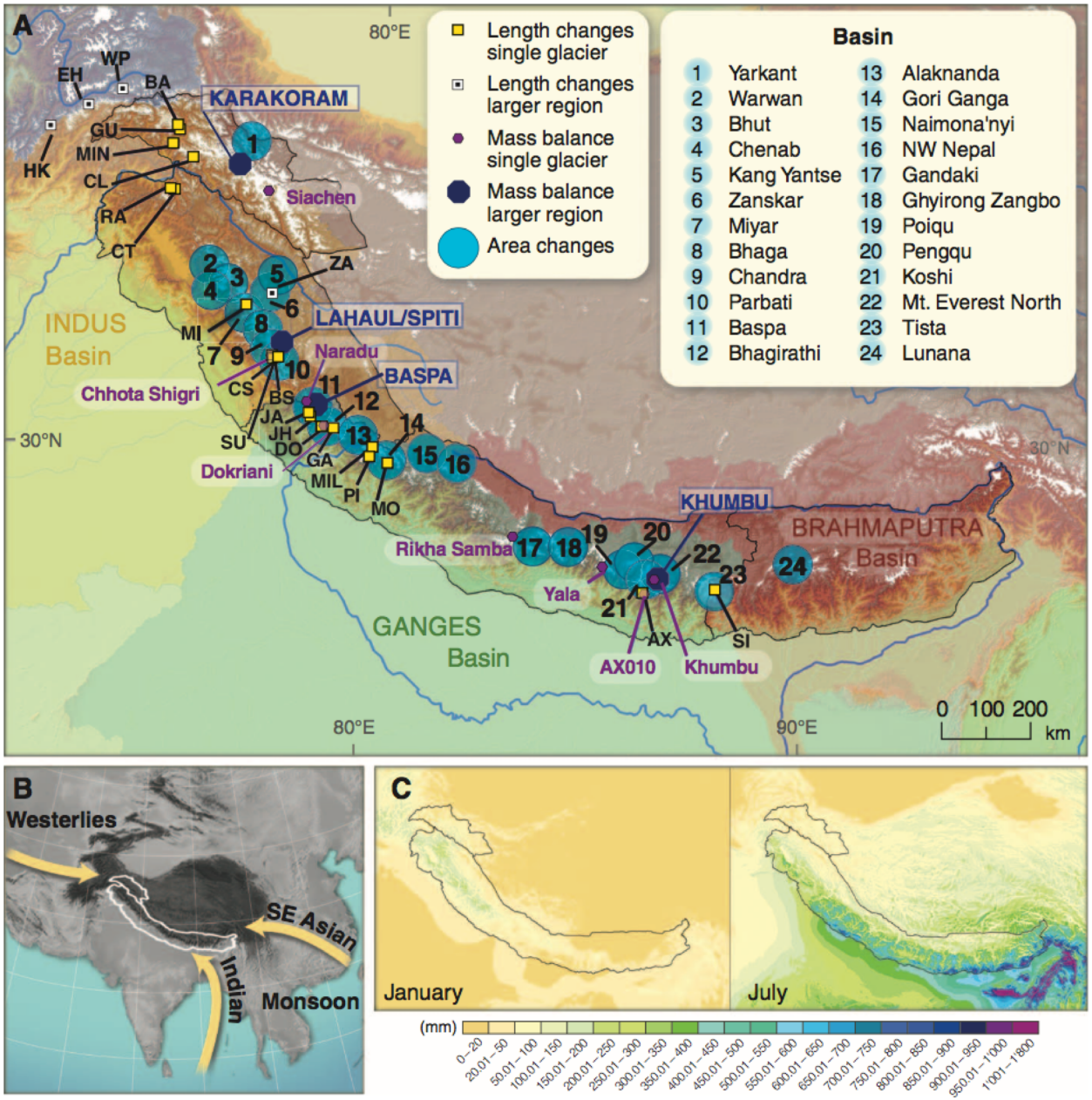
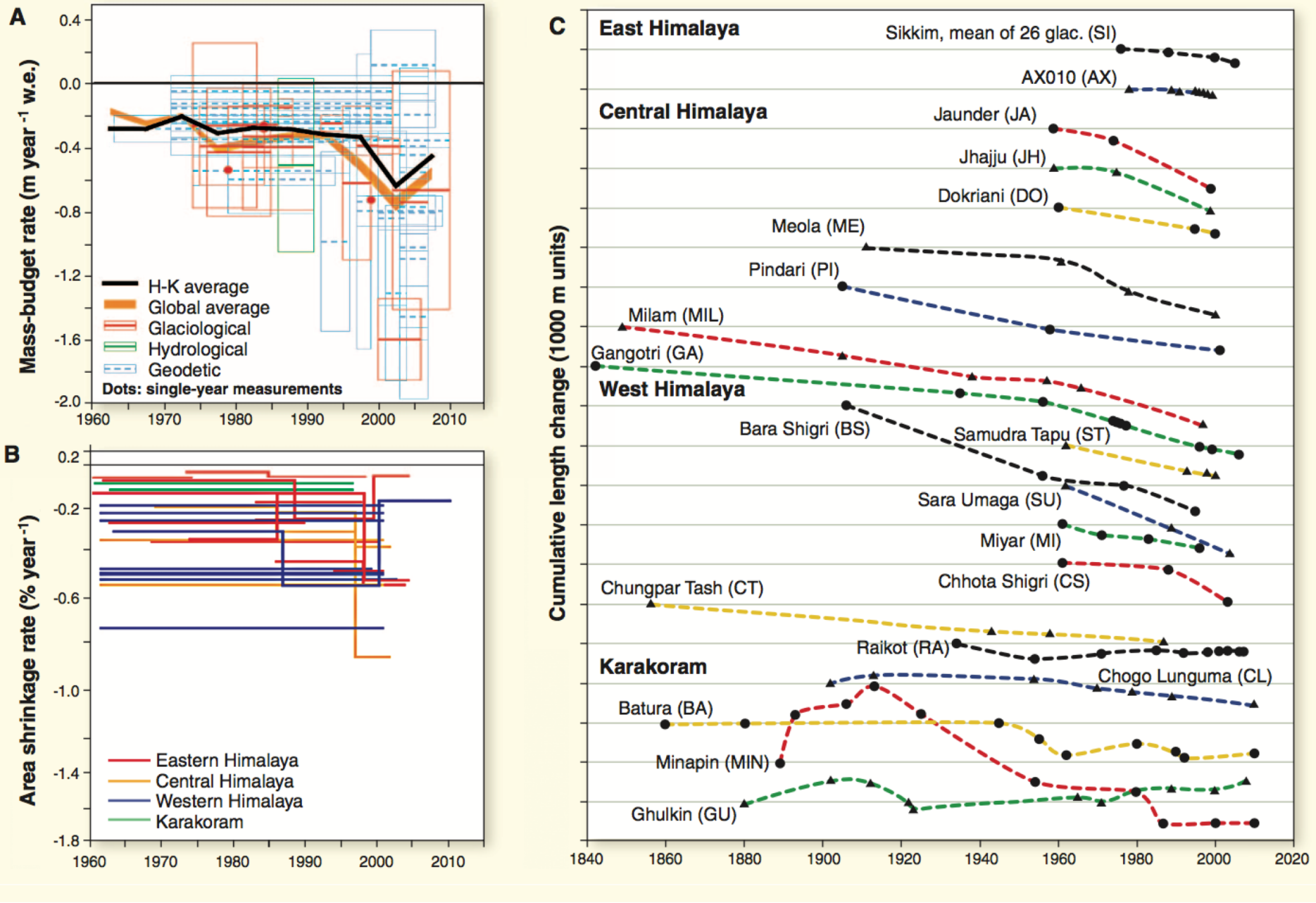


Fig. 1. (**A**) Map of the Karakoram and Himalaya showing the major river basins and the locations of measured rates of change in area and of a sample of glacier length change and mass budget measurements (*4*) (tables S3, S5, and S6). (**B**) Main wind systems. (**C**) Mean precipitation in January and July. [Source: (*9*)]

State & Fate of Himalayan Glaciers

Bolch et al., 2012, Science



Bolch et al., 2012, Science

Causes of Glaciation

- *Ice Age* - began between 2 and 3 million years ago, during mainly the *Pleistocene Epoch*

  - very complex event, characterized by glacial / interglacial cycles that occurred about every 100,000 years (~ 20 cycles)

- Any successful theory must account for:
  - What causes the onset of glacial conditions
  - What caused the alteration of glacial and interglacial stages that have been documented for the Pleistocene epoch

Causes of Glaciation

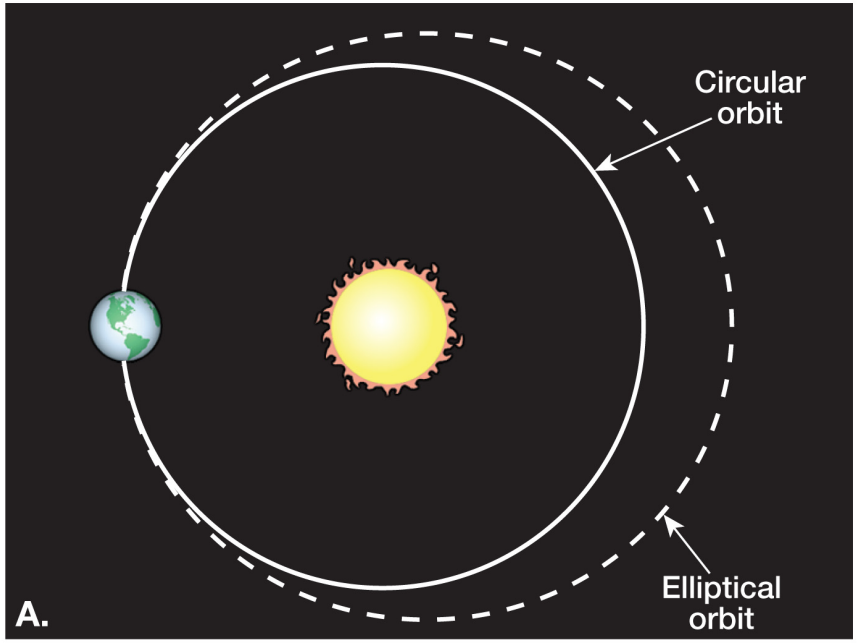
- Variations in Earth's orbit

  Milankovitch hypothesis – based on the premise that variations in incoming solar radiation are a main factor in controlling Earth's climate

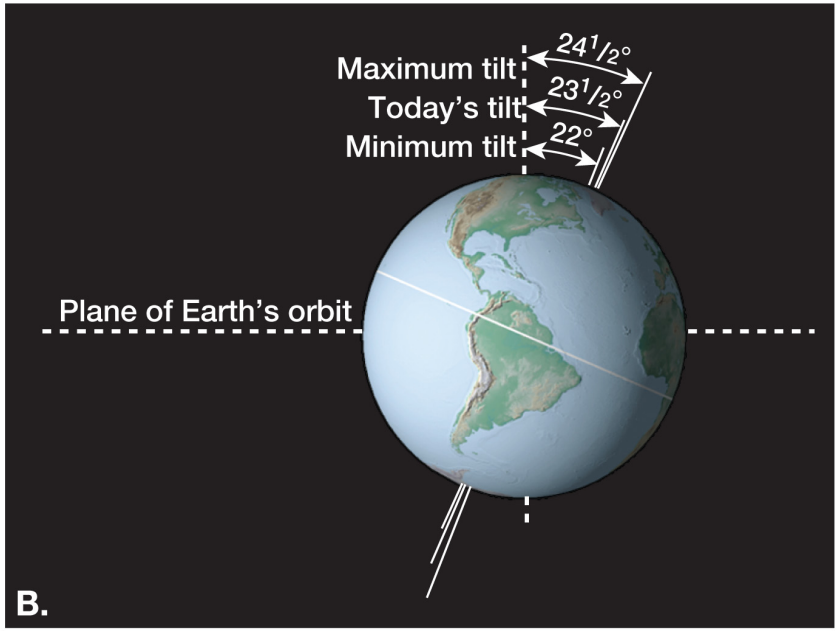
  - Shape (eccentricity) of Earth's orbit varies
  - Angle of Earth's axis (obliquity) changes
  - Earth's axis wobbles (precession)

  - Changes in climate over the past several hundred thousand years are closely associated with variations in the geometry of Earth's orbit.

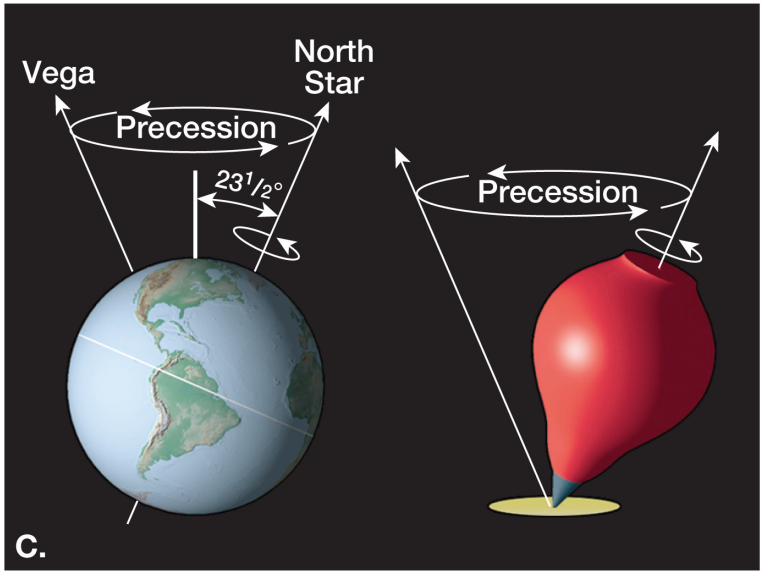
Orbital Variations



Cycle: 100,000 years



Cycle: 41,000 years



Cycle:

26,000 years

Other factors:

1. Reduction in Green house gasses
2. Changes in Ocean Circulation during Ice age