Glaciers and Climate

Summary

- Glaciers are permanent bodies of moving ice that consist largely of recrystallized snow.
- The phase behavior of water as a function of pressure and temperature is important to an understanding of how water and ice coexist on Earth.
- The ratio of oxygen isotopes in water can be used to measure Earth temperatures.
- Cirque glaciers, valley glaciers, fjord glaciers, piedmont glaciers, ice caps, ice sheets, and ice shelves have characteristic appearances.
- Ice in a temperate glacier is at the pressure melting point, and liquid water exists at the base of the glacier; in a polar glacier, ice is below the pressure melting point and is frozen to the rock on which it rests.
- Glaciers can form only at or above the snowline, which is close to sea level in polar regions and rises to high altitudes in the tropics.

- The mass balance of a glacier is measured in terms of accumulation and ablation. The equilibrium line separates the accumulation area from the ablation area and marks the level on the glacier where gain is balanced by loss.
- Temperate glaciers move as a result of internal flow and basal sliding. In polar glaciers, which are frozen to their bed, motion is much slower and involves only internal flow.
- Glaciers erode rock by plucking and abrasion. Rock debris, transported chiefly at the base and sides of a glacier, includes fragments of all sizes, from fine rock flour to large boulders.
- Mountain glaciers erode stream valleys into U-shaped glacial valleys with cirques at their heads. Fjords are excavated far below sea level by glaciers in high-latitude coastal regions.
- Glacial drift is sediment deposited by glaciers and glacial melt water. Whereas till is deposited directly by glaciers, glacial-marine drift is deposited on the seafloor from floating glacier ice. Stratified drift includes outwash deposited by melt water streams and ice-contact stratified drift deposited on or against stagnant ice.
- Ground moraine is built up beneath a glacier, whereas end moraines (both terminal and lateral) form at a glacier margin.

- Permafrost, a common feature of periglacial zones, is confined mainly to areas where annual air temperature is at least -5ƒC. It reaches a maximum thickness of at least 1500 m and is believed to have formed during glacial ages in subfreezing landscapes not covered by continental ice sheets.
- Permafrost can present unique engineering problems. Thawing commences when the vegetation cover is broken, leading to collapse and extreme instability of the ground surface.
- During glacial ages, huge ice sheets repeatedly covered northern North America and Eurasia, causing the crust beneath the ice to subside and world sea level to fall.
- Glacial ages have alternated with interglacial ages in which temperatures approximated those of today. Studies of marine cores indicate that more than 20 glacial-interglacial cycles occurred during the Pleistocene Epoch.
- Glacial eras in Earth history probably are related to the favorable positioning of continents and ocean basins, brought about by movements of lithospheric plates. The timing of glacial-interglacial cycles appears to be closely controlled by the Earth's precession as well as by changes in the eccentricity of the Earth's orbit and the tilt of the axis rotation, which affect the distribution of solar radiation received at the Earth's surface.

- Changes in the atmospheric concentration of carbon dioxide, methane, and dust may help explain the magnitude of global temperature lowering during glacial ages, while changes in ocean circulation may help explain the shifts between relatively stable glacial and interglacial modes of the climate system.
- Climatic variations on the scale of centuries and decades have been ascribed to fluctuations in energy output from the Sun and/or to injections of volcanic dust and gases into the atmosphere

Motivations

- Last 2.5 million years has been "Ice Age"
  - Currently in an interglacial period
  - Ice will return and engulf Seattle
- Homo Sapien: "Children of the Ice Age"
  - Species emerged and shaped by the climate
- Western Washington landscape:
  - shaped by glaciation
- Earth Climate
  - Geologic record
  - Clues to understand "Earth System"

Outline

- Glacial History
- Properties of water and ice
  - Phase diagram
  - Isotopes of oxygen
- Glaciers
  - Types
  - Mass balance
  - Snowline
  - Equilibrium
  - Terminus response
  - Flow

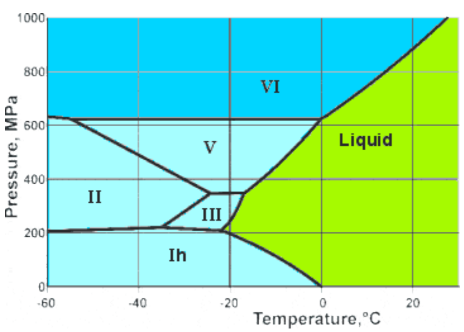
- Glacial Landforms
  - Cirques
  - Glacial valleys
  - Fjords
  - Abrasion features
  - Deposits
    - Till & Erratics
    - Drift
    - Moraines
    - Outwash
    - Eskers, Kames, Kettles
- Pleistocene Ice Age

The Ice Ages

- On average Earth is typically warmer
  - Rare shifts to “Glacial Ages”
- “Snowball Earth”
  - Snow reflects solar energy: too much snow cover -> earth cools even more -> runaway glaciation
  - Ice cover to equator (including oceans)
  - Recover only when CO_2 levels increase
- The “Glacial Ages”
  - 2.8 Ga (billion years)
  - 2.2 Ga
    - Caused by O_2 production of life?
  - 800 and 600 Ma (million years)
  - 450 Ma (very short duration)
  - 360-286 Ma
  - Current (Pleistocene) Glaciation

- Paleozoic glaciation (360-286 Ma)
  - Gondwanaland drifted over south pole
  - Provided evidence for “continental drift”
- Pleistocene glaciation
  - “End game” of Mesozoic climate collapse
  - Cooling began 30 my ago
  - Polar ice caps formed 12 my ago
  - Continental ice sheets began 2.5 my ago

H_2O Phase Diagram



- Many crystal phases of ice
- Unusual negative melt slope
  - Implications:
    - Pressure induces melting
    - Ice Ih is less dense than water!

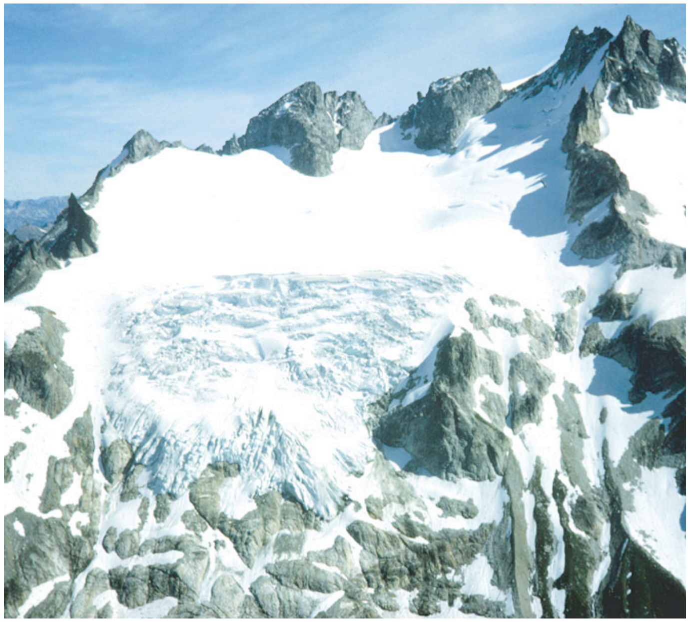
Ice on surface insulates aquatic life from cold.
Consider what would happen if ice sank to bottom.

Isotopes of Oxygen

- ^{16}O and ^{18}O have difference atomic mass
- $H_2{}^{16}O$ evaporates more readily from water than $H_2{}^{18}O$
- ^{16}O/ ^{18}O ratio in ocean is measure of ice cap volume

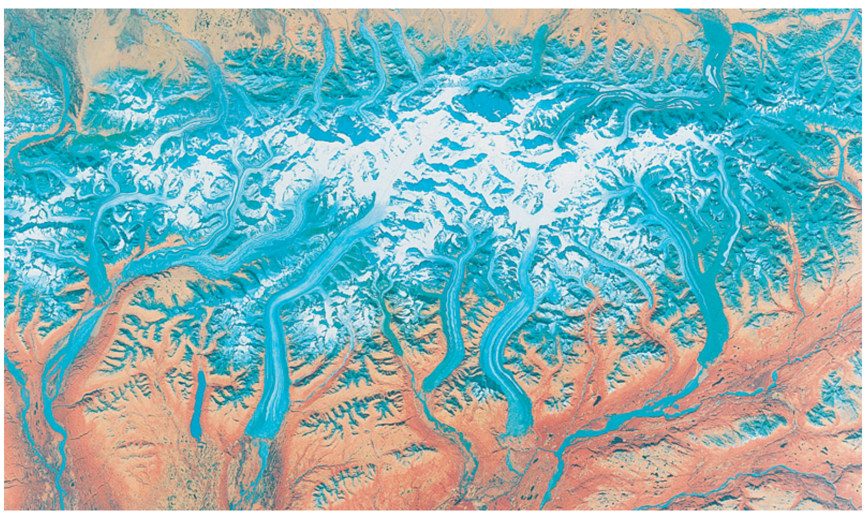
Glaciers

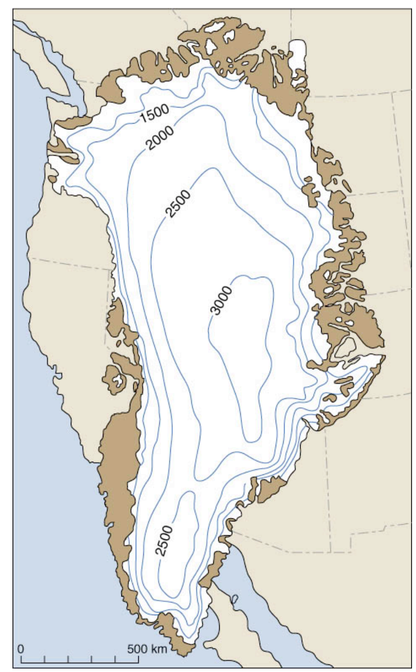
- accumulation exceeds melt off
- Weight leads to recrystallization into ice
- Gravity causes ice to flow

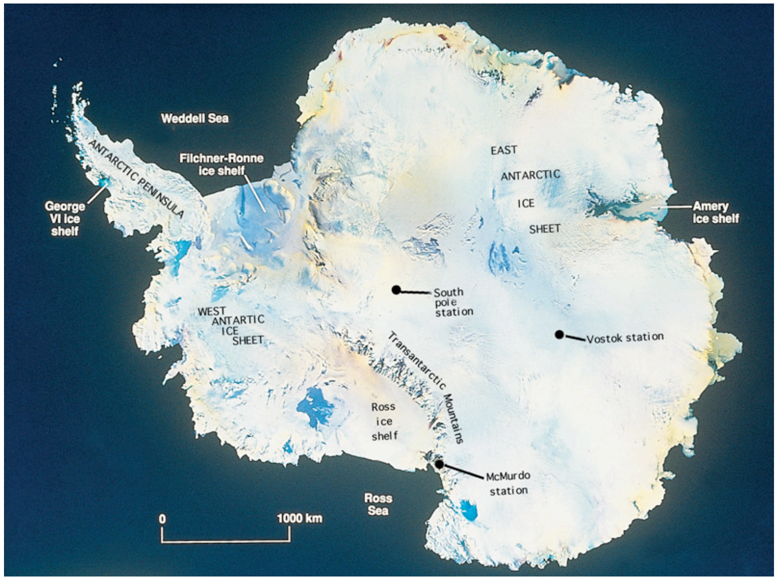


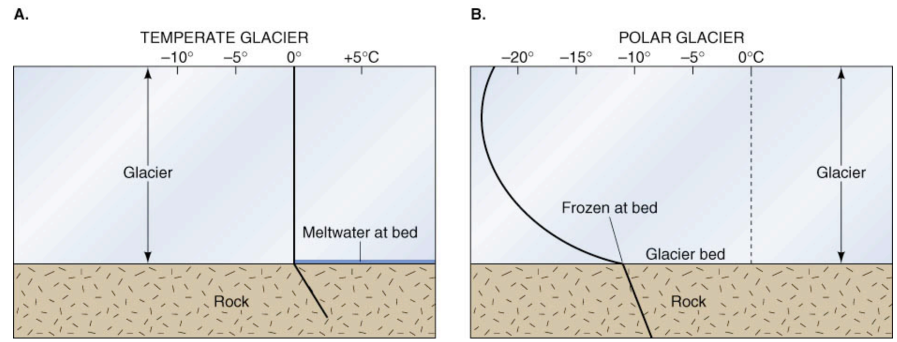
Glacier Types

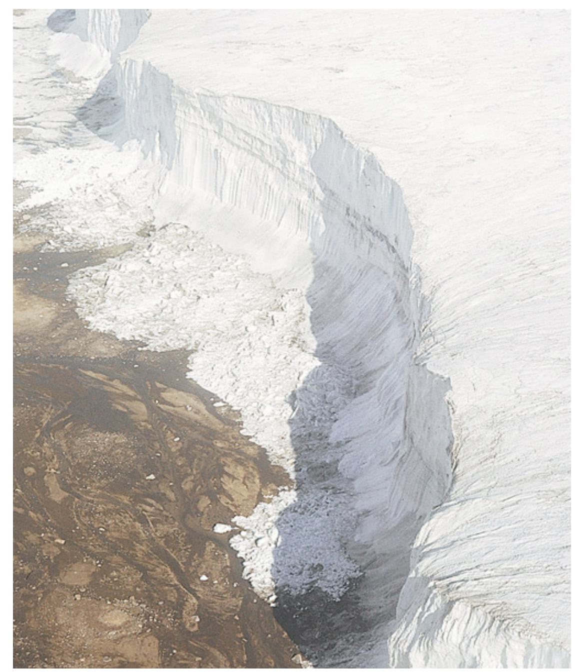
- Cirque, Valley, Fjord, Piedmont, Ice caps, Ice field, Ice sheet, Ice shelf




1500
2000
2500
3000
2500
0
500 km

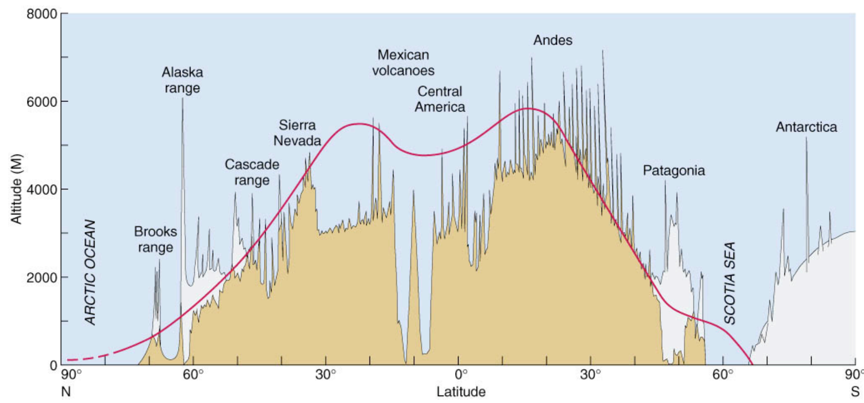

Weddell Sea
ANTARCTIC PENINSULA
Filchner-Ronne ice shelf
George VI ice shelf
EAST ANTARCTIC ICE SHEET
Amery ice shelf
South pole station
WEST ANTARTIC ICE SHEET
Vostok station
Transantarctic Mountains
Ross ice shelf
McMurdo station
Ross Sea
0
1000 km

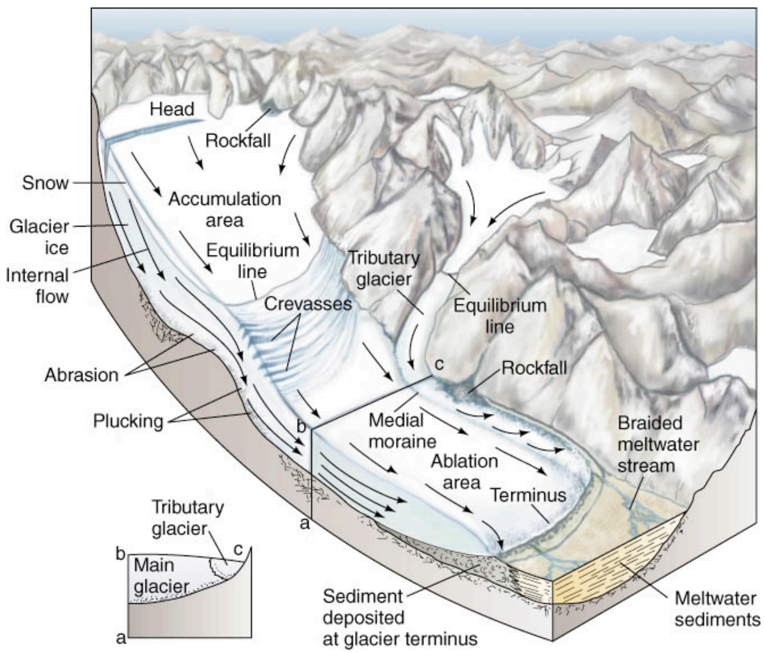

A.
TEMPERATE GLACIER
−10° −5° 0° +5°C
Glacier
Meltwater at bed
Rock
B.
POLAR GLACIER
−20° −15° −10° −5° 0°C
Glacier
Frozen at bed
Glacier bed
Rock

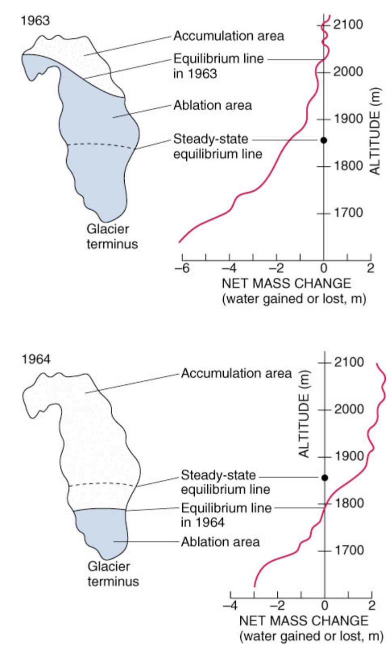


Mass Balance

- Zone of Accumulation
- Zone of Ablation
- Snow line
- Equilibrium and response of terminus



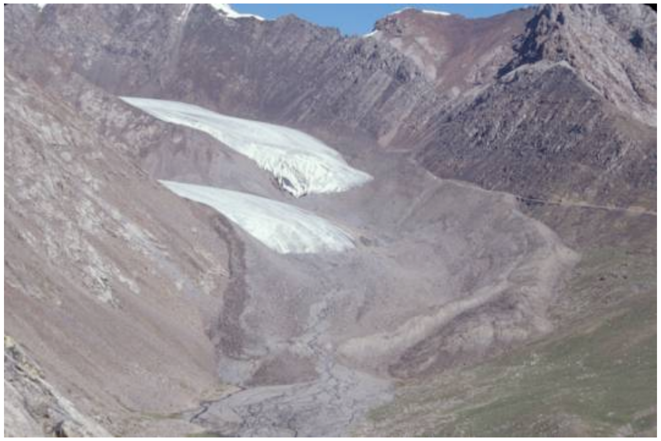




Why Glaciers Change Size

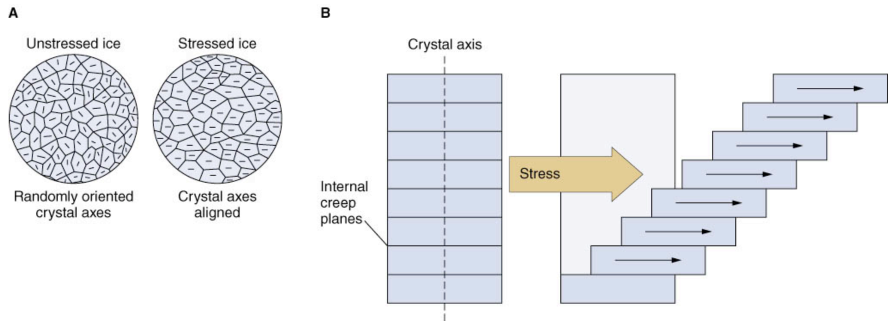
- **Equilibrium line** : boundary between the accumulation area and the ablation area.
- Equilibrium line fluctuates in altitude from year to year and is higher in warm, dry years than in cold, wet years.
- If, over a period of years, a glacier's mass balance is positive more often than negative, the front, or terminus, of the glacier advances.
- If negative mass balance predominates the glacier will retreat.

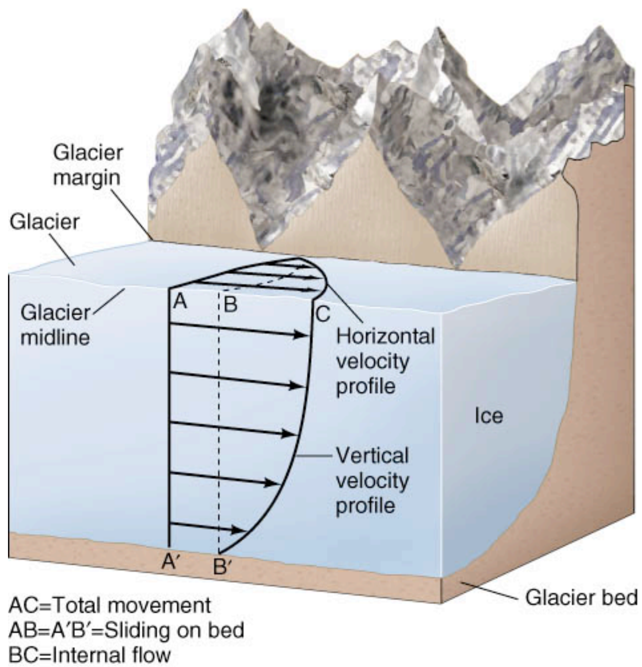
- A lag occurs between a change in accumulation due to a climate change and the response of the glacier terminus to that change.
- The length of the lag depends both on the size of the glacier and the way the ice flows.
  - The lag is longer for larger glaciers than for small ones.
  - Temperate glaciers of modest size (like those in the European Alps) have response lags that range from several years to a decade or more.



Glacier Flow

- Internal deformation
  - – Ductile flow (creep)
  - – Brittle failure
    - **Crevasse**: deep, gaping fissure in the upper surface of a glacier
- Basal slip
- Flow lines within glacier





Glacial Landforms

- Glacial erosion
  - rounded features below ice
  - sharp features above ice
- Evidence of Glaciation
  - Glacial striations
  - Erratics
  - Glacial valleys