Components of Cryosphere

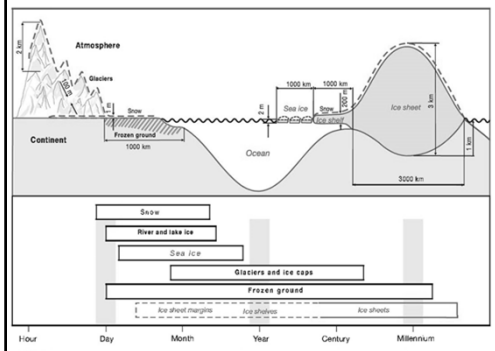

FIGURE 6-1 Components of the cryosphere and their time scales. (Source: Lemke, P., J. Ren, R. B. Alley, I. Allison, J. Carrasco, G. Flato, Y. Fujii, G. Kaser, P. Mote, R. H. Thomas, and T. Zhang, 2007: "Observations: Changes in Snow, Ice and Frozen Ground." In: *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K. B. Averyt, M. Tignor, and H. L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom, and New York, NY, USA.)

(from The Earth System)

The primary components of the cryosphere are :

1. continental ice sheets and ice shelves,
2. mountain glaciers
3. sea ice
4. river and lake ice
5. snow cover
6. permafrost (frozen ground).

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Climate Impacts of the Cryosphere

- ❑ Distribution of sea ice and snow ➔ affect the albedo
- ❑ Amount of glacier ice ➔ affect global sea level
- ❑ Melting of permafrost ➔ releases greenhouse gases to the atmosphere
- ❑ Sea-ice formation ➔ affect ocean salinity ➔ deep-ocean circulation
- ❑ Mountain snow cover and glaciers ➔ an important source of freshwater

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Permafrost

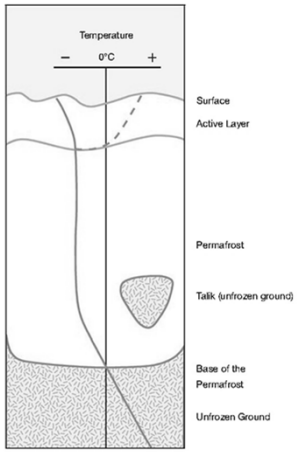

FIGURE 6-6 Sketch cross section of permafrost showing the temperature profile through the different layers.

(from The Earth System)

- ❑ Permafrost is permanently frozen ground and is defined simply in terms of temperature. (In other words, ice does not actually have to be present.)
- ❑ Permafrost is considered to be present if the ground remains at or below 0˚C for 2 or more years.
- ❑ The permafrost is heated from below and cooled from the surface.
- ❑ Temperature changes in permafrost are slow enough that seasonal and interannual variations in air temperature are averaged out and the temperature is actually a response to the decadal and longer-term temperatures.
- ❑ Active layer: Near the surface, temperatures may fluctuate widely on a seasonal basis.
- ❑ Near-surface melting of permafrost results in lakes and water-logged soil with anaerobic (low oxygen) conditions that create an environment in which methane producing organisms can flourish.

Formation of Glaciers

Snow

➔ Persists through the summer and starts to accumulate over time

➔ Snow increases in thickness

➔ The ice crystals fuse together where they contact each other and they bond through a process referred to as pressure sintering.

➔ Density increases, the volume of air between the ice grains is reduced

➔ Snow is transformed into glacier ice

➔ In cold glaciers where temperatures never come close to the melting point, this process can take hundreds to thousands of years.

➔ In regions-such as central Antarctica, snow accumulation may be only centimeters per year.

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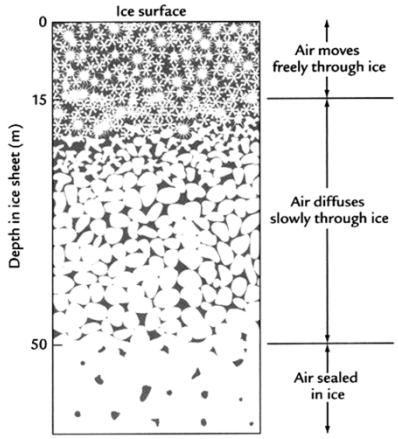
Trapping Gases in the Ice

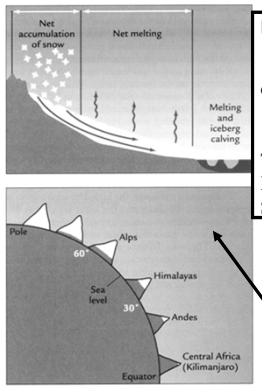


- Air moves freely through snow and ice in the upper 15 m of an ice sheet.
- Flow is increasingly restricted below this level.
- Bubbles of old air are eventually sealed off completely in ice 50 to 100 m below the surface.

(from *Earth's Climate: Past and Future*)

Glaciers

Glaciers are broadly categorized into mountain (or alpine) glaciers and continental glaciers.

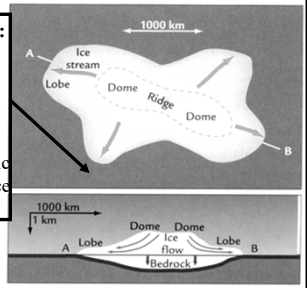


- **Continental Ice Sheets:**

  100-1000 km in horizontal extend.

  1-4 km in thickness.

  Two larges sheets: Antarctic Ice Sheet and Greenland Ice Sheet.

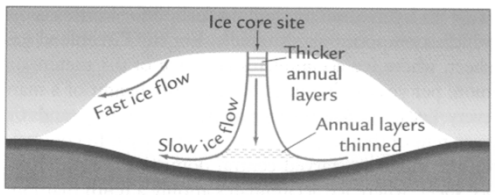


(from *Earth's Climate: Past and Future*)

- **Mountain Glaciers:** a few kilometers in length and 10-100 meters in width and thickness.

Continental Ice Sheets

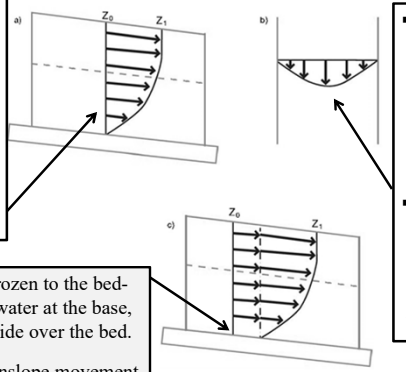
(from *Earth's Climate: Past and Future*)



- Ice cores retrieve climate records extending back thousands of years in small mountain glaciers to as much as hundreds of thousands of years in continental sized ice sheets.
- The Antarctic ice sheet has layers that extend back over 400,000 years.
- The Greenland ice sheet has layers that extended back 100,000 years.

Glacier Flows

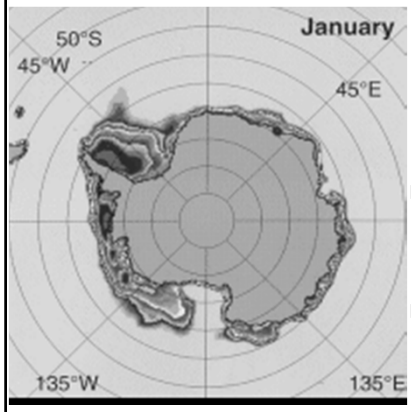
- At higher pressures, deeper within a glacier, slowly applied stress causes the ice to deform more like a plastic.
- If the ice is frozen to the bed, then the flow at the base is zero and the maximum flow is somewhere above the influence of the bed.



- Similarly, friction at the sides in a valley glacier (a glacier flowing down a mountain valley) reduces the flow at the edges.
- So the maximum flow is toward the center of the glacier and between the surface and glacier bed.

- Where the ice isn't frozen to the bed- where there is liquid water at the base, then the glacier can slide over the bed.
- In this case, the downslope movement has two components, one due to plastic deformation and one to basal sliding.

Sea Ice

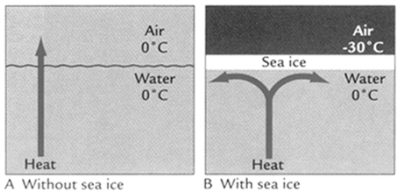


(figures from Gloersen, P. et al. 1992; animated by D. B. Reush)

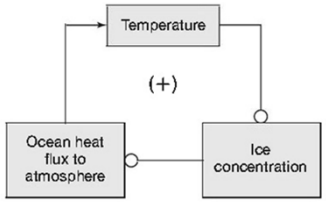
- The seasonal range of the ice cover is extreme: The Northern Hemisphere ice cover almost doubles in size from approximately 8.5 X 10^6 km^2 to 15 X 10^6 km^2 between summer and winter; the Southern Ocean ice cover grows from 4 X 10^6 km^2 to 20 X 10^6 km^2.
- Sea ice forms when the temperature of the ocean surface drops below the freezing point (about -l.8°C for typical ocean salinities).
- Sea ice grows in thickness as new ice formed from seawater freezes onto the bottom of the icepack. Note that this is very different from how glacier ice forms on land, where the ice forms and accumulates at the surface.

Sea Ice-Climate Feedbacks

(from *Earth's Climate: Past and Future*)



(from *The Earth's System*)



- One major climate effect of sea ice is to seal off the underlying ocean from interaction with the atmosphere.
- Without an sea ice cover, high-latitude oceans transfers large amount of heat to the atmosphere, especially in winter.
- **Sea Ice-Albedo Feedback**: Increasing temperature ➔ decreasing ice cover ➔ decreasing albedo ➔ increasing temperature (At high latitudes, works in summer)
- **Sea-Ice-Heat-Flux Feedback**: Increasing temperature ➔ decreasing ice cover ➔ increasing ocean heat flux to the atmosphere ➔ increasing temperature (works year round)