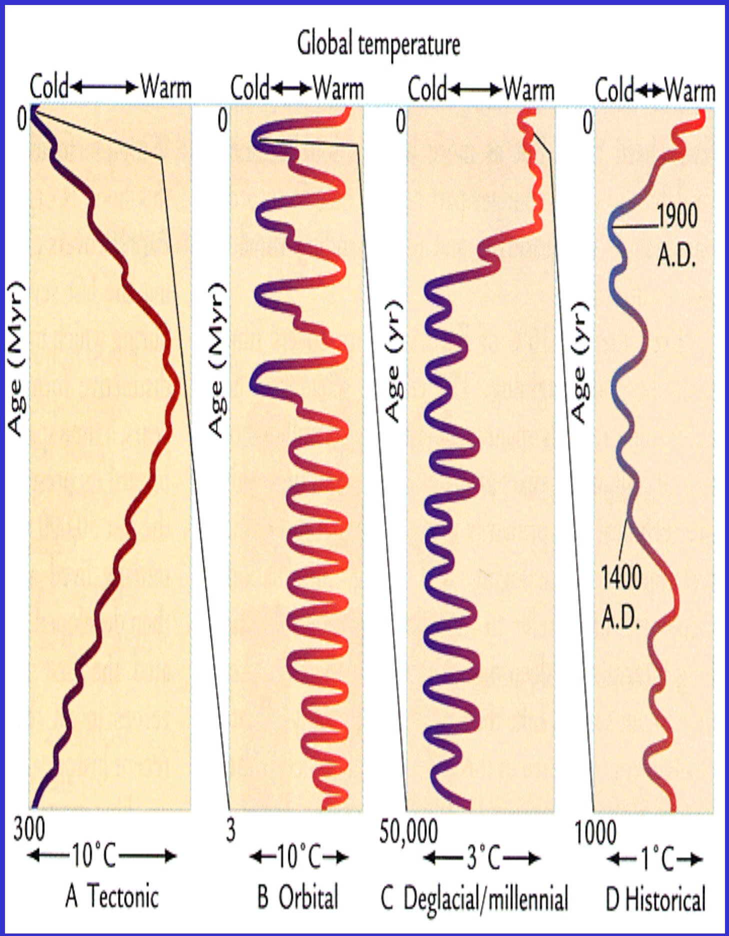
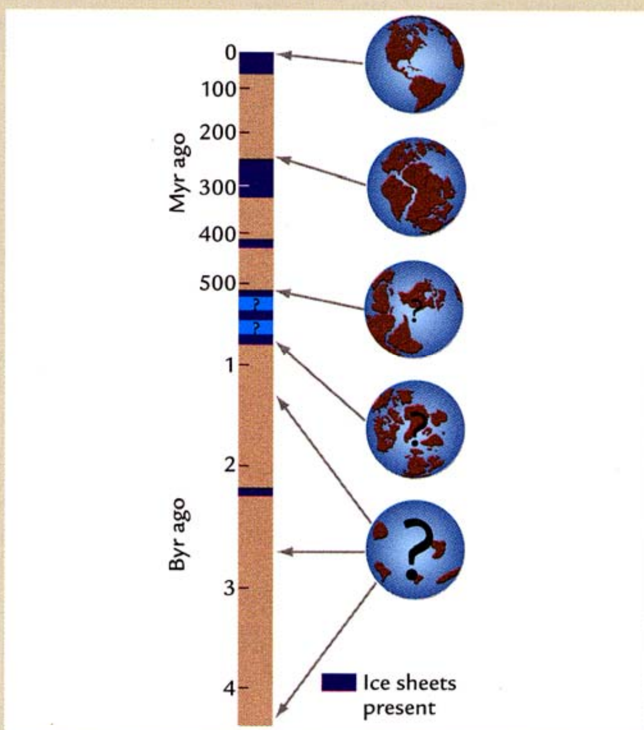
Lecture 10: Natural Climate Change



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

- ❑ Tectonic-Scale Climate Changes
- ❑ Orbital-Scale Climate Changes

Tectonic Scale



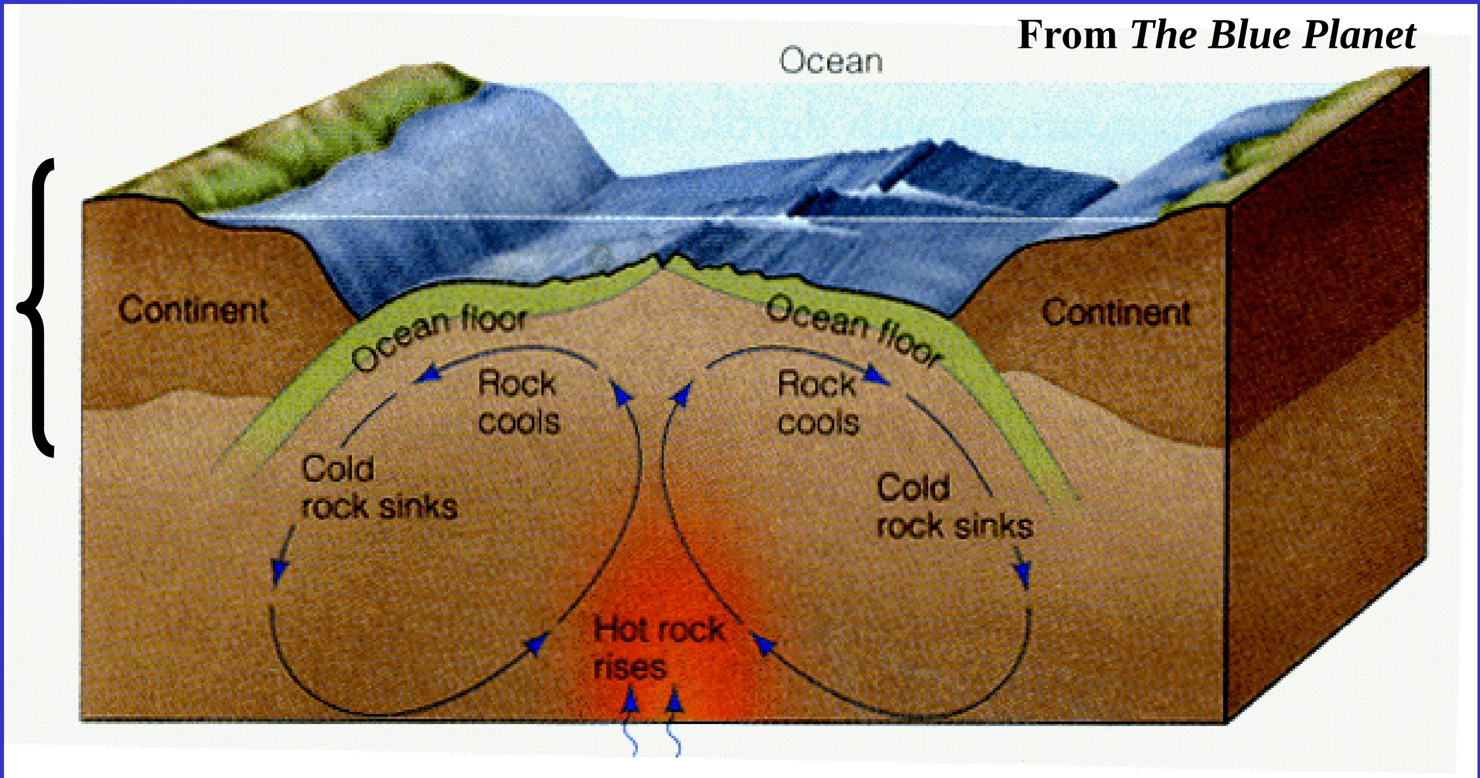
Past glaciations and continental positions. During Earth's 4.55-billion-year history, intervals when large continental ice sheets were present alternated with times when they were not (left). The earliest history of these changes is poorly defined because few ancient records are preserved. The movements of continents in relation to ocean basins are well known only for the last several hundred million years (right). (Globes adapted from D. Merritts et al., *Environmental Geology*, © 1997 by W. H. Freeman and Company.)

- Tectonic Scale: the longest time scale of climate change on Earth, which encompasses most of Earth's 4.55-billion years of history.
- Tectonic processes driven by Earth's internal heat alter Earth's geography and affect climate over intervals of millions of years.
- On this time scale, Earth's climate has oscillated between times when ice sheets were presented somewhere on Earth (such as today) and times when no ice sheets were presented.

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

Circulation of the Solid Earth

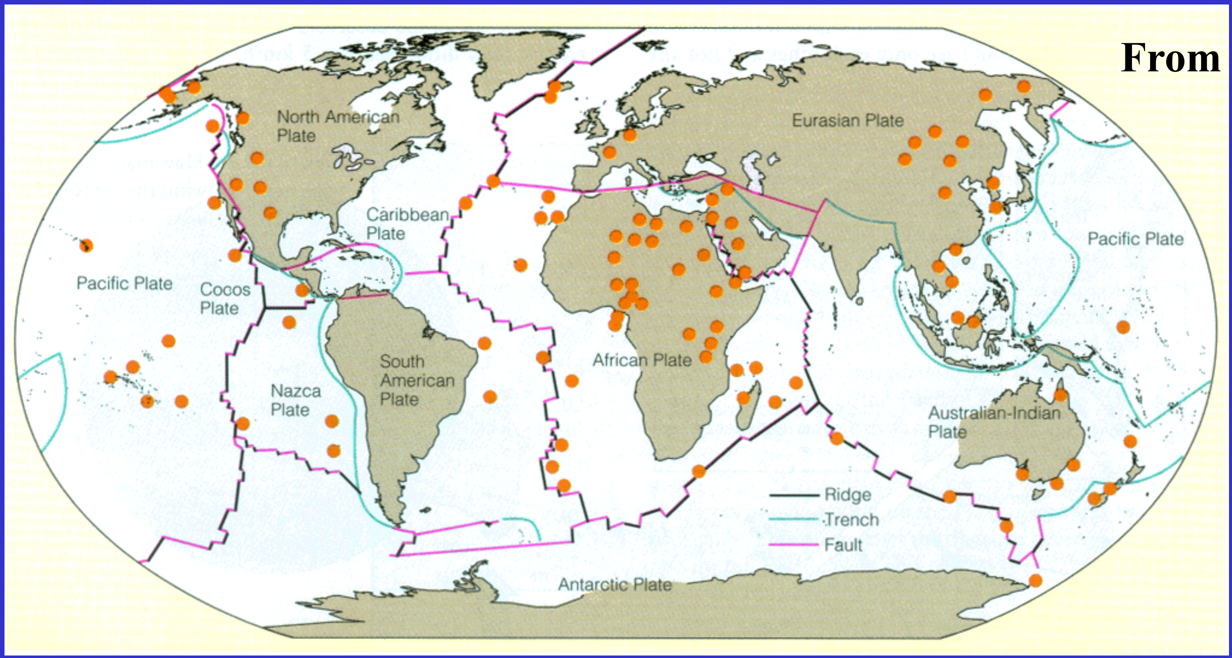
Cold Lithosphere



- The rising hot rocks and slid-away flows are thought to be the factor that control the positions of ocean basins and continents.

➔ The convection determines the shape of the Earth.

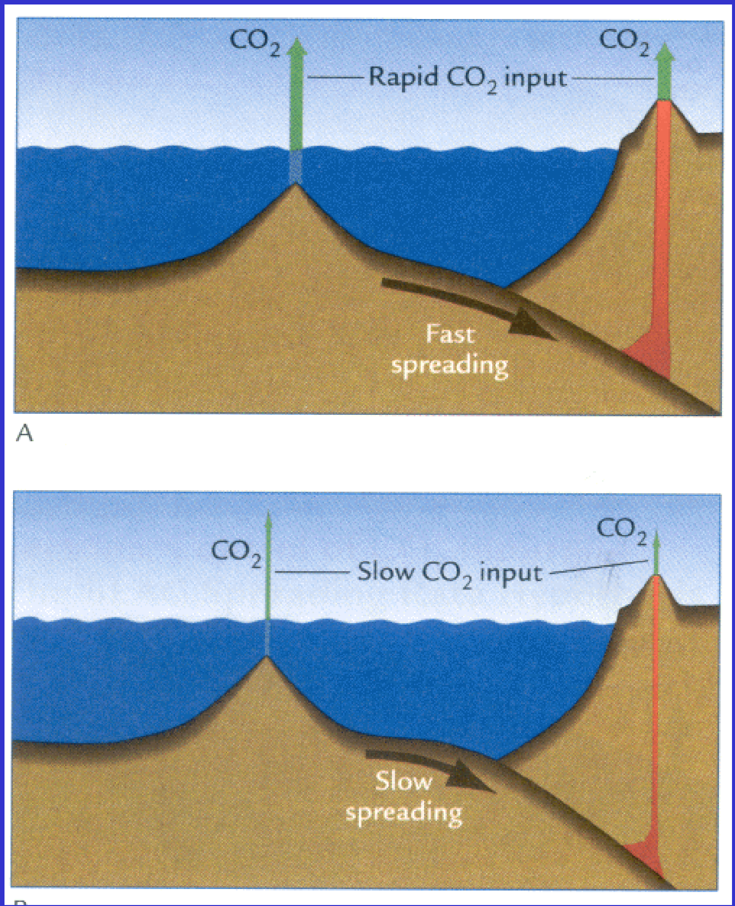
Twenty Rigid Plates



From *The Blue Planet*

- ❑ What can happen to the cold boundary?
- ➔ The lithosphere has broken into a number of rocky pieces, called plates.
- ❑ There are a few large plates plus a number of smaller one comprise the Earth's surface (a total of 20 plates).
- ❑ The plates range from several hundred to several thousand kilometers in width.

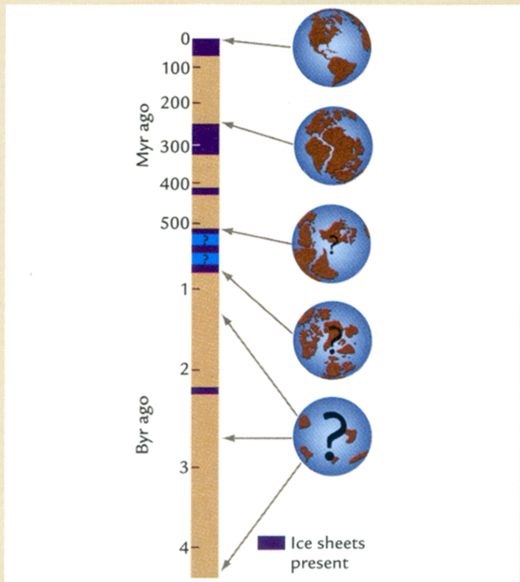
Tectonic Control of CO_2 *Input* – The Seafloor Spreading Rate Hypothesis



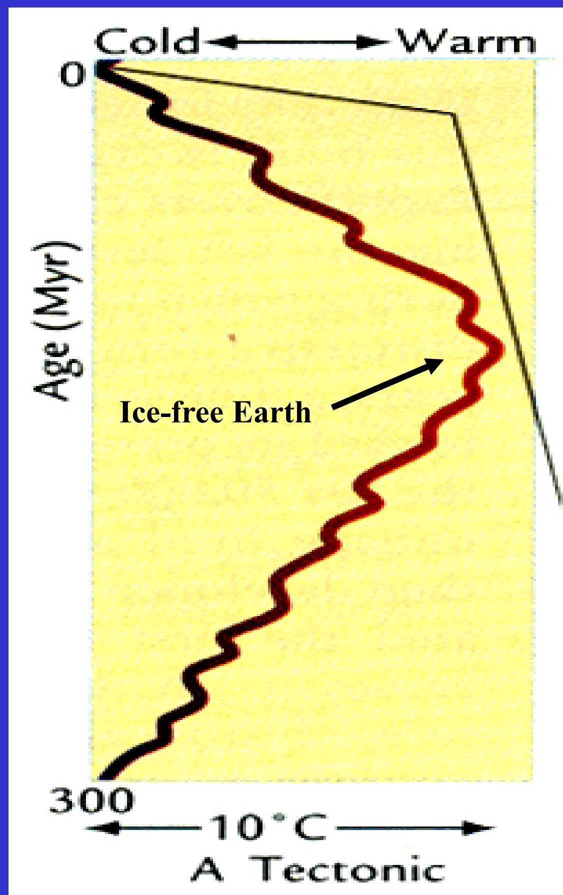
(from *Earth's Climate: Past and Future*)

- During active plate tectonic processes, carbon cycles constantly between Earth's interior and its surface.
- The carbon moves from deep rock reservoirs to the surface mainly as CO_2 gas associated with volcanic activity along the margins of Earth's tectonic plates.
- The centerpiece of the seafloor spreading hypothesis is the concept that changes in the rate of seafloor spreading over millions of years control the rate of delivery of CO_2 to the atmosphere from the large rock reservoir of carbon, with the resulting changes in atmospheric CO_2 concentrations controlling Earth's climate.

Tectonic-Scale Climate Change



Past glaciations and continental positions. During Earth's 4.55-billion-year history, intervals when large continental ice sheets were present alternated with times when they were not (left). The earliest history of these changes is poorly defined because few ancient records are preserved. The movements of continents in relation to ocean basins are well known only for the last several hundred million years (right). (Globes adapted from D. Merritts et al., *Environmental Geology*, © 1997 by W. H. Freeman and Company.)



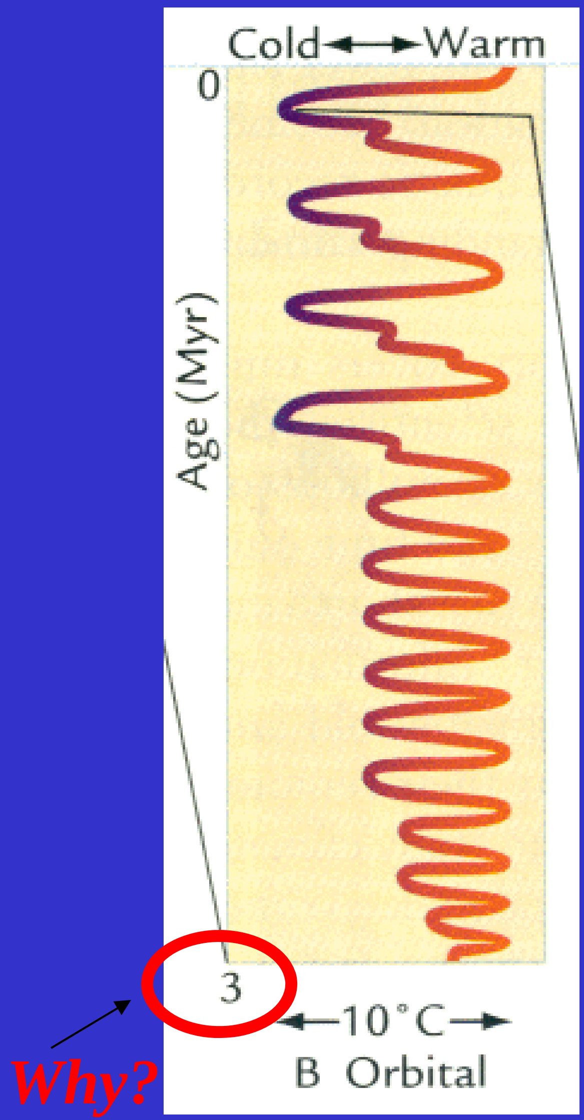
(from *Earth's Climate: Past and Future*)

- The faint young Sun paradox and its possible explanation.
- Why was Earth ice-free even at the poles 100 Myr ago (the Mesozoic Era)?
- What are the causes and climate effects of changes in sea level through time?
- What caused Earth's climate to cool over the last 55 Myr (the Cenozoic Era)?

Summary: Tectonic Control of Climate

- Plate Tectonics probably does influence climate over long time scales (on the order of millions of years).
- The main influence of plate tectonics on climate appears to be indirect: by modulating CO_2 levels in the atmosphere through the chemical weathering process.
- This, in turn, affects climate by way of the greenhouse effect.
- Such change, in combination with the long-term increase in solar luminosity, can account for the main features of the long-term climate changes.

Orbital-Scale Climate Change

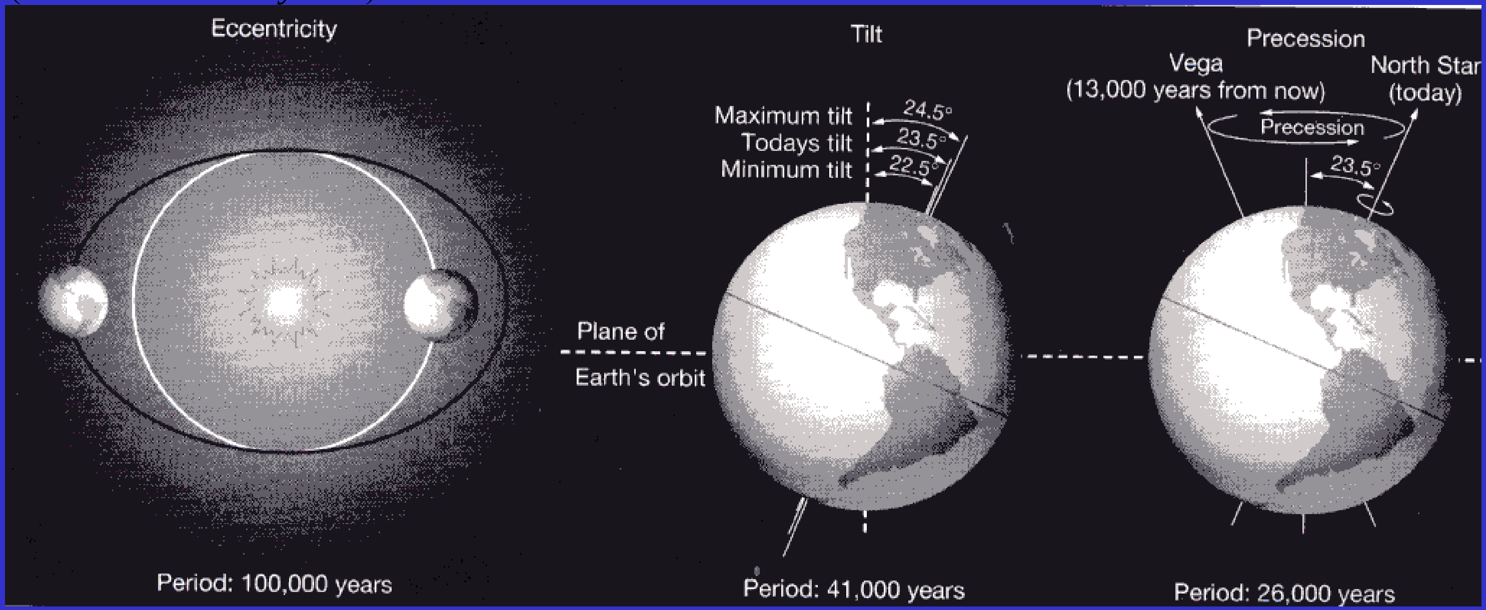


- **Changes in solar heating driven by changes in Earth's orbit are the major cause of cyclic climate changes over time scales of tens to hundreds of thousands of years (23k years, 41k years, and 100k years) .**
- Earth's orbit and its cyclic variations: tilt variations, eccentricity variations, and precession of the orbit.
- How do orbital variations drive the strength of tropical monsoons?
- How do orbital variations control the size of northern hemisphere ice sheets?
- What controls orbital-scale fluctuations of atmospheric greenhouse gases?
- What is the origin of the 100,000-year climate cycle of the last 0.9 Myr (ice sheets melt rapidly every 100,000 years)?

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

Orbital Scale

(from *The Earth System*)



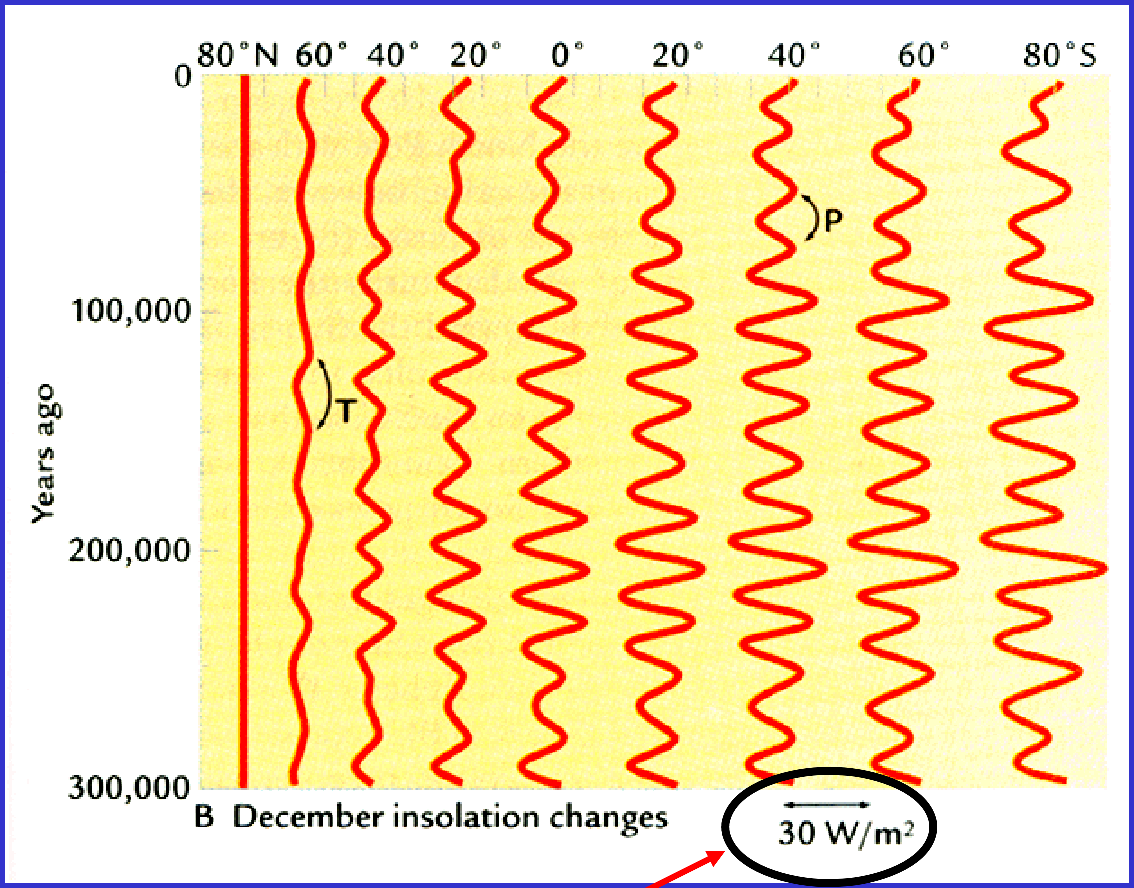
- Orbital-scale climate changes are caused by subtle shifts in Earth's orbit.

- Three features of Earth's orbit around the Sun have changed over time:
  (1) the tilt of Earth's axis,
  (2) the shape of its yearly path of revolution around the Sun
  (3) the changing positions of the seasons along the path.

- Orbital-scale climate changes have typical cycles from 20,000 to 400,000 years.

Seasonal Insolation Changes

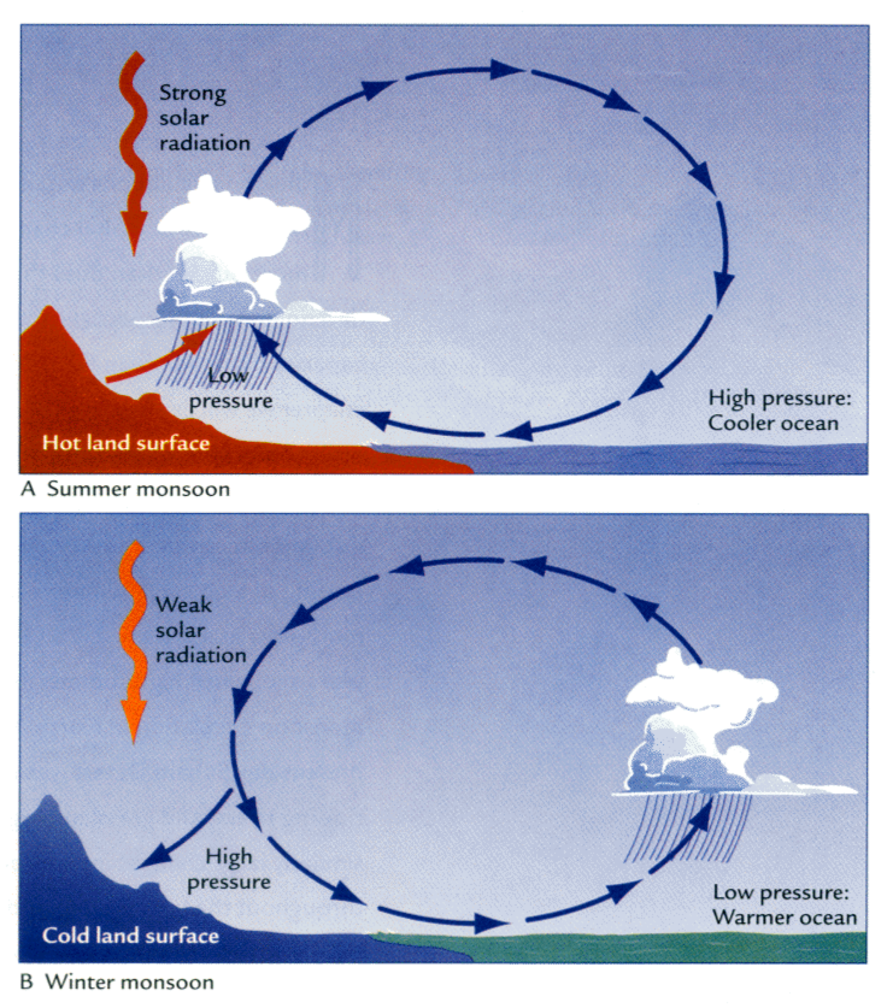
(from Earth's Climate: Past and Future)



Mean isolation value = 340 W/m^2

- The 23,000-year cycle of precissional change dominants the insolation changes at low and middle latitudes.
- The 41,000-year cycle of tilt change dominants the insolation changes at higher latitudes.
- Eccentricity changes (the 1000,000 or 413,000-year cycles) is not a significant influence on seasonal insolation chanes.

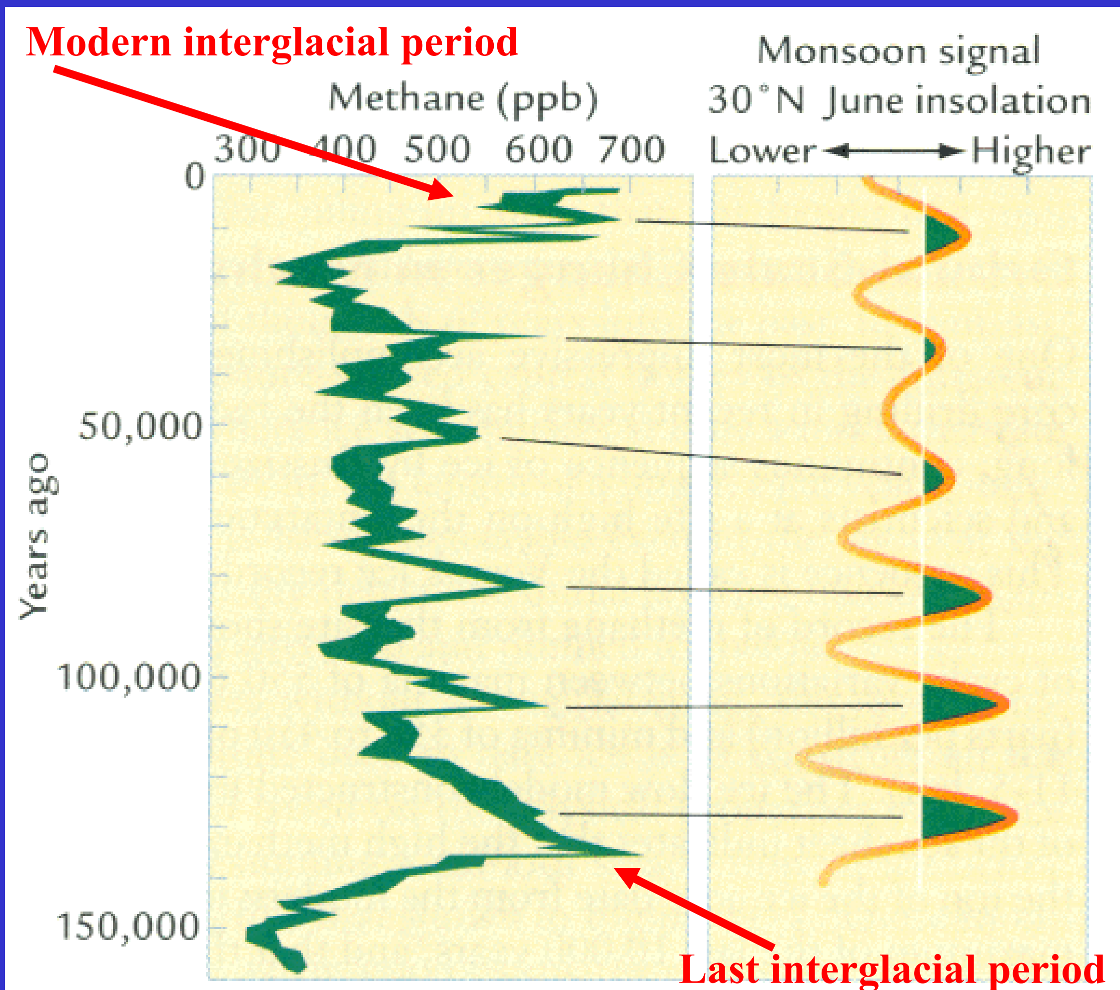
Insolation Control of Monsoons



(from Earth's Climate: Past and Future)

- ❑ Monsoon circulations exit on Earth because the land responds to seasonal changes in solar radiation more quickly than does the ocean.
- ❑ Changes in insolation over orbital time scales have driven major changes in the strength of the summer monsoons.
- ❑ Changes of 12% in the amount of insolation received at low latitudes have caused large changes in heating of tropical landmass and in the strength of summer monsoons at a cycle near 23,000 years in length.

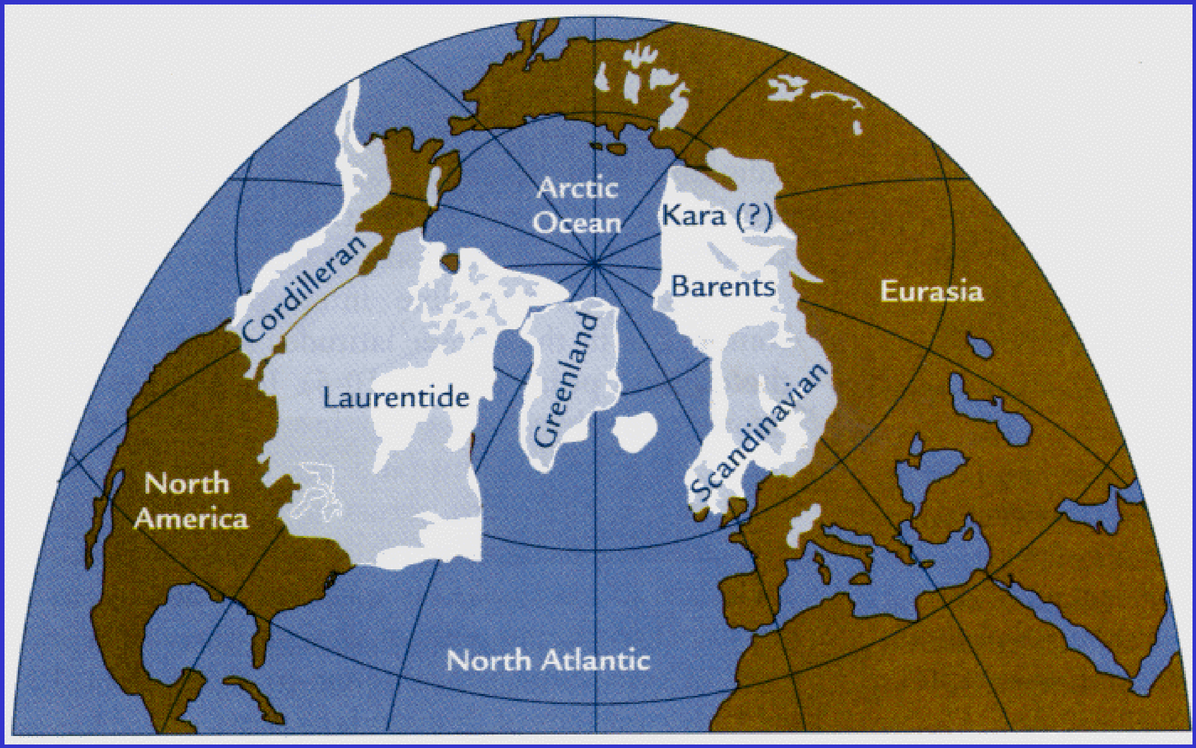
Orbital-Scale Changes in Methane



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

- The Vostok ice record shows a series of cyclic variations in methane concentration, ranging between 350 to 700 ppb (part per billion).
- Each Ch4 cycle takes about 23,000 years.
- This cycle length points to a likely connection with changes in orbital procession.
- The orbital procession dominates insolation changes at ***lower latitudes***.

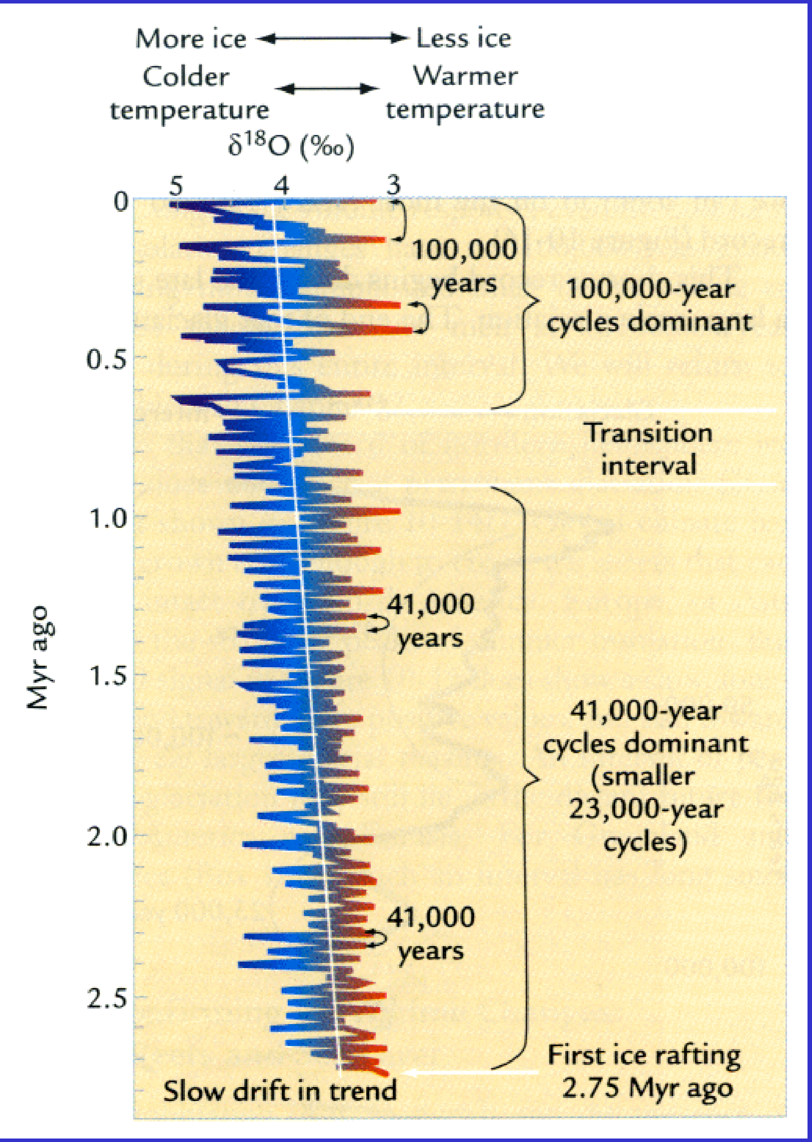
Insolation Control of Ice Sheets



(from Earth's Climate: Past and Future)

- ❑ Ice sheets reacted strongly to insolation changes.
- ❑ ***Summer*** insolation control the size of ice sheet by fixing the rate of ice melting.

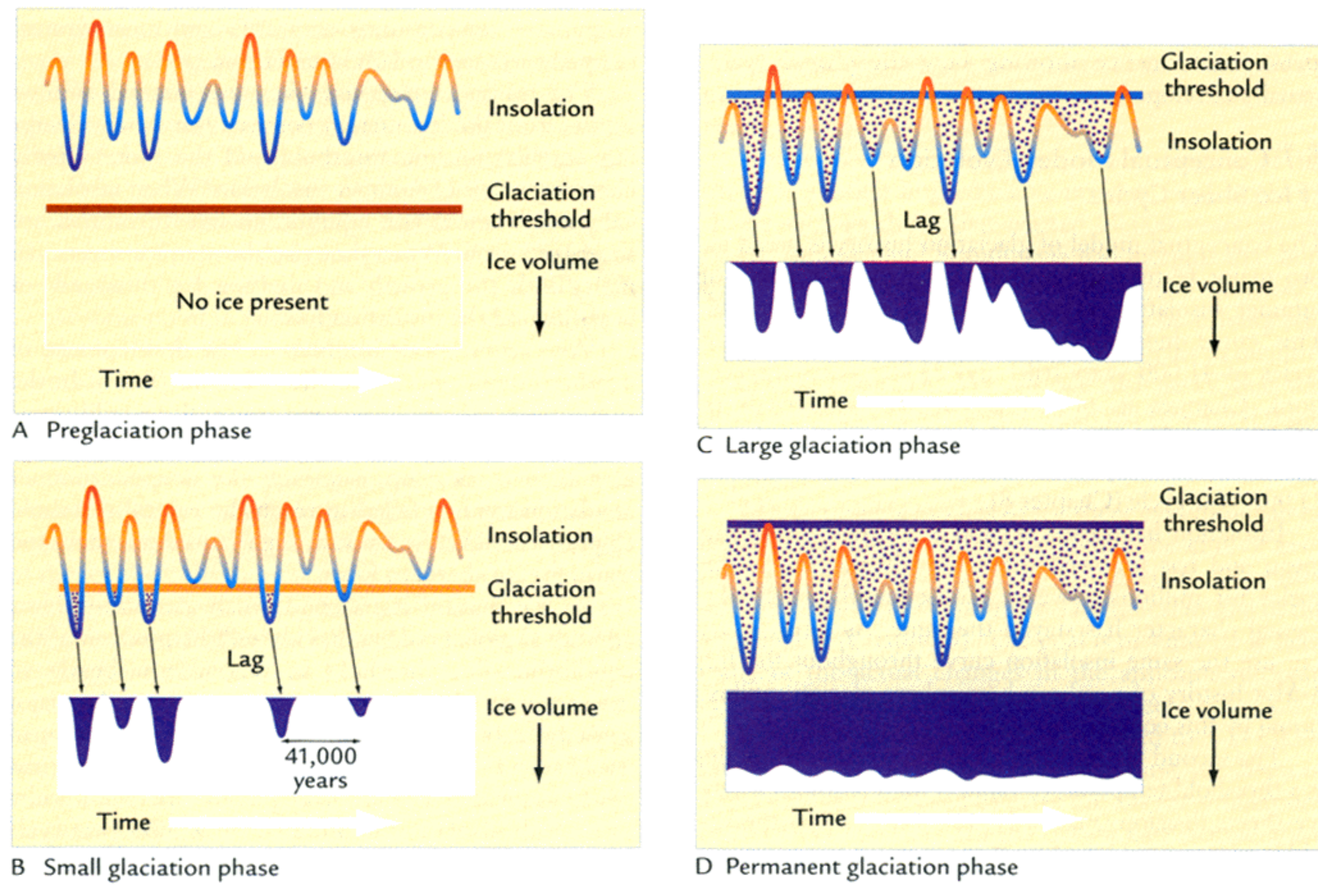
Evidence of Ice Sheet Evolution



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

- This figures shows a North Atlantic Ocean sediment core holds a 3 Myr $\delta^{18}O$ record of ice volume and deep-water temperature changes.
- There were no major ice sheets before 2.75 Myr ago.
- After that, small ice sheets grew and melted at cycles of 41,000 and 23,000 years until 0.9 Myr ago.
- After 0.9 Myr ago, large ice sheet grew and melted at a cycle of 100,000 years.

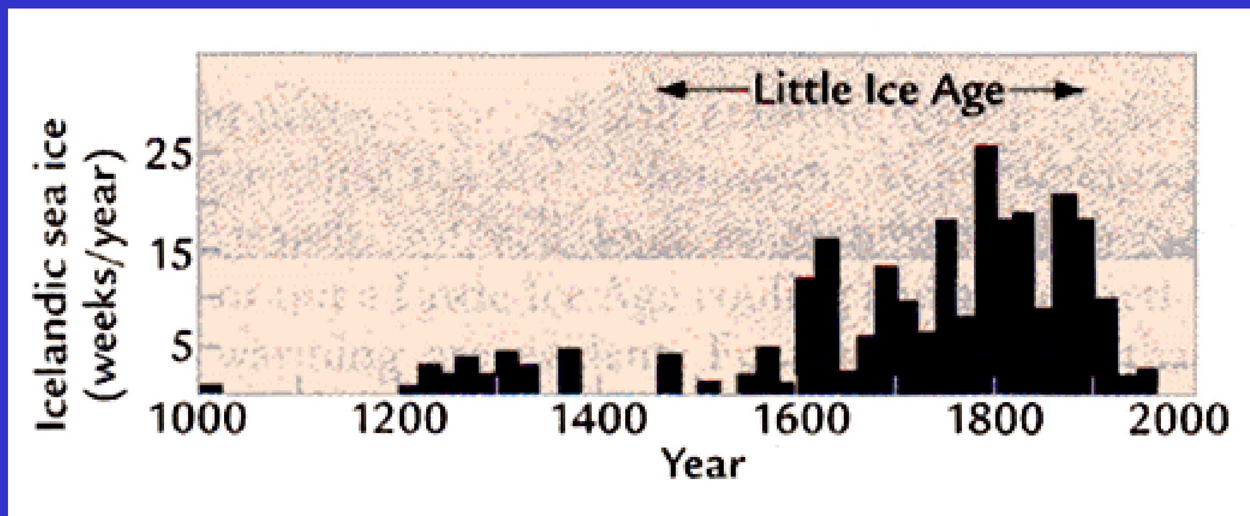
Conceptual Phases of Ice Sheet Evolution



(from Earth's Climate: Past and Future)

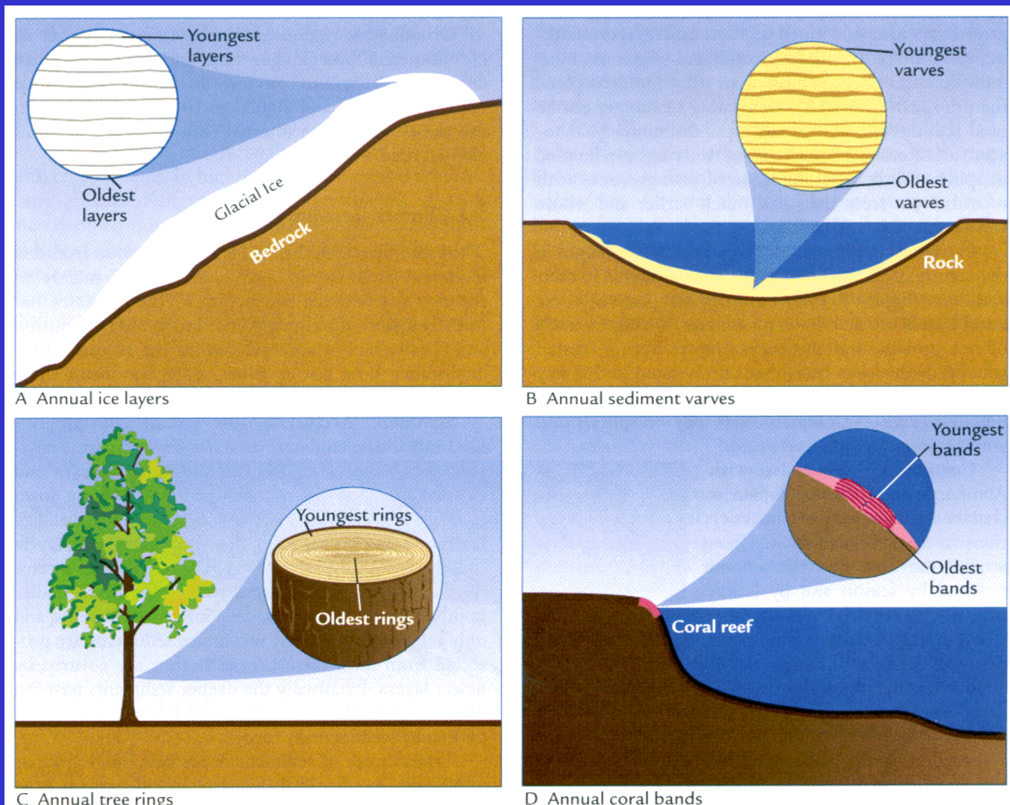
The Little Ice Age

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



- **Medieval Climate Optimum**: A relatively warm climate near 1000 to 1300.
- **Little Ice Age**: The cooling during 1400-1900 that seriously affect Europe.
- **Twentieth-Century Warming**

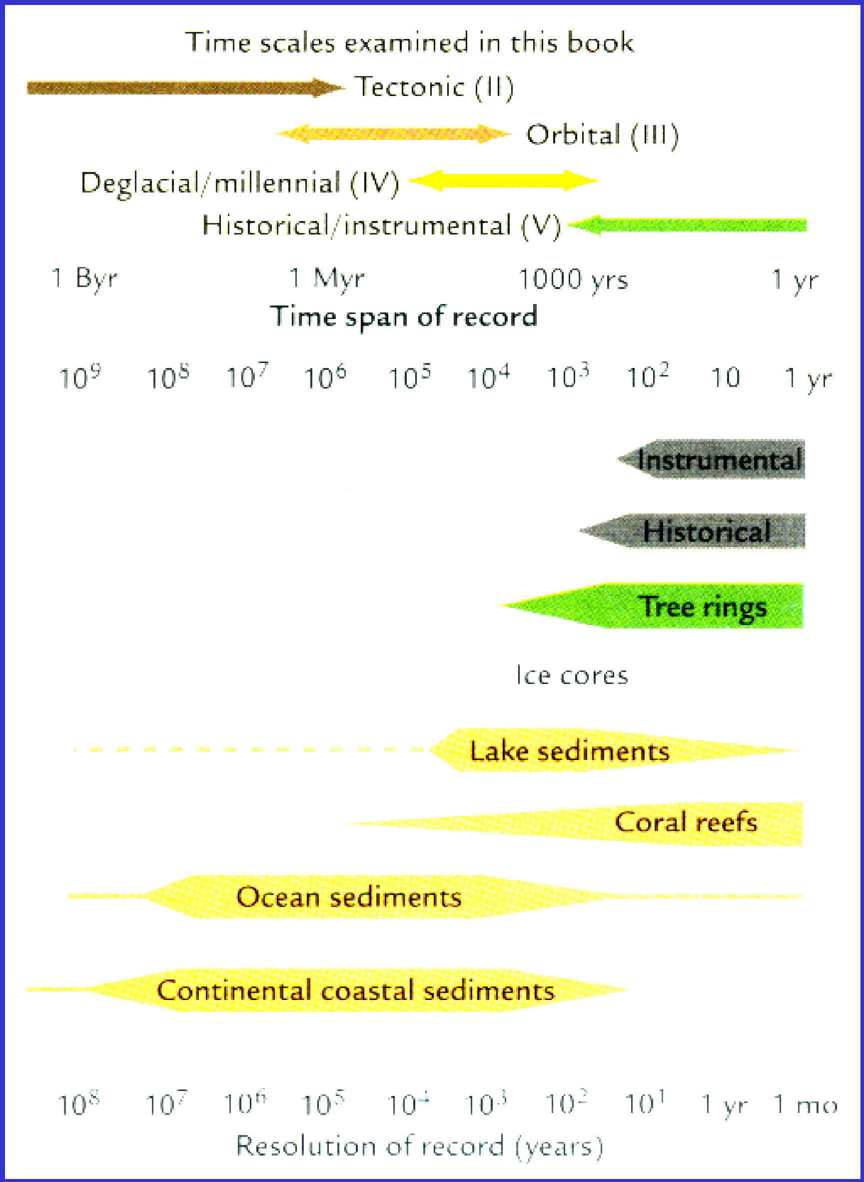
Climate Archives



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

- Much of climate history is recorded in four climate archives:
  (1) Sediments
  (2) Ice
  (3) Corals
  (4) Trees
- How are those records dated?
- Hoe much of Earth's history each archive spans?
- What is the resolution of climate history yielded by each?

Resolution of Climate Records



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