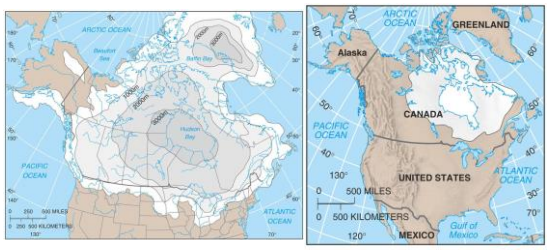
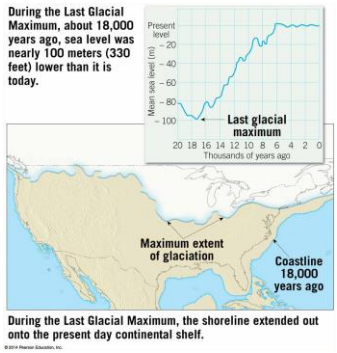
Wisconsin Glaciation Ended ~15,000 Years Ago



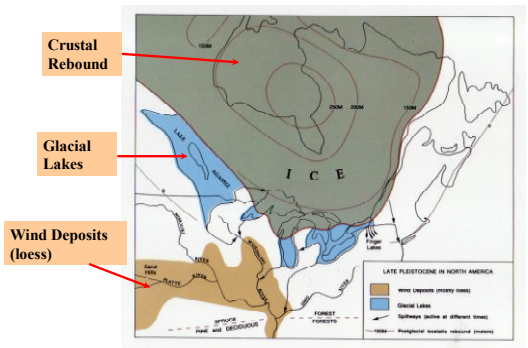
18,000 years ago

9,500 years ago

- During the last glacial maximum ~18,000 years ago, sea level was 100m (330 ft) lower than today
- When Ice Age ended, continental glaciers melted and meltwater was returned to oceans, causing sea level to rise
- Sea level reached its present level ~6,000 years ago

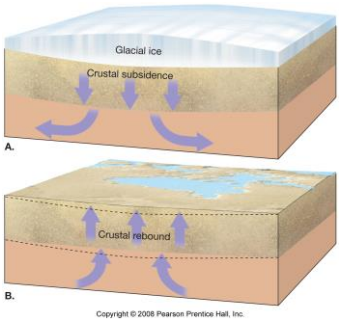


Phenomena Associated with Glacial Retreat (~15,000 yrs ago)



Glacial Isostasy

- Retreat of the glaciers resulted in crustal rebound around Hudson Bay (Canada) and the northern Baltic Sea over the last 10,000 years
- Total rebound since last ice age range from tens to hundreds of meters
- Present rebound rates in northern Baltic Sea are several mm/yr



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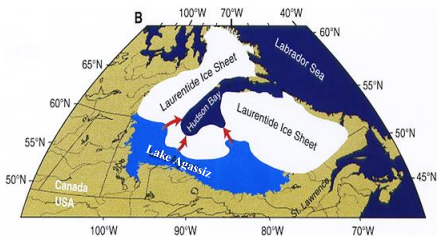
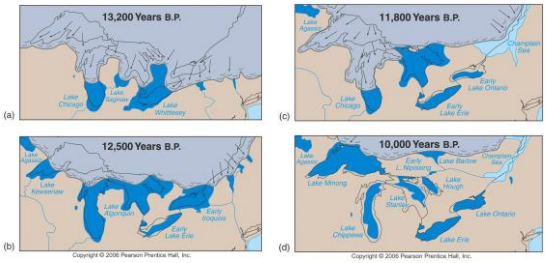
Glacial Isostasy

Huge Glacial Lake Agassiz Formed Temporarily In Canada When Ice Began To Retreat ~15,000 – 10,000 Years Ago

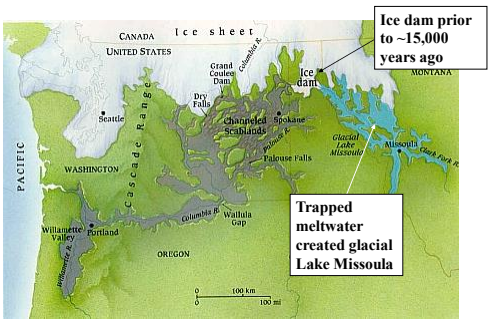


Meltwater From The Retreating Glaciers Also Formed The Great Lakes

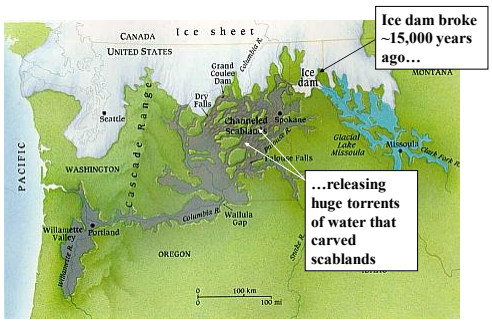


Former Extent and Remnants of Glacial Lake Agassiz Today

Lake Missoula And the Channeled Scablands



Lake Missoula And the Channeled Scablands

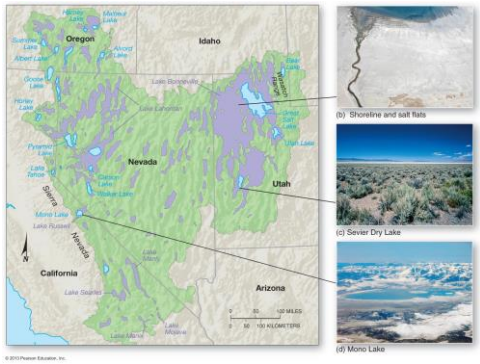


Channeled Scablands, Oregon and Washington

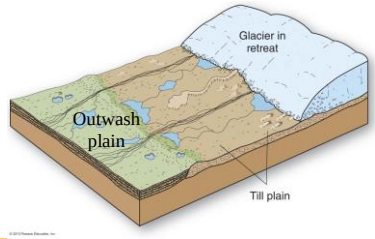
Paleolakes

- Western U.S. was dotted with large lakes 12,000 – 30,000 years ago:
  - A time of wetter conditions
- Most paleolakes have since dried up, leaving behind...
  - Lake sediment (lacustrine deposits)
  - Salt flats
  - Terraces that mark former shorelines

Paleolakes of Western U.S.



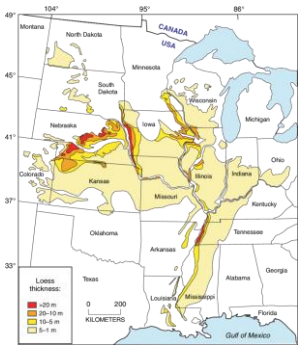
Glacial Loess



- Glacial meltwater carried huge volumes of sediment from the melting ice sheets; sediment was deposited in the outwash plains
- During the fall and winter, melting of ice sheets ceased:
  - Flow of meltwater either ceased or was greatly reduced
  - Un-vegetated floodplains dried out and were exposed to wind
  - Glacially ground silt and clay was winnowed by the wind
  - Particles were blown downwind and deposited as loess deposits

Loess Distribution in North America

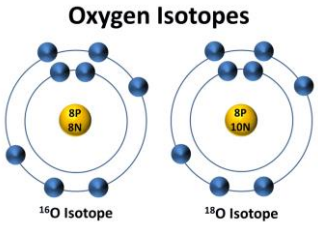
Windblown accumulations of finely-ground sediment left by the glaciers



Paleoclimatology

- **Temperature changes over the last 2.0 My must be obtained indirectly in what are known as proxy recorders:**
  - **Oxygen isotope changes in ice cores**
  - **Trapped atmospheric gases in ice cores**
  - **Oxygen isotope and other changes in fossils in oceans and lakes**

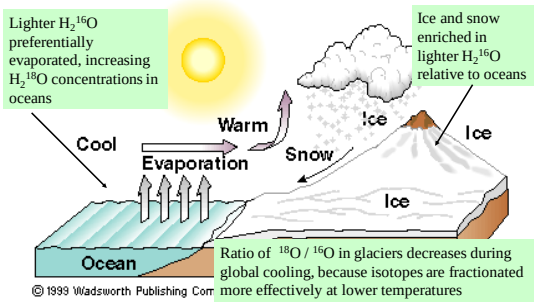
Oxygen Isotopes Measured In Ice Cores And Fossils Are Used To Determine Past Temperature Changes In The Atmosphere And Oceans



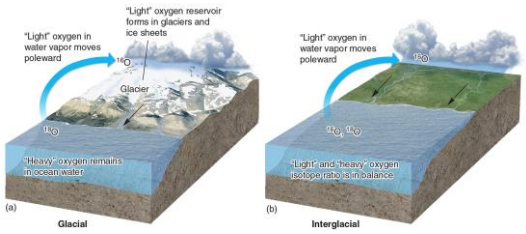
Lighter

Heavier because of two more neutrons

Some Water Evaporated From Oceans Is Stored on Land As Ice and Snow

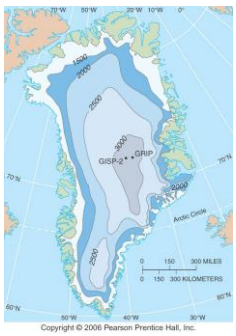


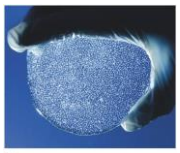
Oxygen Isotopes in Seawater



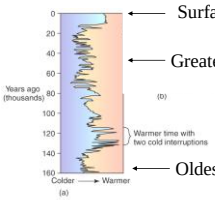
$^{18}O/^{16}O$ ratios are higher in the oceans and lower in glaciers during glacial periods compared to interglacial periods

Greenland and Dome C Ice Cores





Greenland Ice Core Record

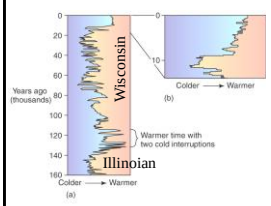


Surface: Present accumulation

Greater core depths record older accumulations

Oldest accumulation dates back 160,000 years

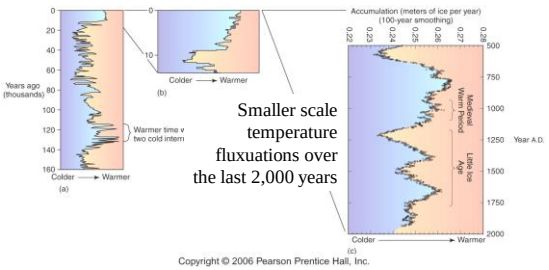
Greenland Ice Core Record



Interglacial Period: Past 9,000 years of gradual warming

Temperature changes based on $^{18}O/^{16}O$ ratios

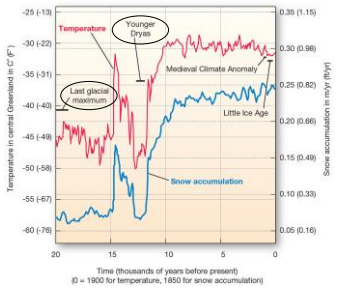
Greenland Ice Core Record



Smaller scale temperature fluxuations over the last 2,000 years

Evidence Of Climate Change Obtained From Greenland Ice Cores For The Past 20 Thousand Years

- Temperatures were colder during the last glacial maximum and also during the Younger Dryas



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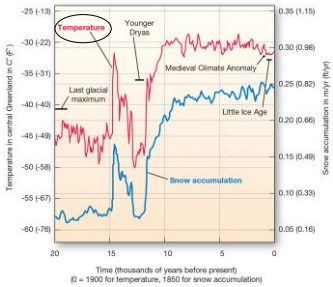
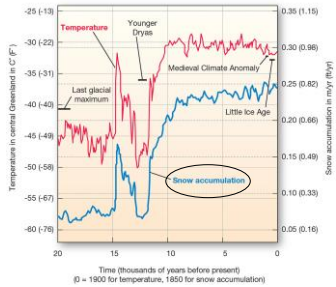
- Abrupt temperature rise occurred about 14,000 years ago and again about 12,000 years ago at the end of the Younger Dryas



Evidence Of Climate Change Obtained From Greenland Ice Cores For The Past 20 Thousand Years

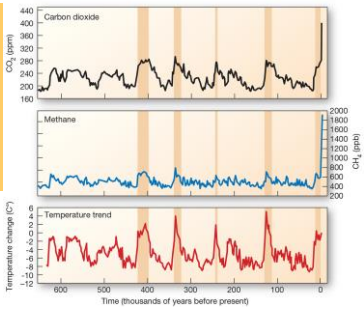
- Temperatures were colder during the last glacial maximum and also during the Younger Dryas
- Abrupt temperature rise occurred about 14,000 years ago and again about 12,000 years ago at the end of the Younger Dryas
- More snow accumulation during warmer periods



The 650,000-year Record For CO_2, CH_4, And Temperature

Higher concentrations of greenhouse gases (CO_2 & CH_4) during interglacial periods (shaded bands) and warmer temperatures

Temperature trends based on deuterium (^2H) concentrations in Antarctic ice-cores



Why Atmospheric CO_2 Concentration Is Lower During Ice Ages

- Falling sea level exposes more land plants that take up CO_2
- Colder ocean water dissolves more CO_2
- Expanding sea ice covers more ocean, limiting amount of CO_2 released from oceans to atmosphere
- Falling sea level impacts the growth of coral reefs and other ocean ecosystems that affect the amount of CO_2 stored in the ocean
- Frozen ground and ice cover limits biodegradation and microbial activity that would otherwise release CO_2 and CH_4 into the atmosphere

Changes in Seawater Temperatures Over Time

Past Global Temperature Cycles Also Determined From Deep-sea Cores

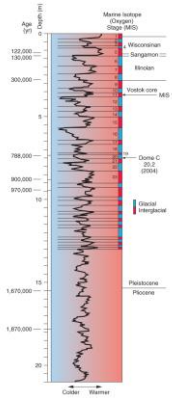
- Deep sea sedimentary record is more complete (continuous) than glacial deposits on land
- Foraminifera shells in sediment can be analyzed for oxygen isotopes to determine seawater temperatures at the time shells formed:
  - Shells formed over the last 80,000 years can be dated by carbon 14
  - Protactinium 231 - thorium 230 can date associated deep-sea clays back to 300,000 years
  - Other methods used to date older fossils


(a) Core samples of ocean sediments are split open for analysis.


(b) The U.S. *JOIDES Resolution* drilling ship.

Temperature Record Of Deep-sea Sediment Cores For The Past 2 Million Years As Determined From Oxygen Isotopes In Fossil Foraminifera

Fossil marine foraminifera: magnification x225



Many more glacial-interglacial cycles recorded in deep-sea sediment than are recognized on land

Support for Global Temperature Changes

- **Ice core records of gases and oxygen isotopes from Greenland are similar to those obtained from Antarctica**
- **Oxygen isotope records from ice cores match those obtained from marine fossils**
- **Ages obtained from glacial deposits on land match the ice core records**
- **Migrations of land plants and animals, as determined from fossils on land, are consistent with temperature changes recorded by ice cores and marine fossils**