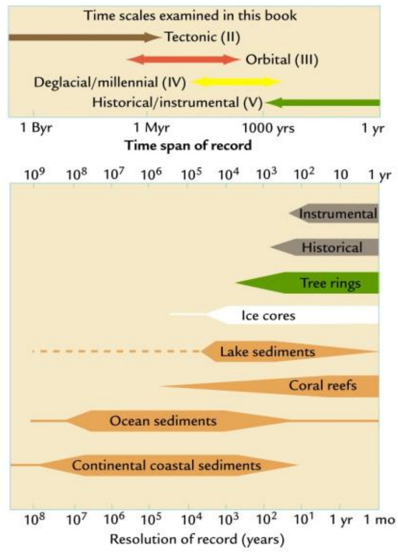
Paleoclimatology

Anna Klene
Department of Geography
University of Montana

3 Objectives

- Discuss climate archives
  - Piecing the puzzle together
- Discuss key climate events using these different archives
  - Current understanding of atm evolution
- Review key time periods of interest to current warming

Time scales for Proxy Data



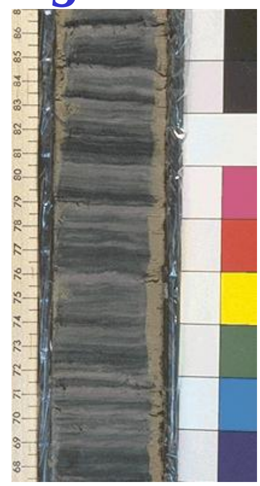
Ruddiman, 2008

Archives of Climate Change:

Geological
Biological: Fossils & Pollen
Cryological: Ice Cores
Historical
Biological: Tree-Rings
Instrumental Records

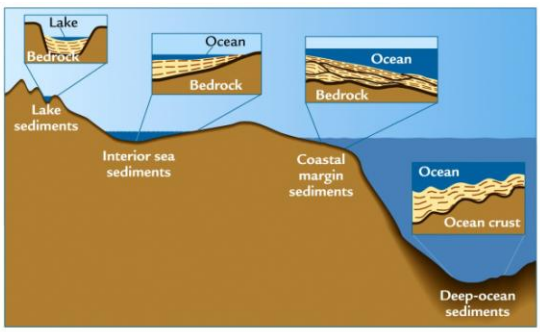
- Proxy: Using one thing in place of another...
- Always better if 2 different, independent proxies agree ☺

Archives of Climate Change:



Geological

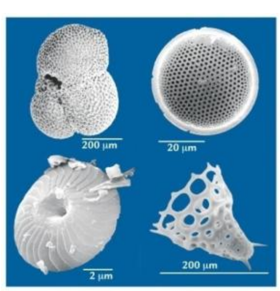
Sediment structures & material (loess)
Glacial moraines
Lake sediments
Coastal & Deep Ocean sediments



Archives:

Biological

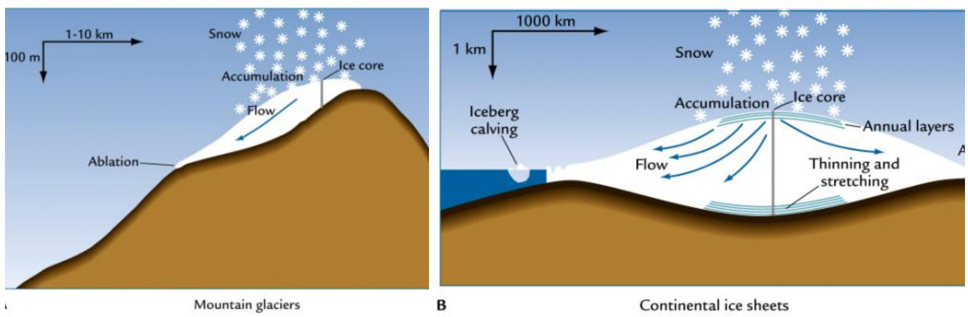
Fossils or dead material
Trees
Critters (macro: mammals, beetles, etc.
& micro: corals, plankton, forminifera, etc.)



Archives of Climate Change:

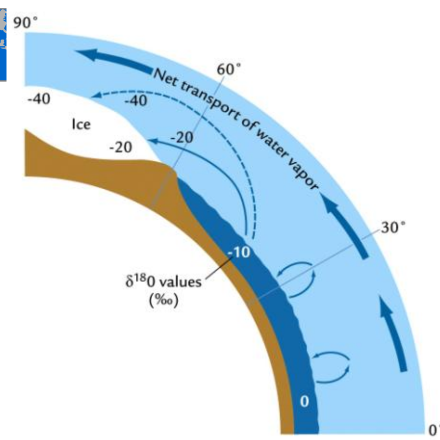
Cryological

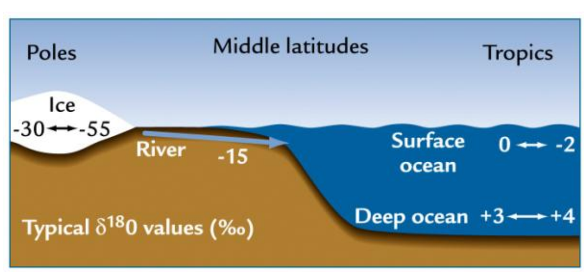
Glaciers & Ice Caps



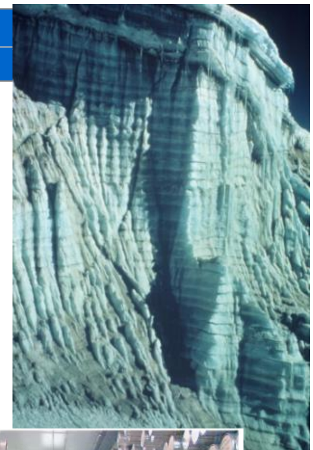
Ice & Sediment Cores

- Oxygen-isotope analysis:
  - **$\delta^{18}O$**
  - Measure ratio of ^{16}O to ^{18}O
  - Water from ocean enriched in 18 as 16 evaporates better…
  - When glaciers advance, more 16 frozen, so even more 18 in water…



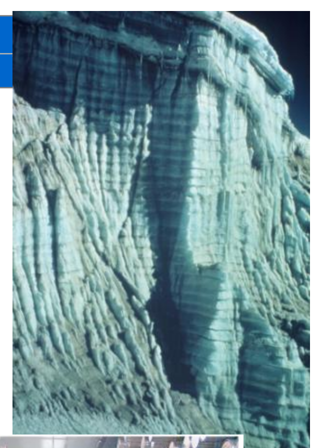


Ice Cores & Sediment Cores



- deuterium/hydrogen ratio:
  - δD‰
  - Measure ratio of ^{2}H to ^{1}H…
  - Deuterium is heavier than normal Hydrogen, so it takes more energy to evaporate any water molecule made with “heavy hydrogen”.
  - The result is that the colder it gets, the less Deuterium ends up in precipitation.
  - The smaller the D/H ratio, the colder the climate.

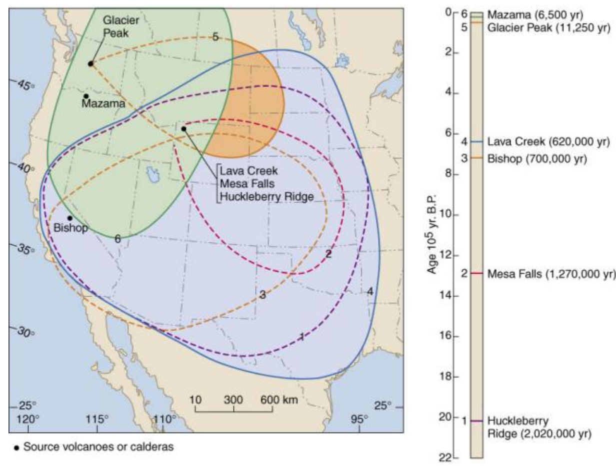
Ice Cores



- Ice cores:
  - volcanic ash
  - particulates (dust),
  - pollen,
  - chemical composition of the air trapped inside,
  - etc..

Archives

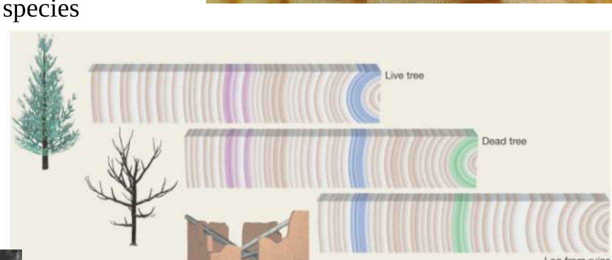
- Volcanic Ash
- Source by chemical signature
- Provides a calibration layer across variety of deposits

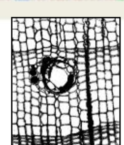


From Skinner

Tree-rings:

- Annual layers of growth
  - Depends on temp, precip, evapotrans.
  - Varies from species to species





http://web.utk.edu/~grissino/gallery.htm

Archives of Climate Change:

Historical Records

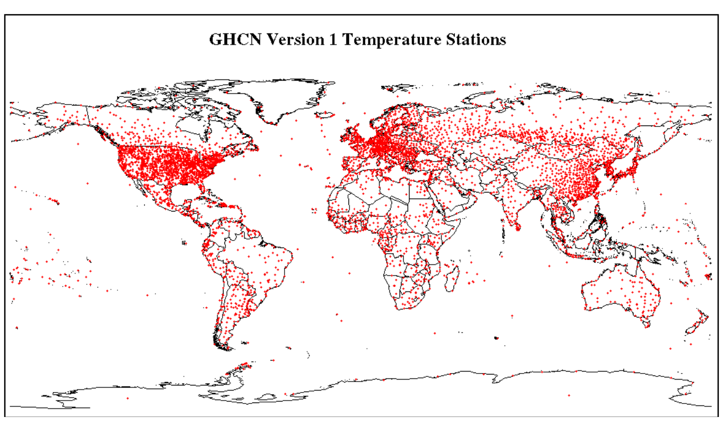
Letters, Diaries, Other Records

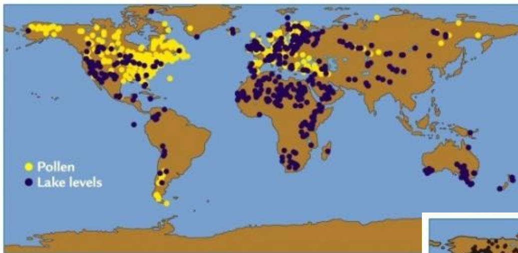
- ***Hunters in the Snow***, 1565
Pieter Bruegel the Elder
(Netherlandish, ca. 1525/30—1569)
Oil on panel; 46 1/8 x 63 7/8 in. (117 x 162 cm)
Image courtesy of the Kunsthistoriches Museum, Vienna

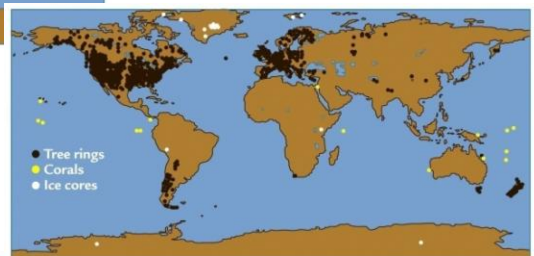
Archives of Climate Change:

Instrumental Records

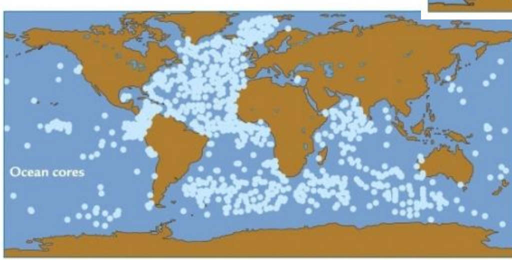
Only within last ~200 years







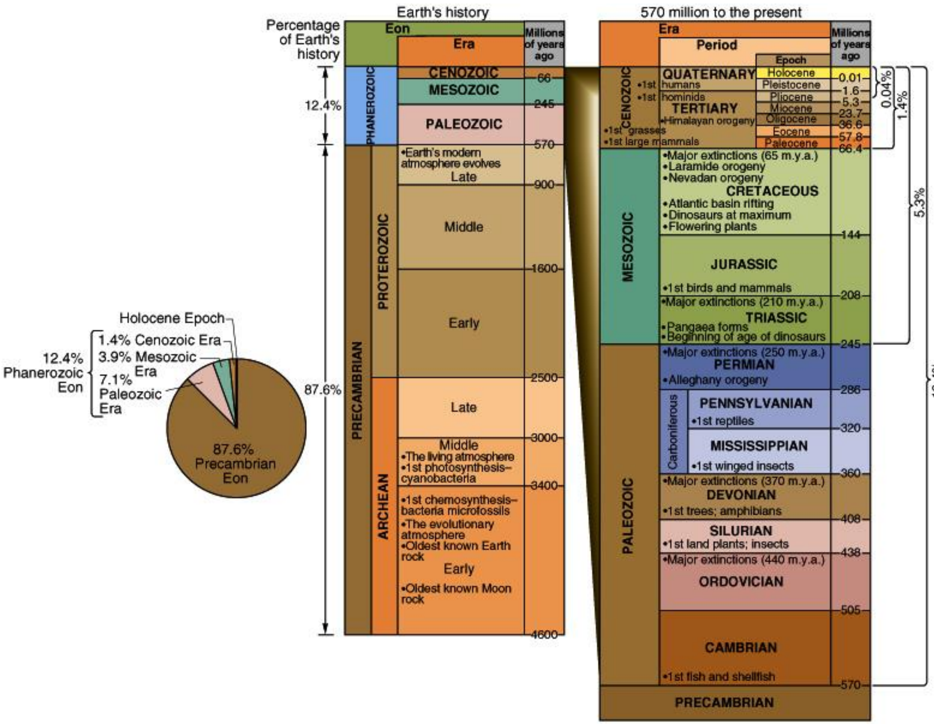
- Location, location, location!



Earth's Evolution

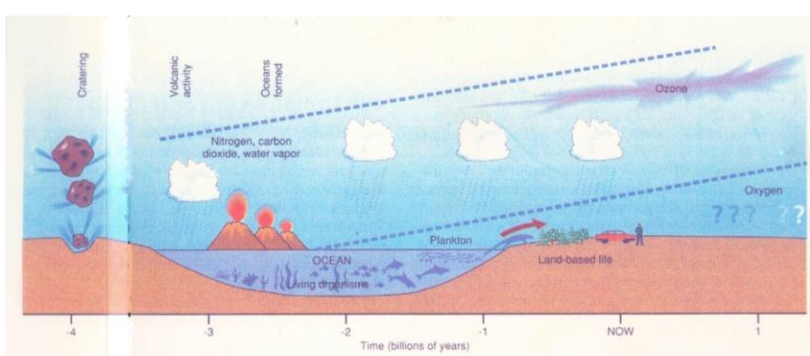
- ~4+ BYA: All blown away
- ~4: Magnetic field forms & atm held in place – no O_2
- ~3.8: Out-gassing continues but liquid earth possible as planet cools below 100 C
- ~3.5 BYA: First life forms release O_2
- ~500 MYA: O_2 levels high enough for ozone layer & plants & animals can now colonize land

- **All from geological evidence!!**



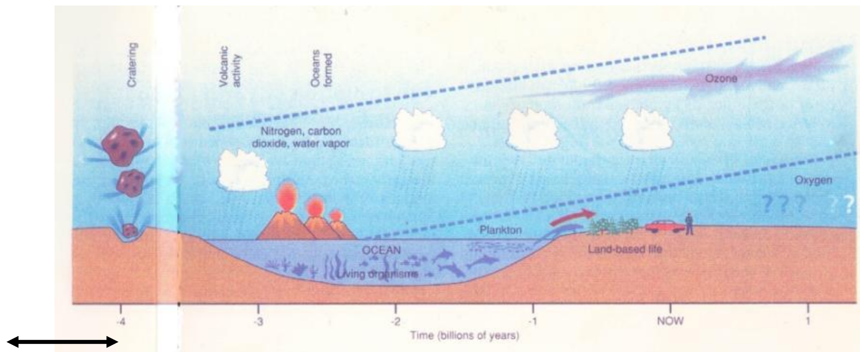
Earth's Primordial Atmosphere

- 4+ billion years ago (Y.A.)
- Consisted of gases most abundant in solar system, hydrogen and helium (lightest elements)
- Mainly blown away



Earth's Primordial Atmosphere

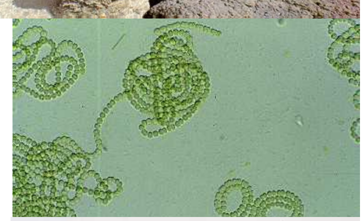
- 4+ Billion Y.A.
- Begins build up once magnetic field developed
- Consists of CO_2, NO*, H_2O



Stromatolites

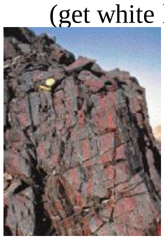
Photosynthesis

- $CO_2 + H_2O + \text{light} \rightarrow CH_2O + O_2$
- Cyanobacteria (Eubacteria) aka blue-green algae, appear ~ 3.5 bya
  - Release O_2 as byproduct
- Accumulation of O_2 in the atmosphere didn't start until oceanic Fe_2+ was oxidized (~2 bya).

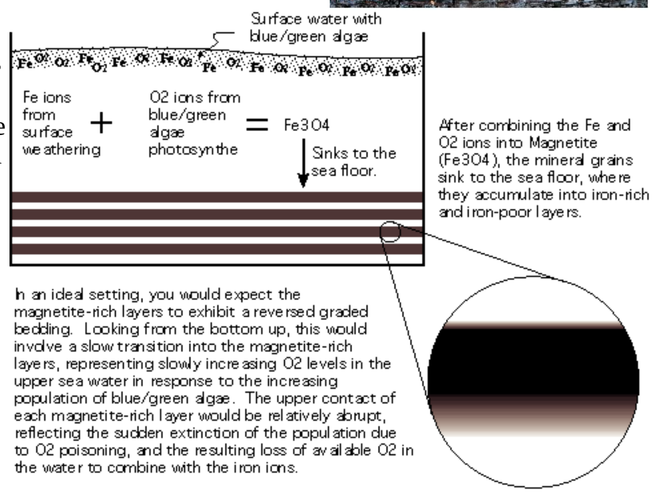


Banded Iron Formations

- Water with O_2 (from blue-green algae) & Fe from surface weathering.
- Get deposits (iron-rich layer) This cleans algae's environment.
- Too much algae, produce too much O_2, not enough Fe to remove it…
- O_2 toxic to algae, population collapse… (get white layer)



The red bands are hematite, and are interbedded with chert.



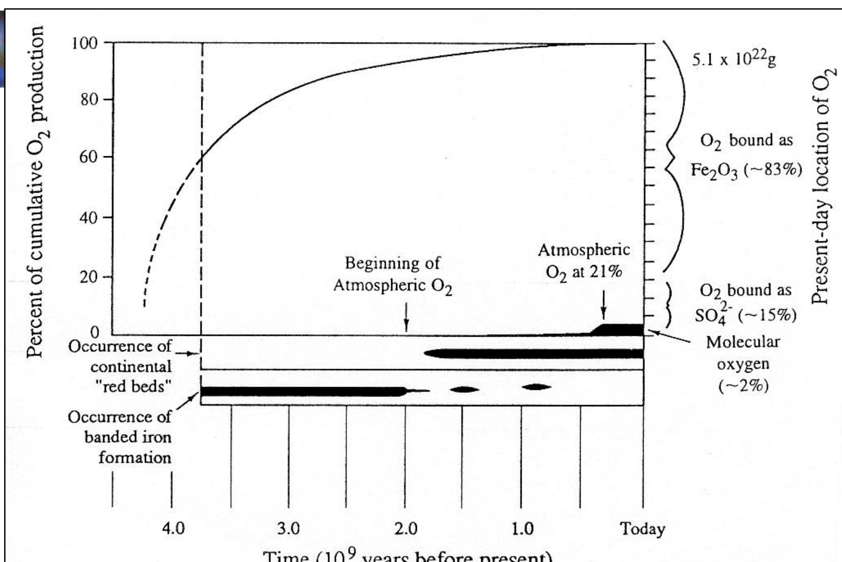


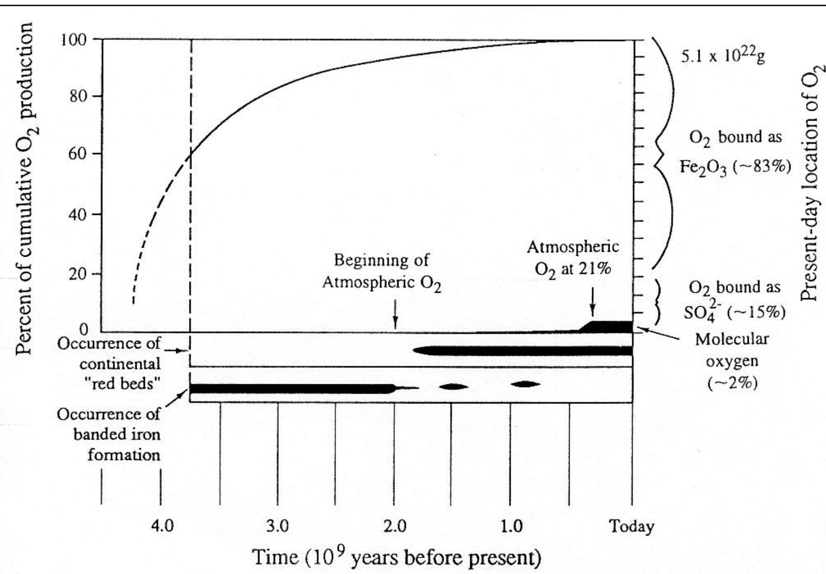
Figure 2.7 Cumulative history of O_2 released by photosynthesis through geologic time. Of more than 5.1×10^{22} g of O_2 released, about 98% is contained in seawater and sedimentary rocks, beginning with the occurrence of Banded Iron Formations at least 3.5 billion years ago (bya). Although O_2 was released to the atmosphere beginning about 2.0 bya, it was consumed in terrestrial weathering processes to form Red Beds, so that the accumulation of O_2 to present levels in the atmosphere was delayed to 400 mya. Modified from Schidlowski (1980).

Core from the Permian red beds that underlie the High Plains aquifer in southwestern Kansas and the Oklahoma panhandle

Red Beds

- ~1.8 BYA once all iron in ocean reacted with O_2, it could build up in the atmosphere, leading to the oxidation of iron on exposed surface.
- This Fe_2O_3 is seen in geological formations called Continental Red Beds
- Only after the surface iron reacted could O_2 then build up in the atmosphere

Carachipampa Volcano and Red Beds, N.W. Argentina



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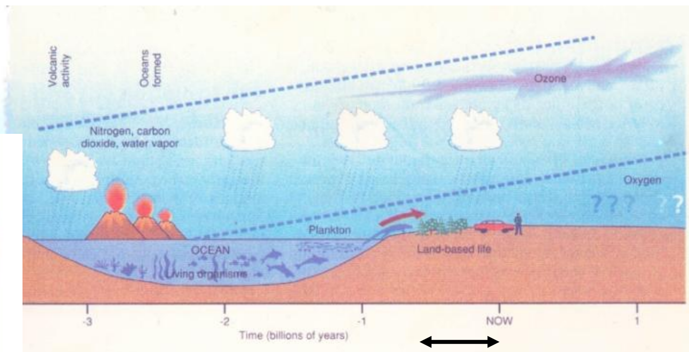
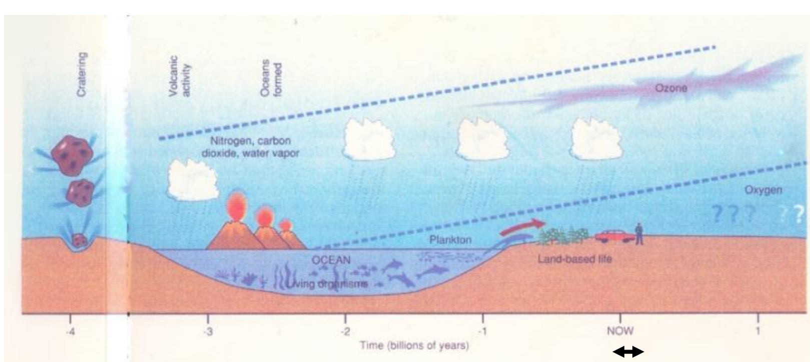
Earth's Modern Atmosphere

- 500 MYA enough O_2 that O_3 layer began
- That protects green plants to colonize land



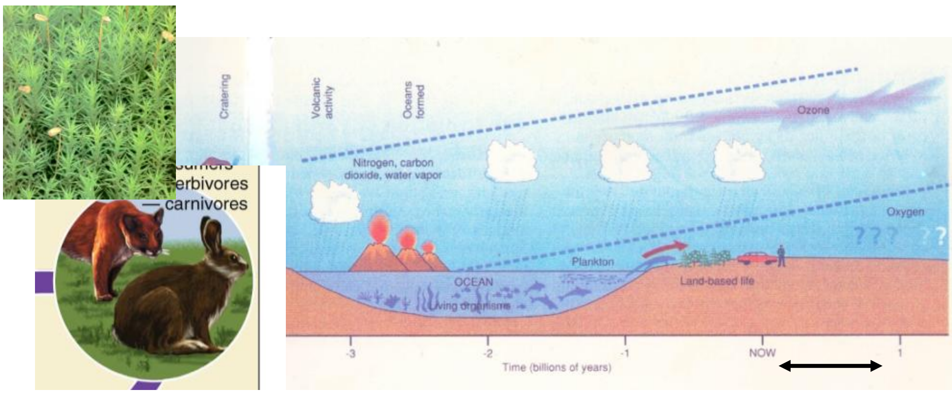
Atmospheric Composition

- The release of O_2 by photosynthesis is probably the most significant effect of life on the geochemistry of the Earth.....until man!

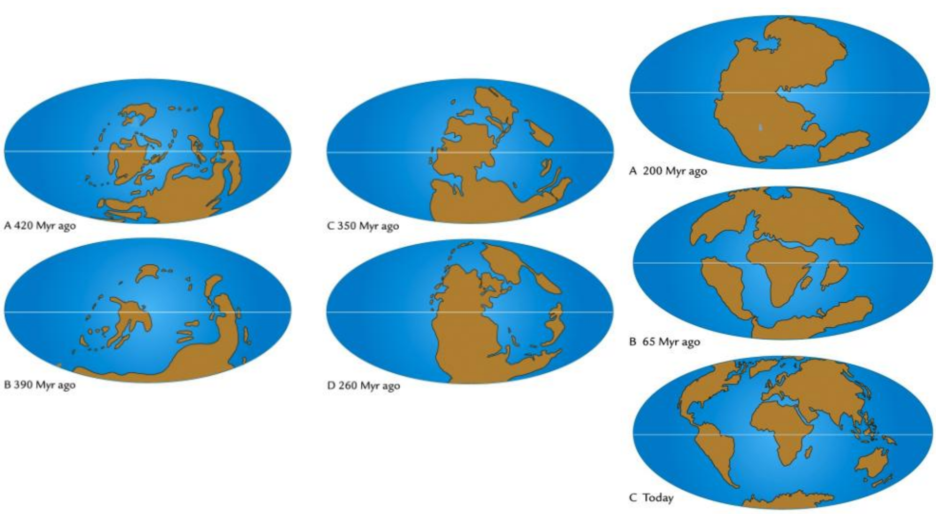


Earth's Modern Atmosphere

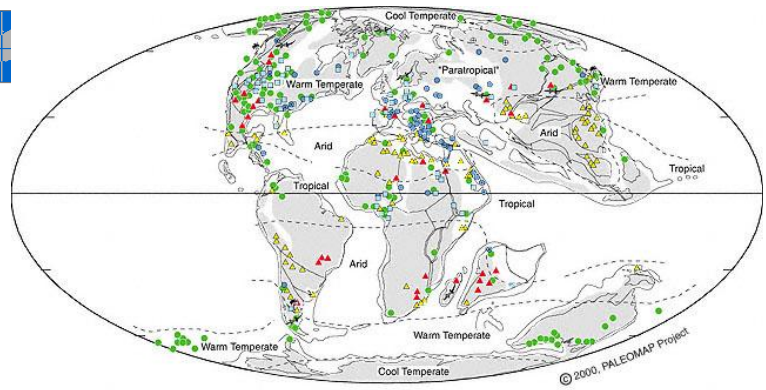
- Just 2% of all O_2 released over 3.8 BY is in atm.
- Now, a balance between O_2 producers and users??



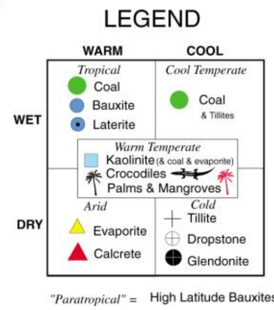
The last 500 MYA or so…



Fossils



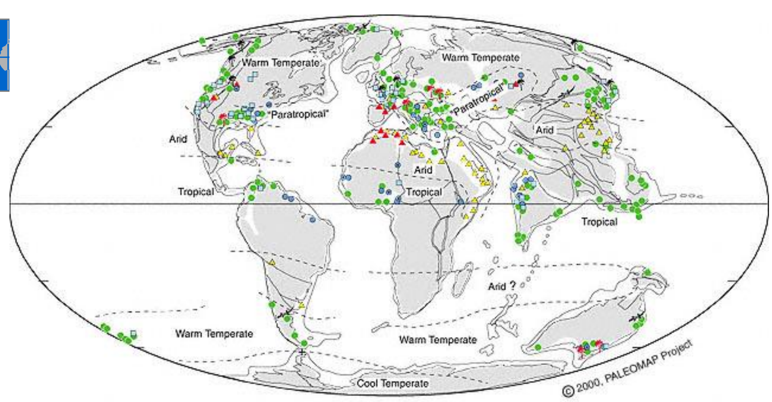
Upper Cretaceous



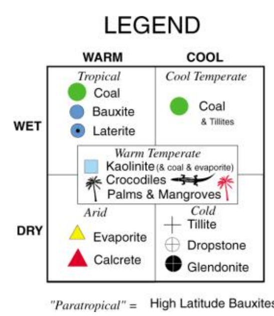
- Cretaceous (100 million ya): +15 C warmer than now
  - Sea level 200 m higher

http://www.scotese.com/Default.htm

Fossils



Lower Eocene



- Early Eocene (55 million ya): +7 C warmer than now

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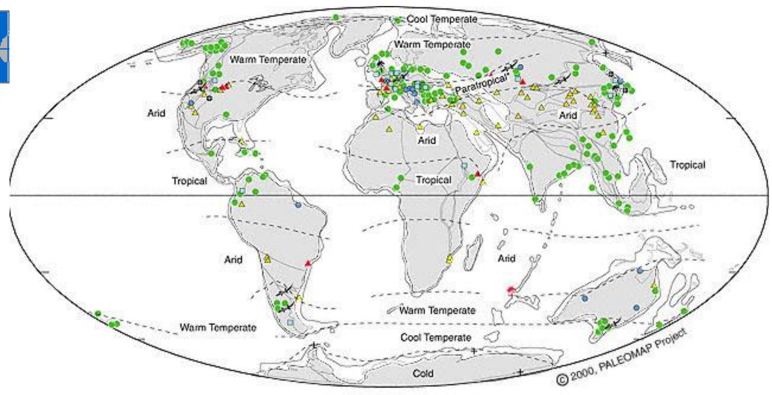
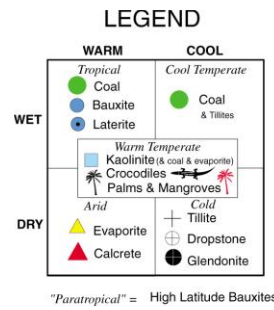
Fossils



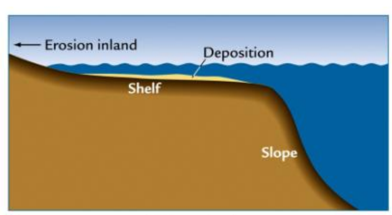
Oligocene



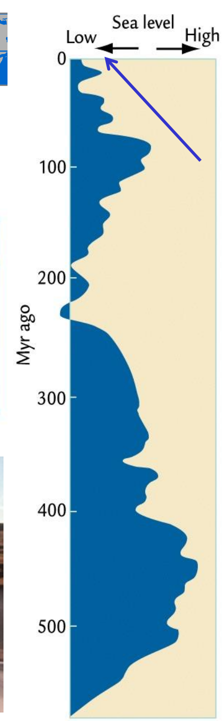
- Messinian Crisis (5-6 Mya): may be coldest, sea level well over 100 m lower than today

Sea-level changes

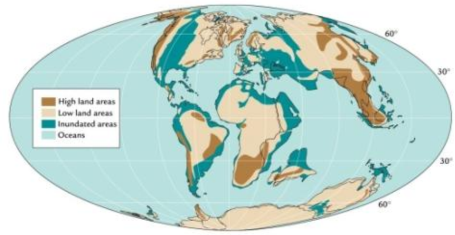
- Can think of sea level as reflecting relative warmth of whole planet
- Basin factors
  - Shape
  - Slower sea-floor spreading
  - Continental collisions
  - Volcanic plateaus



B High sea level



Sea-level changes



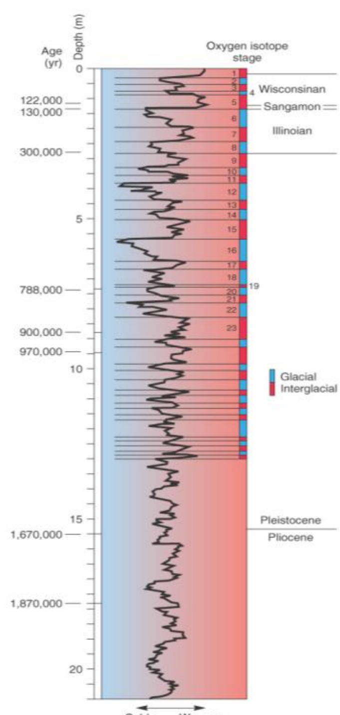
- Climate factors
  - Ice sheets
  - Thermal expansion (0.015% for each 1 C)

TABLE 6-1 Factors Contributing to Sea Level Fall in the Last 80 Million Years

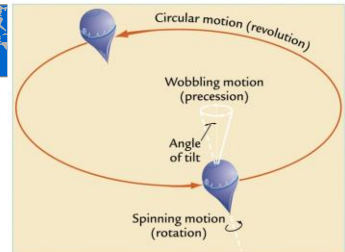
Cause of sea level change	Estimated change (meters)
Decrease in ocean ridge volume	−200 to −300
Collision of India and Asia	−40
Decrease in volcanic plateau volume	−10 to −40
Water stored in ice sheets	−50
Thermal contraction of seawater	−7
All factors	−300 to −440

Past 2.75 Million Years

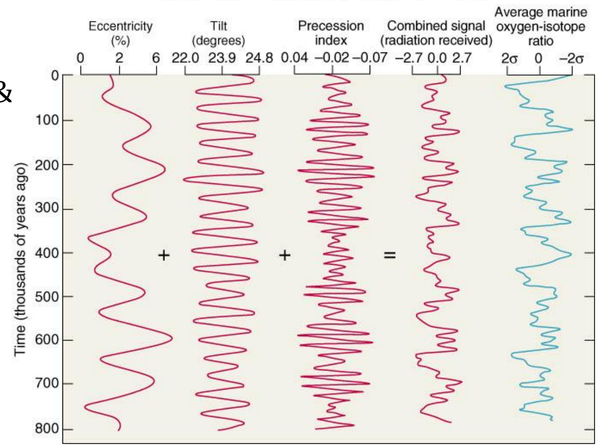
- From deep-sea drilling:
  - At least 50 glacial-interglacial cycles superimposed on the long term cooling trend…
  - 90% of last 0.9 MY there were ice sheets on Earth



Astronomy

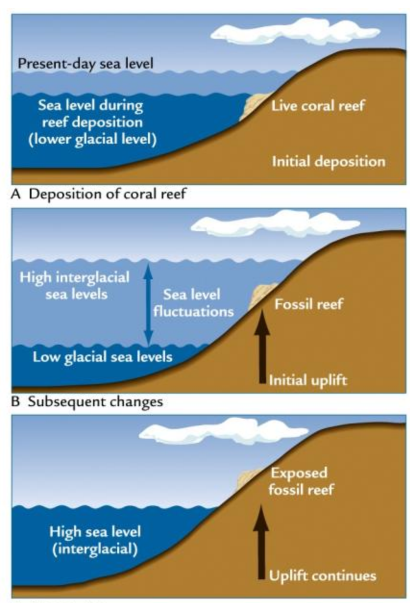


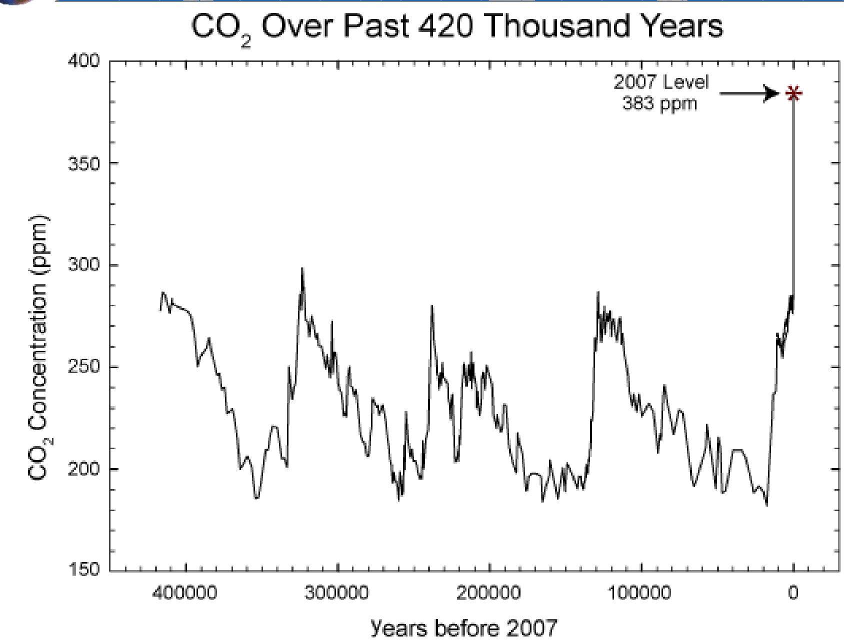
- 1911: Milutin Milankovitch proposes:
  - All 3 cycles (23, 41, & 100 KYA) together control ice ages
  - Summer insolation is driver



Milankovitch Cycles

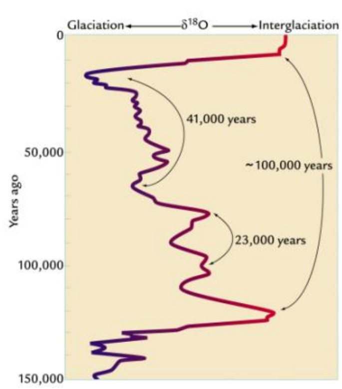
- 1976: Jim Hays, John Imbrie, and Nick Shackleton publish first confirmation of Milankovitch theory
  - Used corals to give dates with uranium decay isotope analysis

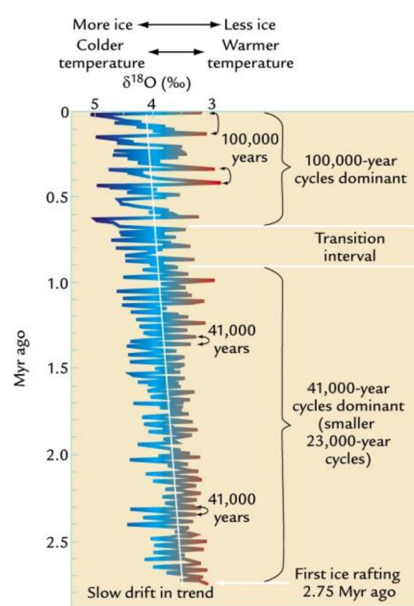




Milankovitch Cycles

- Get reconstructed temps.
  - Switch from 41 & 23 dominant to 100 dominant about 800 KYA





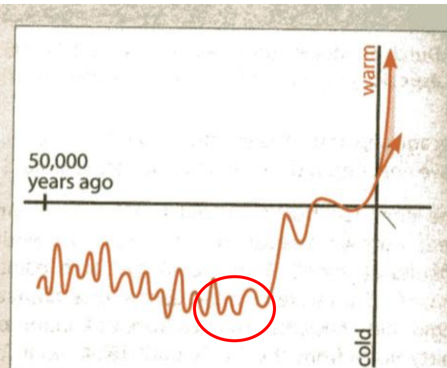
Chronology of Pleistocene Glaciations

North America	Alpine Region	Years before Present
WISCONSINIAN	Würm	— 10,000
Sangamon	Riss-Würm	— 75,000
ILLINOIAN	Riss	— 125,000
Yarmouth	Mindel-Riss	— 265,000
KANSAN	Mindel	— 300,000
Aftonian	Günz-Mindel	— 435,000
NEBRASKAN	Günz	— 500,000
Pre-Nebraskan	Pre-Günz	— 1800,000

In North America, the glacial stages are Nebraskan, Kansan, Illinoian, and Wisconsinian. These terms correspond approximately to the Günz, Mindel, Riss, and Würm in Europe.

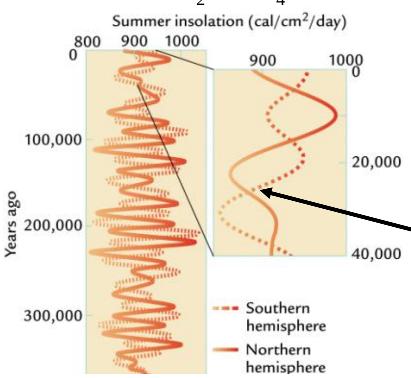
The Last 50,000 Years

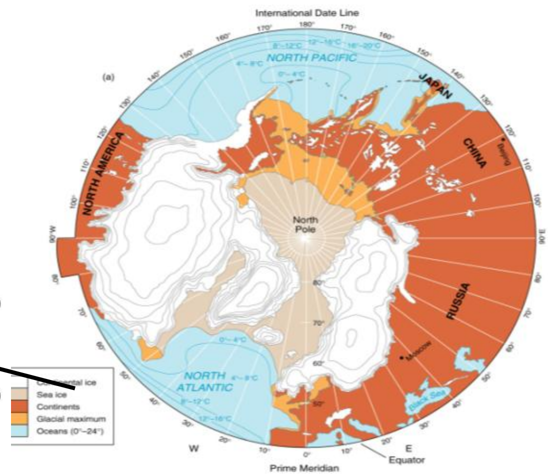
▶ Over tens of thousands of years The most recent ice age began about 115,000 years ago and ended about 11,500 years ago. Then came a dramatic warm-up, which lasted until about 3000 BC. Since then, Earth's temperature has changed relatively little, with a very slight cooling interrupted by warmer periods and punctuated by the last century's sharp temperature rise. More than a thousand years from now, after humans have exhausted fossil fuels and the resulting greenhouse gases have left the atmosphere naturally (mostly through slow absorption by the ocean), we may return to cooler times. If the length of the



Last Glacial Maximum

- Cold & Dry
  - Low insolation in northern & southern! (N similar to today)
  - Large ice sheets (lag)
  - Lower CO_2 & CH_4





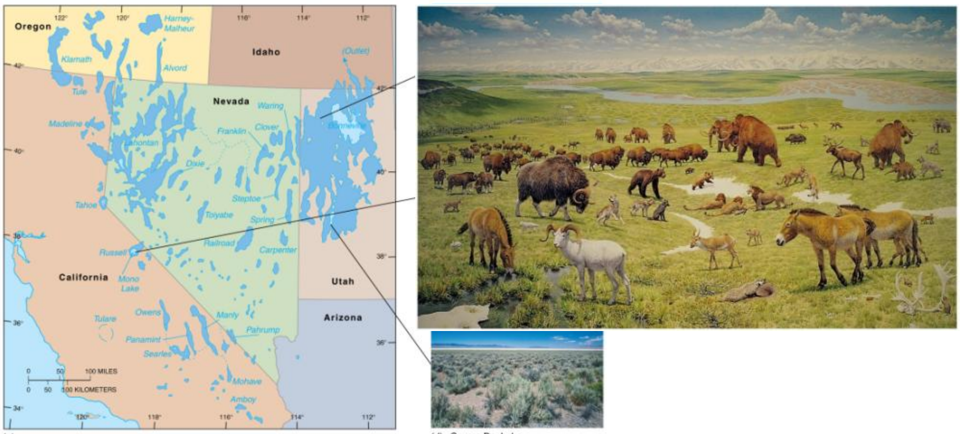
Last Glacial Maximum

• World sea level fell at least 100 m, thereby causing large expanses of the shallow continental shelves to emerge as dry land

•Disruption of major stream systems.

• The Missouri and Ohio rivers to move into new courses beyond the ice margin.

Last Glacial Maximum

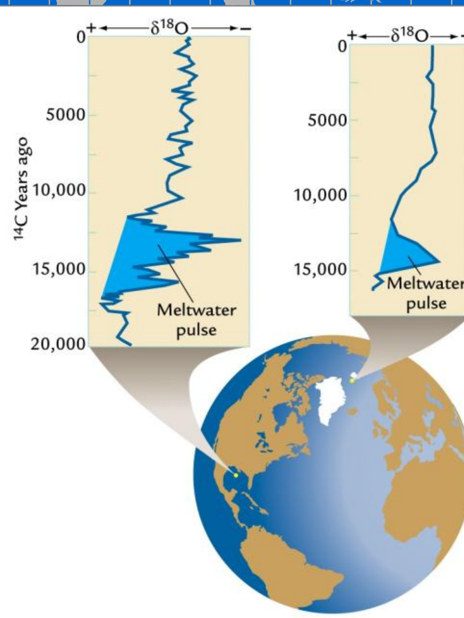


(a)

(d) Severe Dry Lake

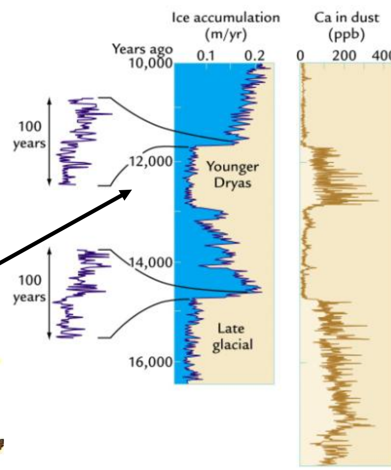
Deglaciation

- Meltwater pulses…
  - Several different ones interrupt steady retreat of ice sheets



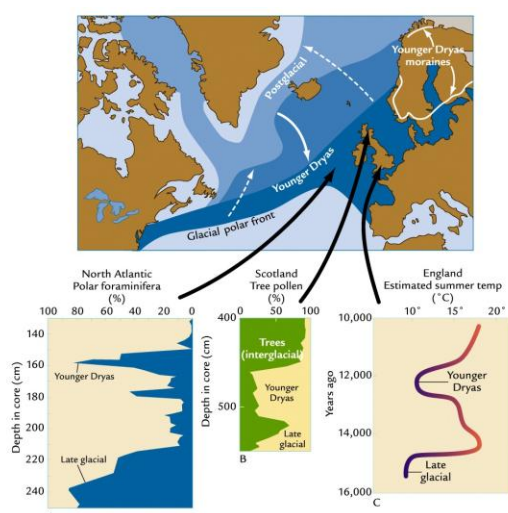
Younger Dryas

- ~3,000 year return to glacial conditions in midst of deglaciation
- "Younger Dryas"
  - 15-12,000 years ago
  - Pollen of dryas returns to Europe
  - Scary part: transitions very sudden, within a decade!!!



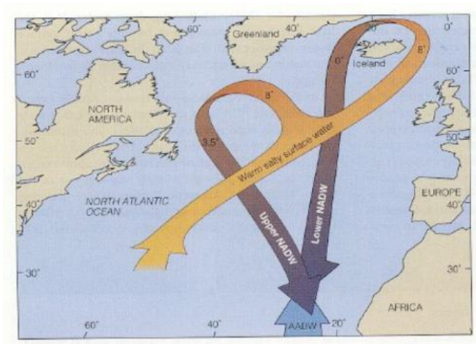
Younger Dryas

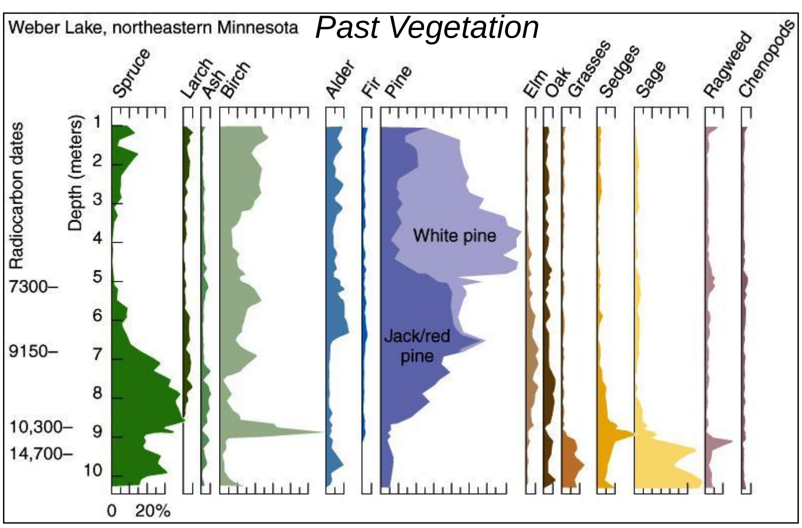
- Think caused by movement in polar front.
  - Front: area between two air masses
  - Was S of England during glacial, shifts N during interglacial.
  - During YD, it reverted…



Thermohaline Circulation

- Wally's hypothesis:
  - Cut off NADW = return to glacial conditions
  - Must suddenly change input into North Atlantic…
  - What could happen???





Pollen diagrams provide information on past vegetation at a site, which is useful for determining past climates.

Quelccaya Ice Cap, Peru

1977

2002

Photos: Lonnie G. Thompson: O

Quelccaya Ice Cap, 2002

200 – 400 m above its modern range

Cushion Plant

Photos: Lonnie G. Thompson
Ohio State University

Unpublished data: Courtesy of the Thompsons at Ohio State University; for educational use only; Plant identification by Don Les (U Conn) and Blanca Leon (UT Austin)

Radiocarbon dates of plants from base of Quelccaya Ice Cap

	^{14}C age	Error (+/-)	Calibrated age (Before 1950 A.D.)	Relative area under probability distribution
Lawrence Livermore National Laboratory				
Sample 1 First run	4470	60	5284-5161 (1σ) 5302-4961 (2σ)	.534 .926
Sample 1 Second run	4525	40	5186-5121 (1σ) 5311-5047 (2σ)	.413 1.000
Sample 2 First run	4530	45	5186-5120 (1σ) 5317-5040 (2σ)	.396 .993
Sample 2 Second run	4465	40	5278-5171 (1σ) 5295-4967 (2σ)	.580 .984
National Ocean Sciences AMS Facility at Woods Hole Oceanographic Institution				
Sample 1	4530	45	5186-5120 (1σ) 5317-5040 (2σ)	.396 .993
Sample 2	4510	40	5188-5119 (1σ) 5307-5040 (2σ)	.404 .988

"The Tyrolean Iceman" - "Ötzi"
"Man from the Hauslabjoch"

Age 5175 ± 125 years

Source: http://info.uibk.ac.at/c/c5/c552/Forschung/Iceman/iceman-en.html#Finding

“Drought Events”

- Now looking for more evidence of that shift in climate 5000 years ago…
- Kind of show both linear & cyclic trend depending on which examined…
- Very messy picture, especially on regional scale.

TROPICAL GLACIER AND ICE CORE EVIDENCE OF CLIMATE CHANGE 143

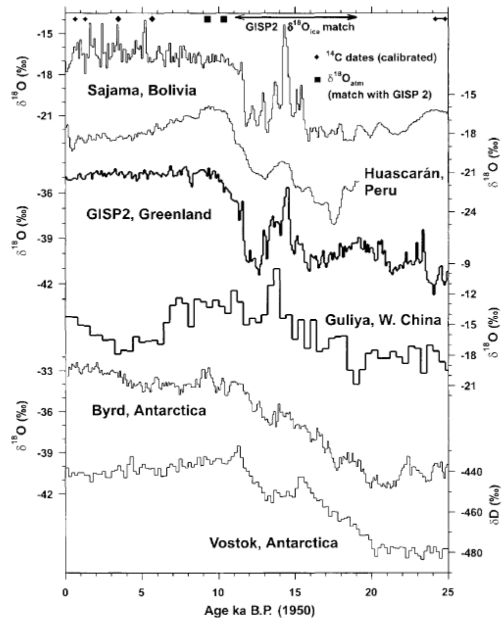
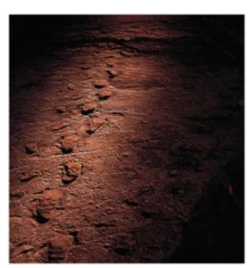


Figure 4. The $\delta^{18}O_{ice}$ histories for the last 25,000 years for six cores from the tropics to the poles show similar isotopic depletion (~5 to 7‰) in the Late Glacial Stage ice relative to Holocene ice.

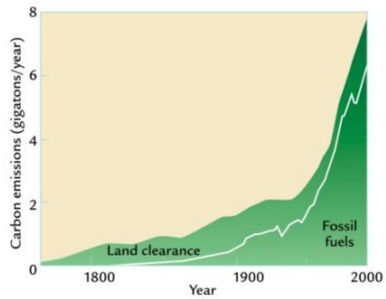
Anthropocene

- Term used for climate where humans are the dominate controlling mechanism…



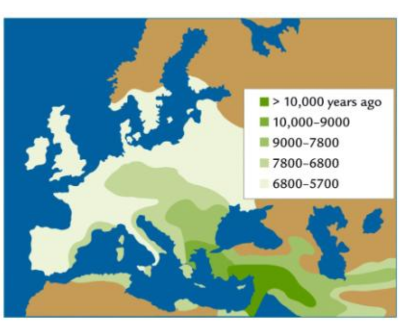
Clearing of Land

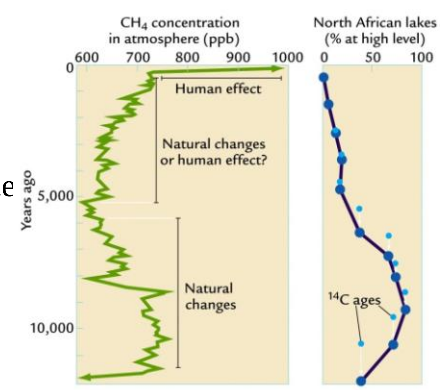
- Deforestation:
  - Since 8000 years ago in Europe…
  - Sagan proposed in 1970s
  - Ruddiman proposes change in CO_2 since then



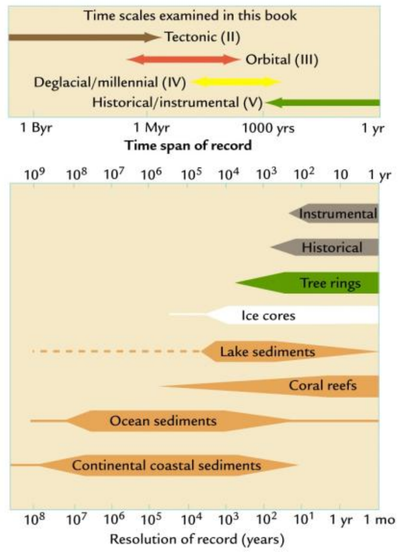
Effects of Agriculture

- Agriculture:
  - First arose in fertile crescent & Yellow River Valley in China…
  - Unexplained rise in methane
  - Ruddiman credits irrigation of rice





Time scales for Proxy Data



Take Home

- Proxy data is very important to our understanding of climate.
- We are improving our ability to read these signals and what they tell us about the Earth's past.
- They are revealing a complicated but fascinating story about our Earth's climatic evolution.
- We still have a great deal to learn.

Climate of the Last 2000 Years…

- Coming next Tuesday…

Additional Courses

- GEOS 108N – Climate Change: Past&Future
- GEOG 322N – Weather & Climate
- GEOS 382 – Global Change
- FOR 407 – Biogeochemistry
- GEOG 550 – Seminar in Paleoclimate & Global Change

Resources

- W. Ruddiman. *Earth's Climate: Past and Future*. 2008. W.H. Freeman.
- E.C. Pielou. *After the Ice Age: The Return of Life to Glaciated North America*. 1992. University of Chicago Press.
- Broecker & Kunzig. *Fixing Climate*. 2008. Hill & Wang.