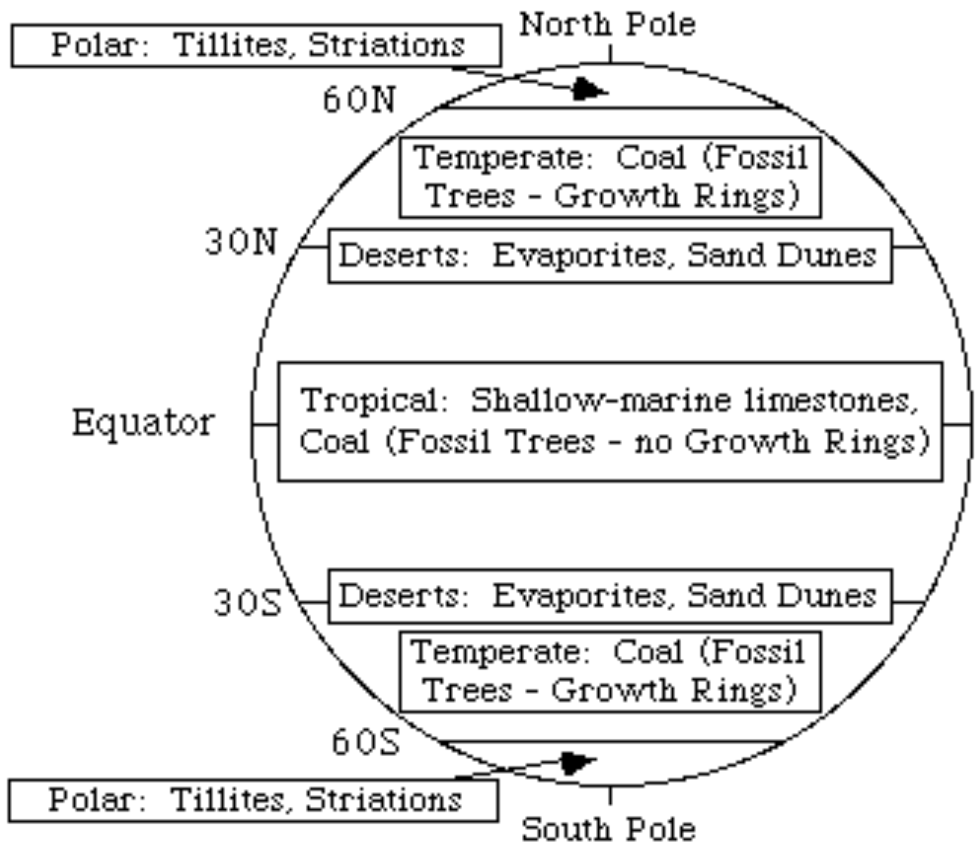
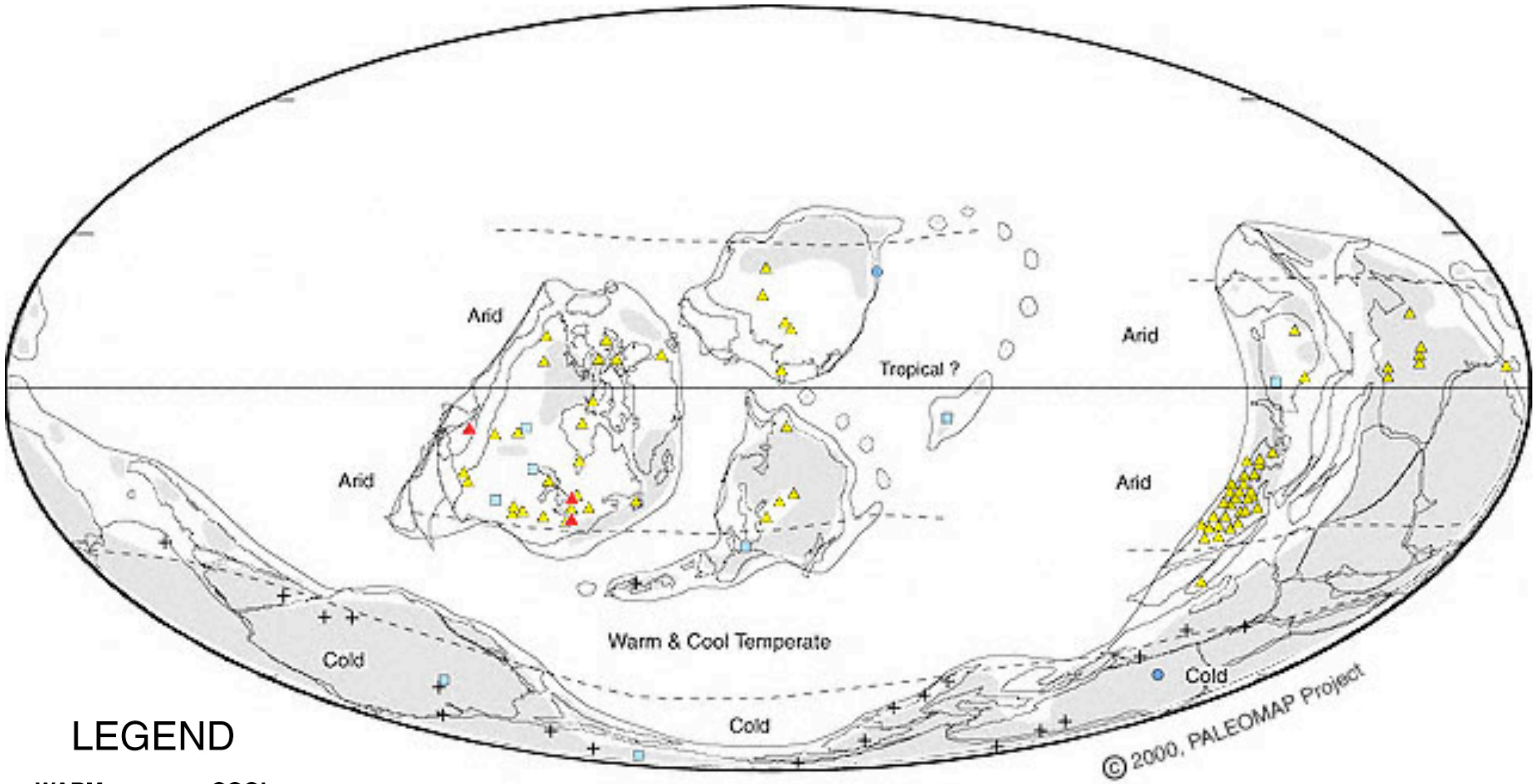
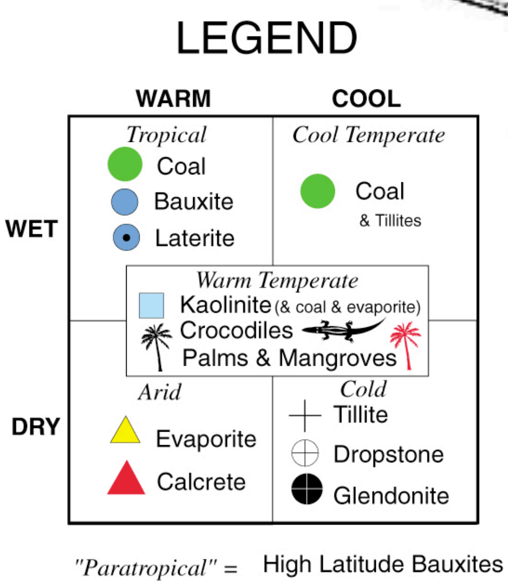
Paleoclimate indicators

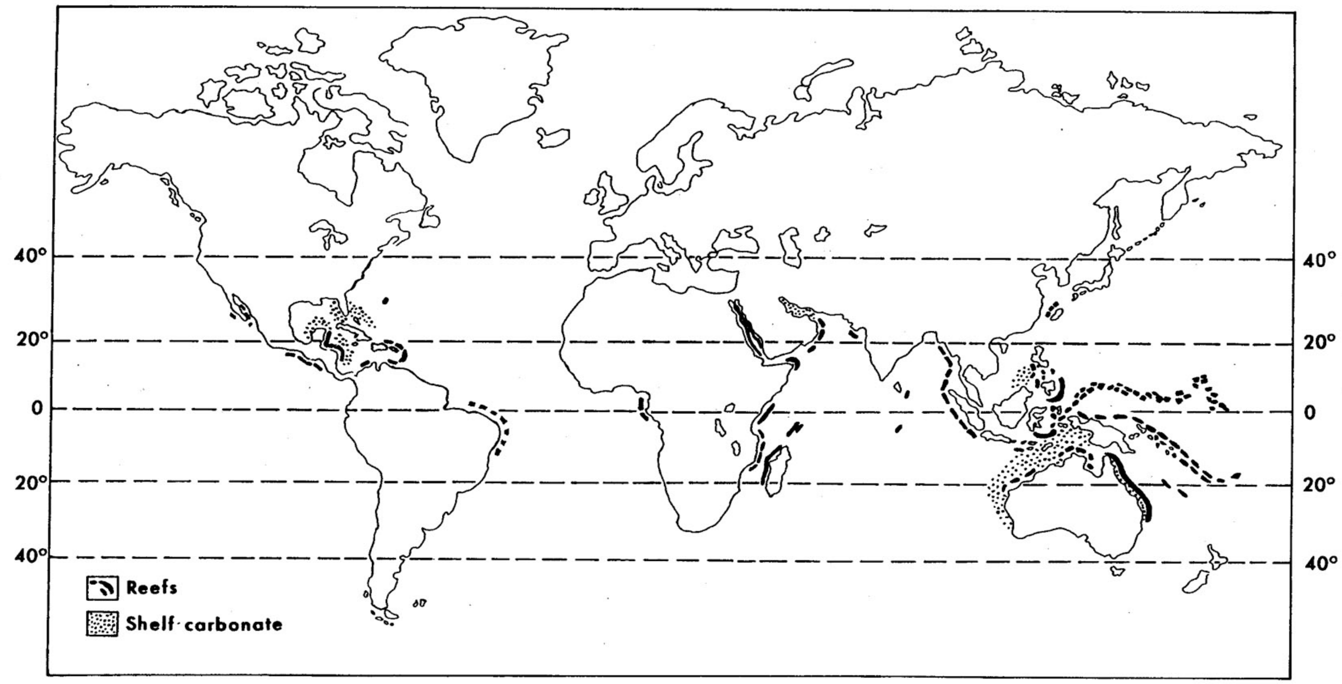
Rock types as indicators of climate





Middle & Upper Ordovician





. Distribution of modern marine carbonate sediments in shallow water

Accumulation of significant thicknesses of limestone and reef-bearing limestone is restricted to ~20º + - equator

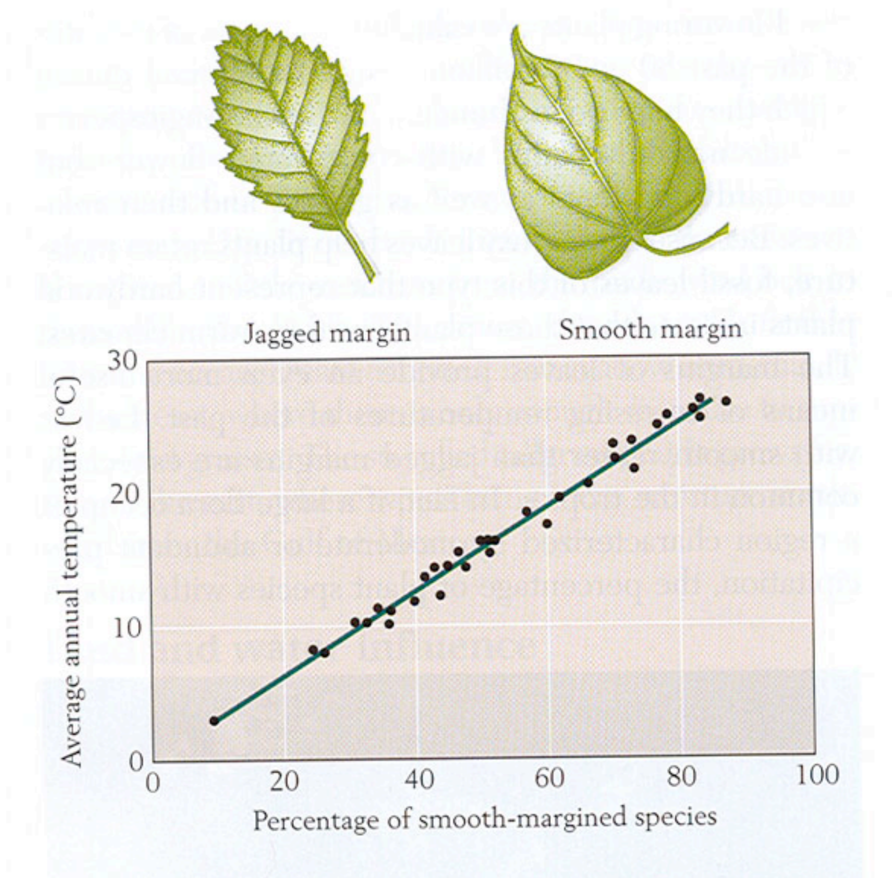
Gowganda tillite, Ontario

Rock record of glaciation, this one ~2.3 billion years ago!

The concept of climate proxies

- A climate proxy is something that records or reflects a change in temp or rainfall but does not DIRECTLY measure temperature or precipitation

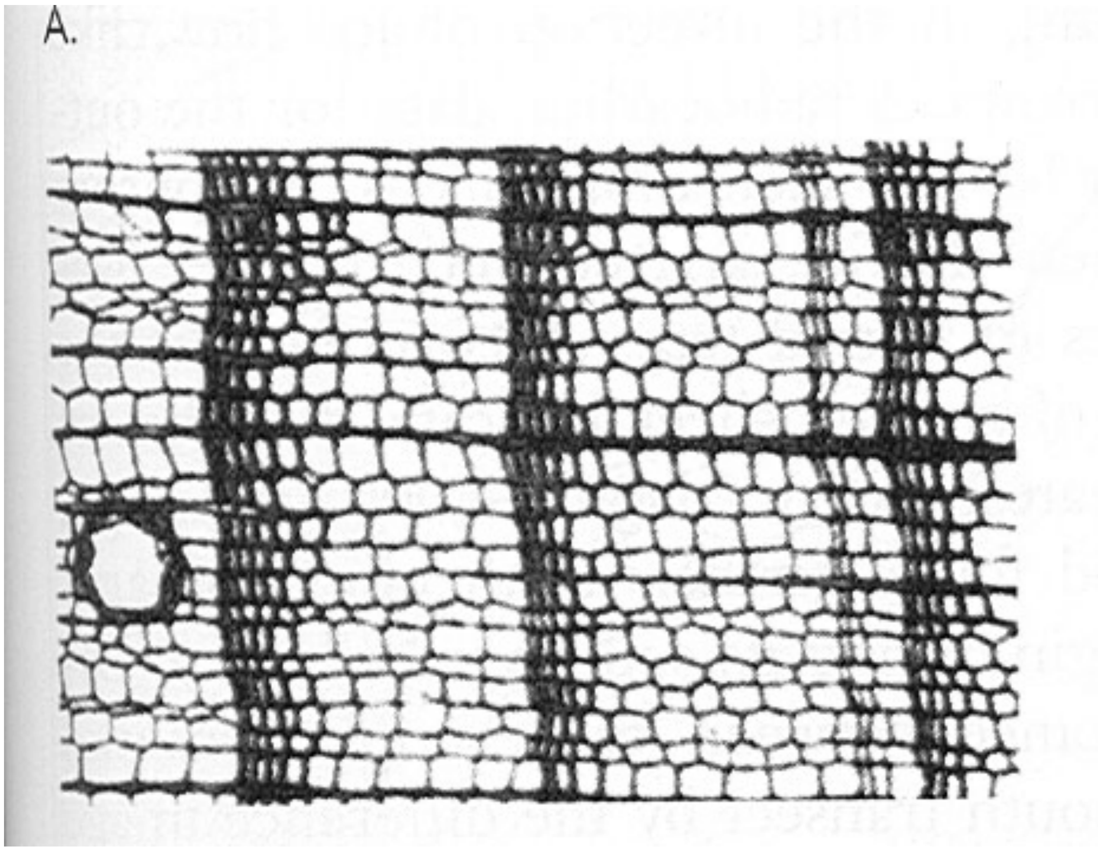
For example…



Serrations on leaf margins indicate temperature: jagged edges indicate cooler climate

Leaf waxiness is an indicator of moisture retention

Tree rings:degree of seasonality



In the tropics there is no difference in growing seasons and tree rings are not well developed. These are tree rings from a tree in a temperate climate

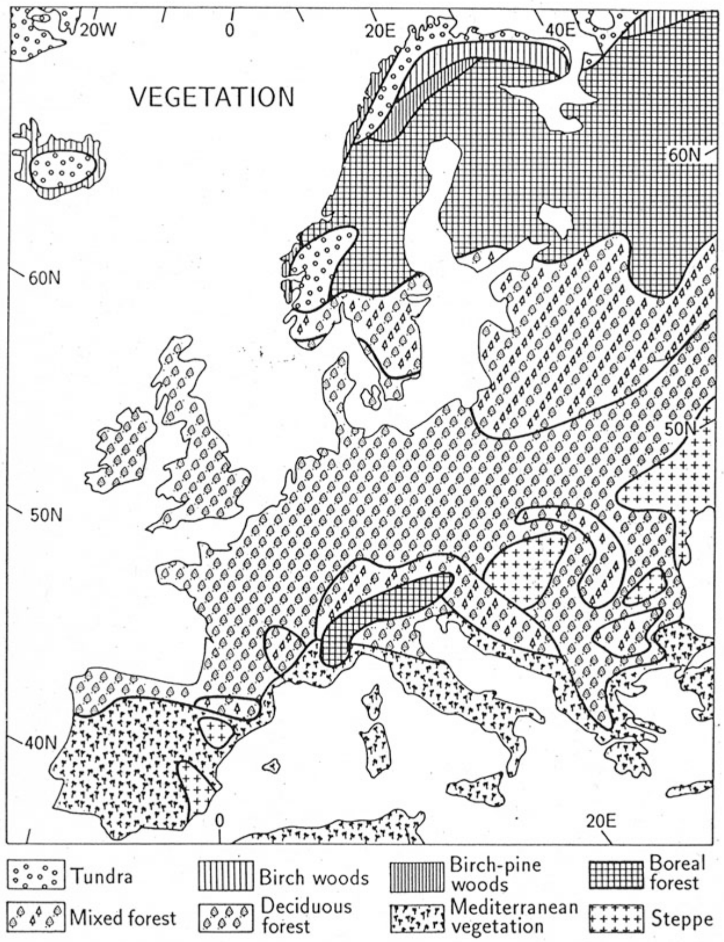
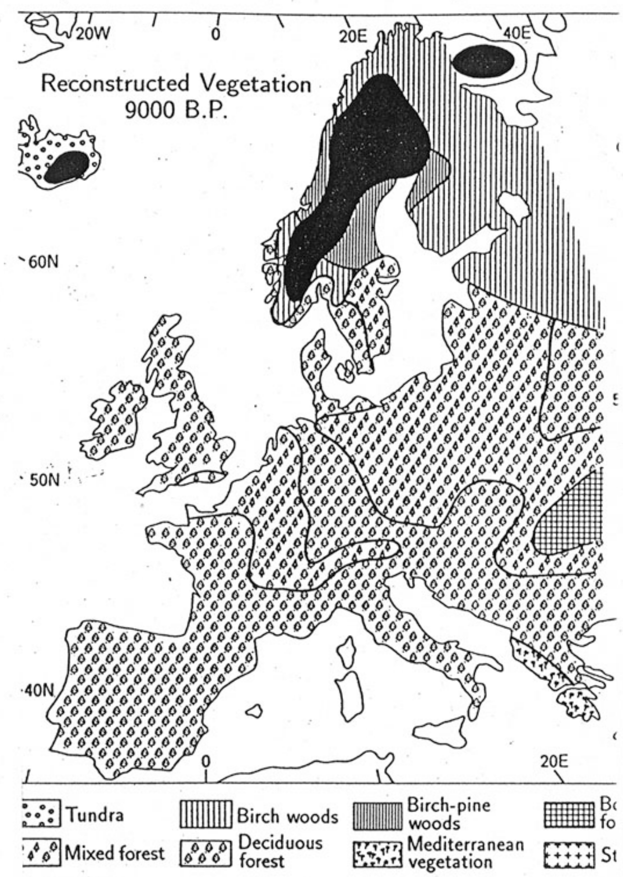
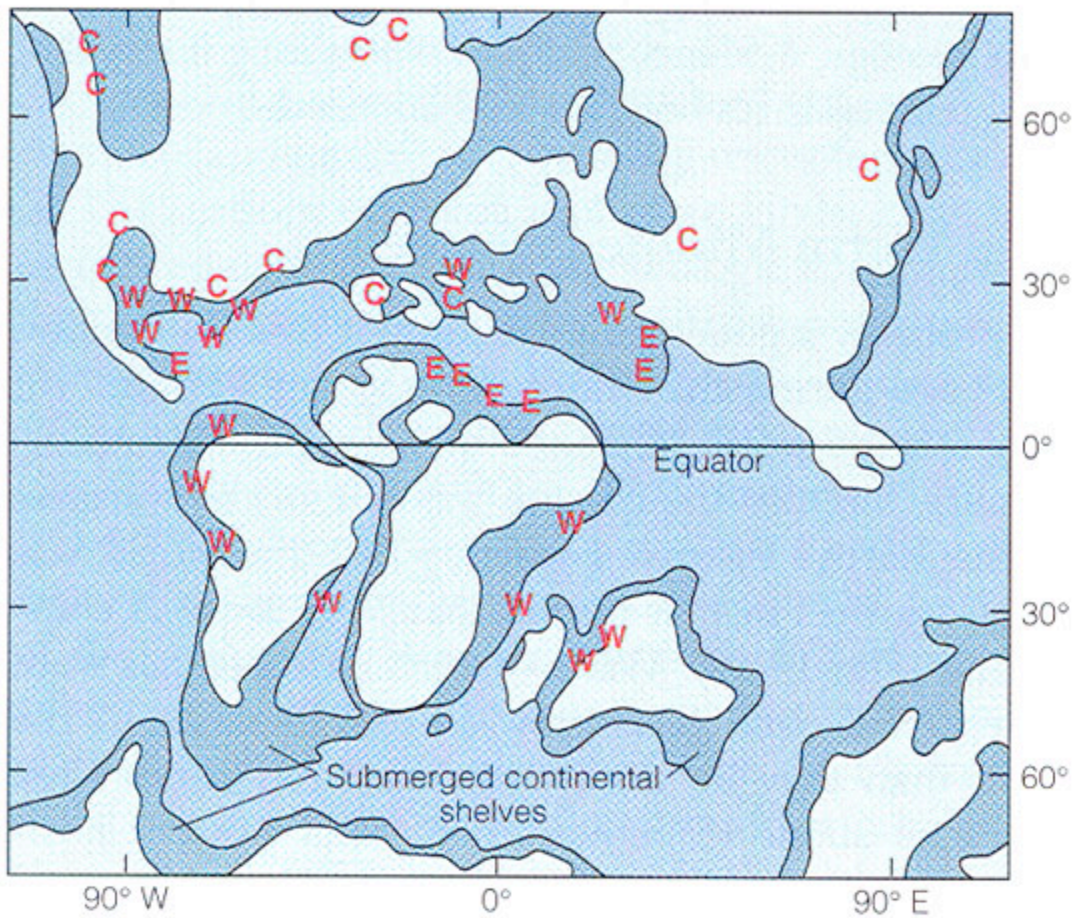


Fig. 73. European vegetation regions (data from Fullard and



Vegetation zones in Europe parallel latitude now and 9,000 yr before present

Middle Cretaceous climate indicators



W = warm-water animal occurrences; E = evaporite minerals; C = coal deposits. Coal is not particularly temp sensitive but animals and evaporation are.

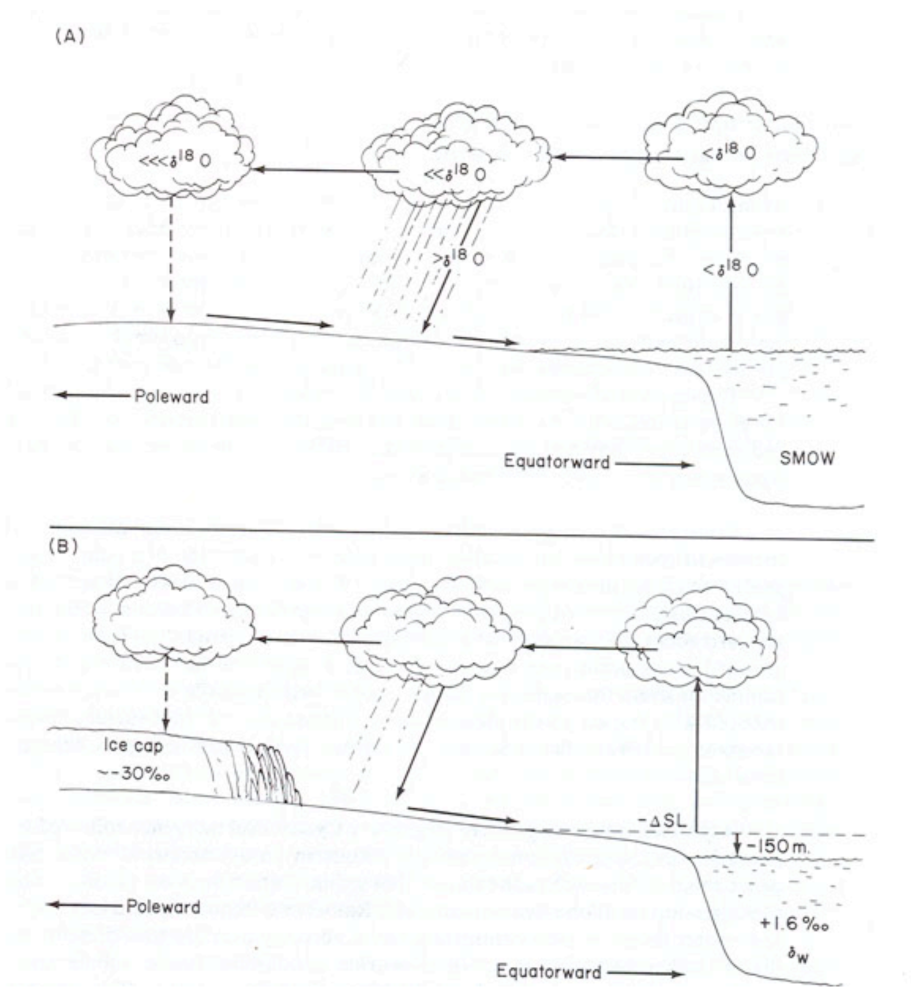
Stable isotopes of oxygen: a proxy for temperature but now considered an almost direct measurement

- Stable isotopes: do not decay over time. Ex, O_{16} and O_{18}.

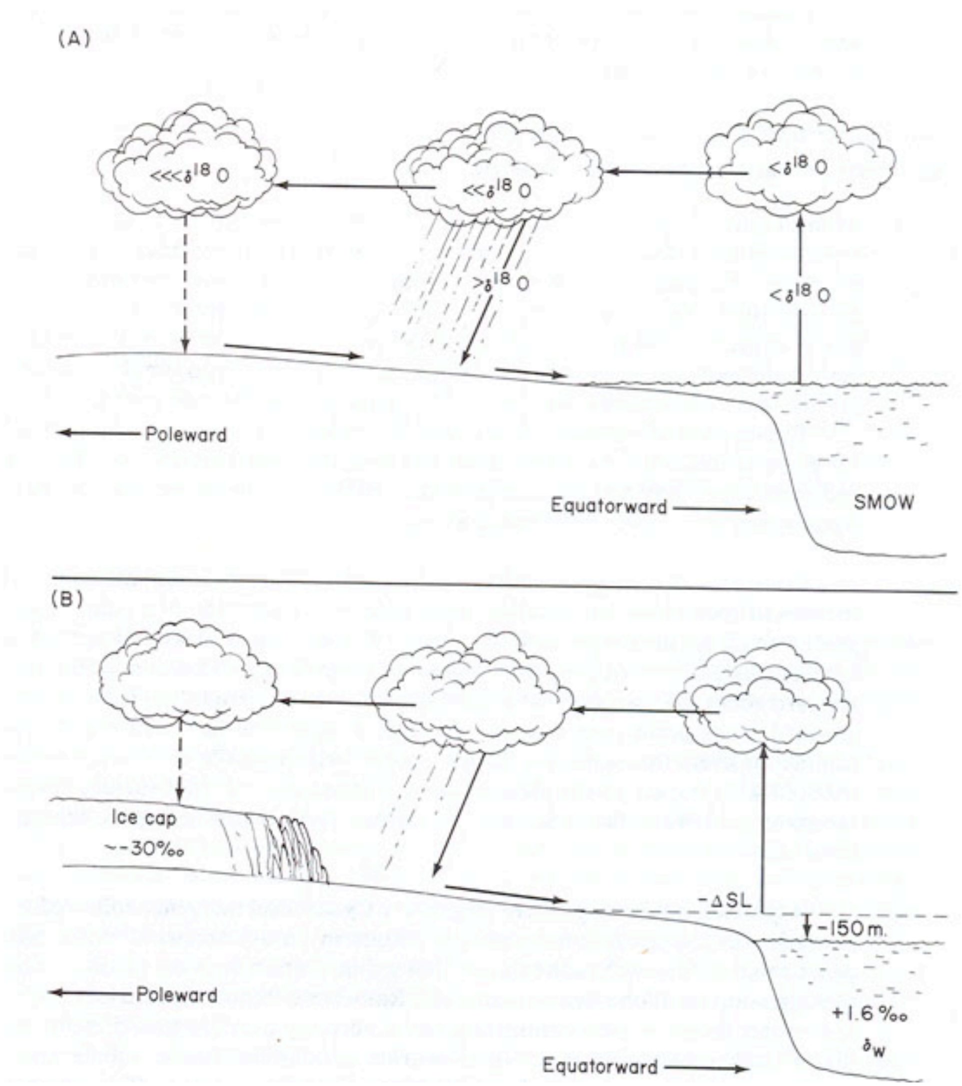
O_{18} is produced from O_{16} through nucleosynthesis in supernovae

Anything that incorporates oxygen into its chemical structure will do so with some ratio of O_{18}:O_{16}. We can measure the ratios of these isotopes in the lab

O_{18}/O_{16} fractionation



H_2O is evaporated from sea water. The oxygen in the H_2O is enriched in the lighter O_{16}.
This H_2O condenses in clouds,falling on land as precipitation. Thus, H_2O that is part of the terrestrial water cycle is enriched in the light O_{16} isotope and sea water is enriched in the heavier O_{18} isotope



Glacial ice is therefore made up primarily of water with the light O_{16} isotope. This leave the oceans enriched in the heavier O_{18}, or “more positive.”

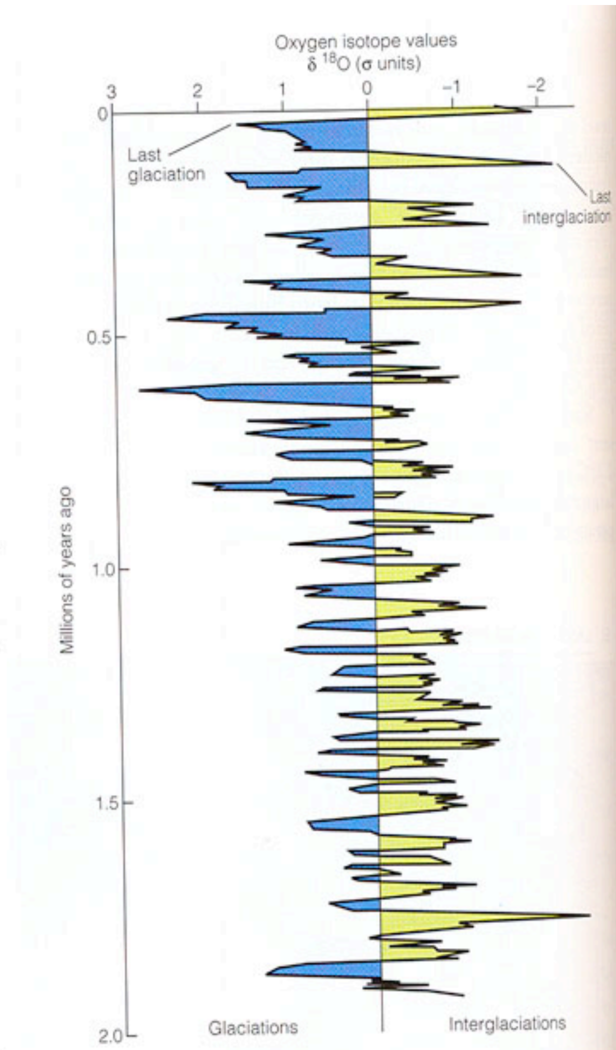
During glacial periods, more O_{16} is trapped in glacial ice and the oceans become even more enriched in O_{18}. During interglacial periods, O_{16} melts out of ice and the oceans become less O_{18} rich, or “more negative” in O_{18}

If we collect a shell made out of $CaCO_3$, we can analyze the O_{18}:O_{16} ratio by the following formula:

delta O_{18}= [(O_{18}/O_{16} sample/O_{18}/O_{16} standard) -1] x1000

The standard that your sample is compared to is either one prepared from ocean water or from a fossil standard. Positive delta O_{18} values mean that your sample is enriched in the heavy O isotope; negative delta O_{18} values mean it's depleted in the heavy O_{18}.

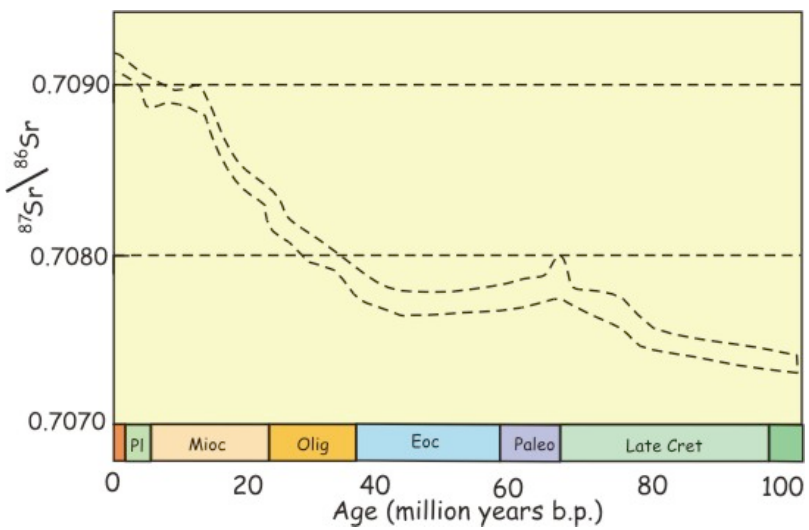
Curve of average O_{18} isotope variation over the past 2my based on analysis of deep sea sediment

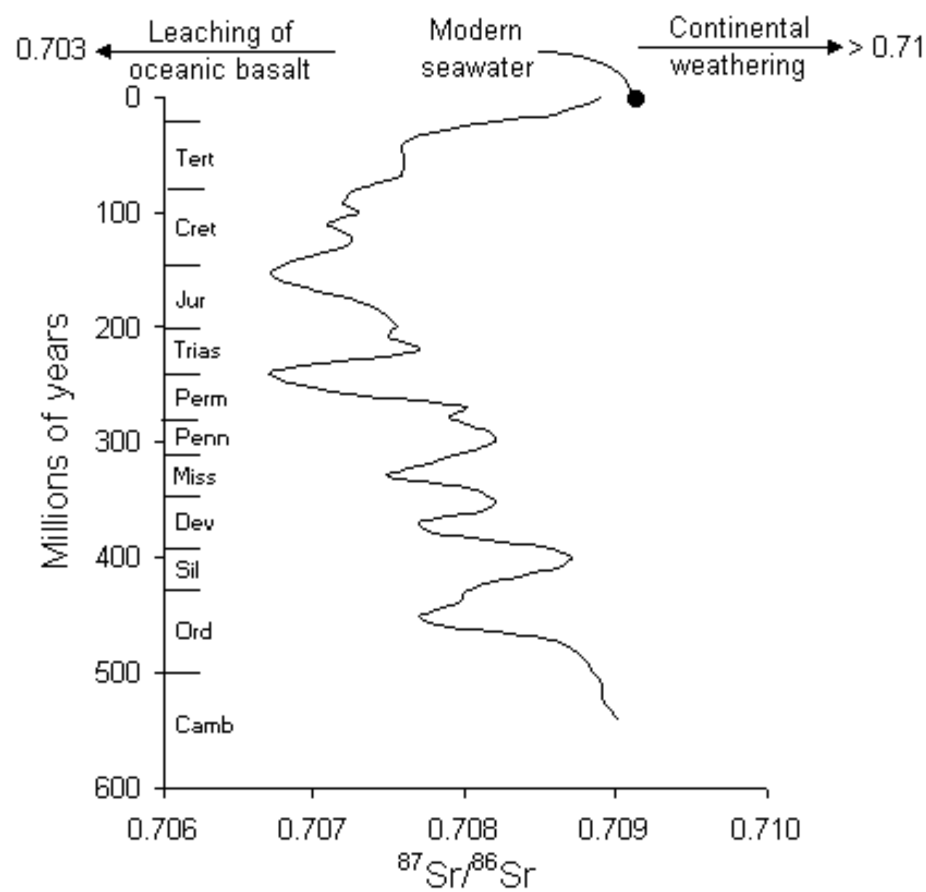


The curve illustrates changes in global ice volume in successive glacial (blue) and interglacial (green) cycles of the Quaternary Period.

Note that this graph does not show fluctuating temperatures, but changes in the dilution of sea water as a result of freshwater influx from melting glacial ice, i.e., this is a climate proxy

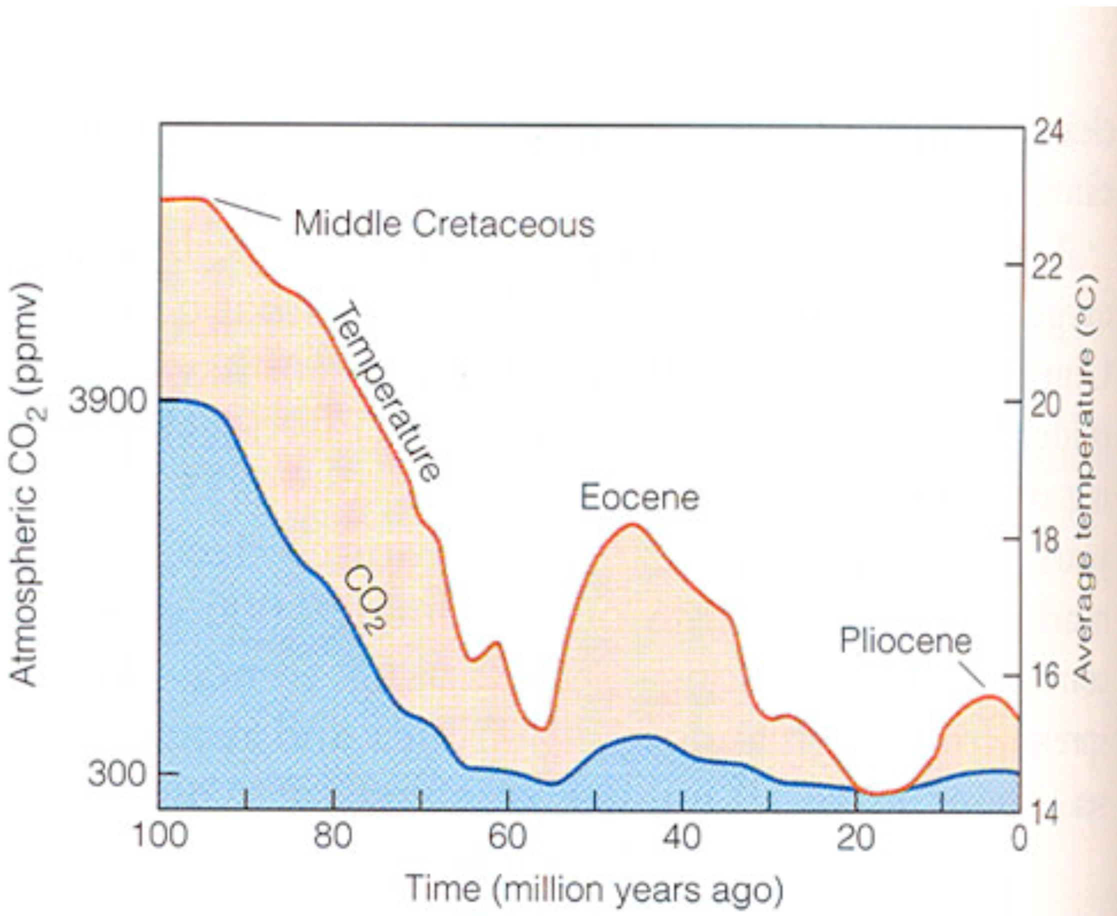
Sr_{87}/Sr_{86}
a proxy for salinity/rainfall (evap vs ppt)





During wet climates, more Sr is released from weathering minerals in granite

Middle Cretaceous and early Tertiary temperatures



A reconstruction of changing atmospheric CO_2 levels (blue) and resulting global temps (pink) over the past 100 my, based on analysis of climate proxies such as pollen, leaf serration, and O_{18} values. Note that the Mid-Late Cretaceous was significantly warmer than the early Tertiary (or today)

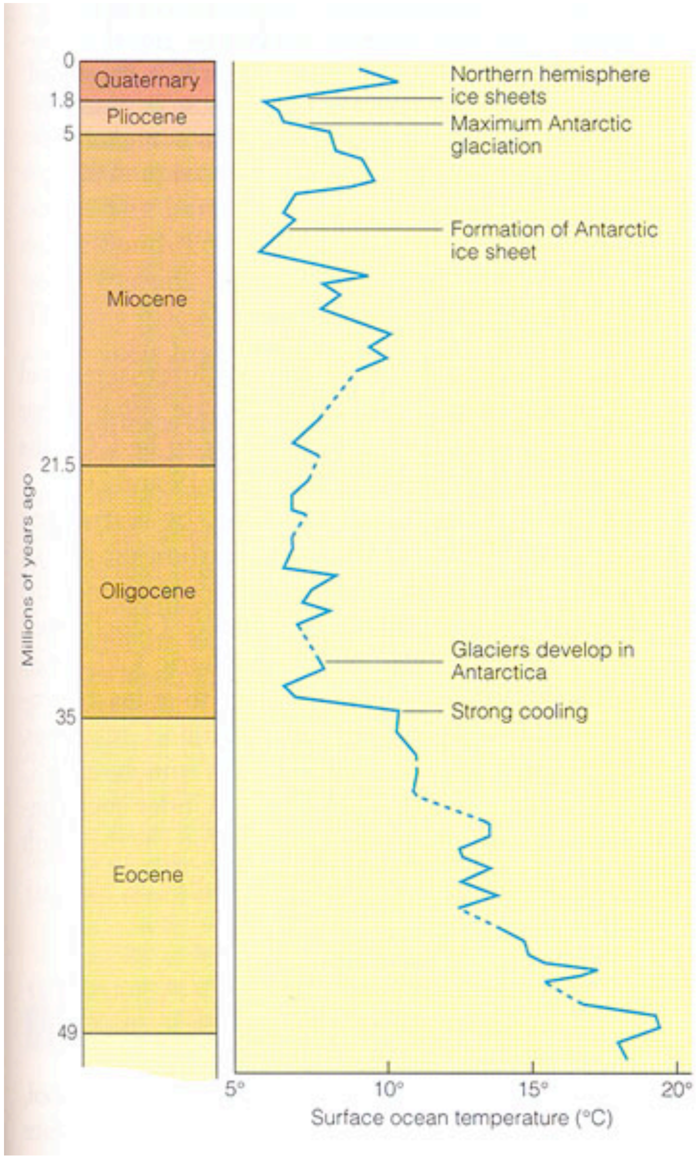
Not proxies, but direct measures Sr:Ca ratios in aragonite: a measure of seawater temperature

Trace elements such as cadmium, barium, manganese and strontium replace Ca in the lattice of aragonite (a $CaCO_3$ mineral). These trace elements often substitute for Ca as a result of climate-related variables.

The following relationship between Sr:Ca ratios and temp was developed: Sr:Ca x 103 = 10.48 (=/- 0.01) - 0.0615 (+/- 0.0004) x temp.

Thus we can measure trends in Sr:Ca ratios in coral aragonite skeletons as a way to determine surface sea water temps.

Ocean surface temps and climate in the Tertiary, determined by Sr ratios



Surface temps measured in shell-bearing sediment from the western Pacific Ocean. Relatively warm surface waters from 49-35 M.a. are followed by a climate change to cooling and the buildup of glaciers. By 2.5 M.a. the onset of glaciation in the Northern hemisphere occurred, several Ma after it started in Antarctica.

Using a variety of data sets we have determined paleoclimates for the history of the Earth

- O_{18}/O_{16} ratios; Sr:Ca ratios, $Sr_{87}/Sr/_{86}$
- Rock types (coal, tillites, evaporites, reefs)
- Vegetation types (pollen, leaf characteristics, tree rings
- modelling

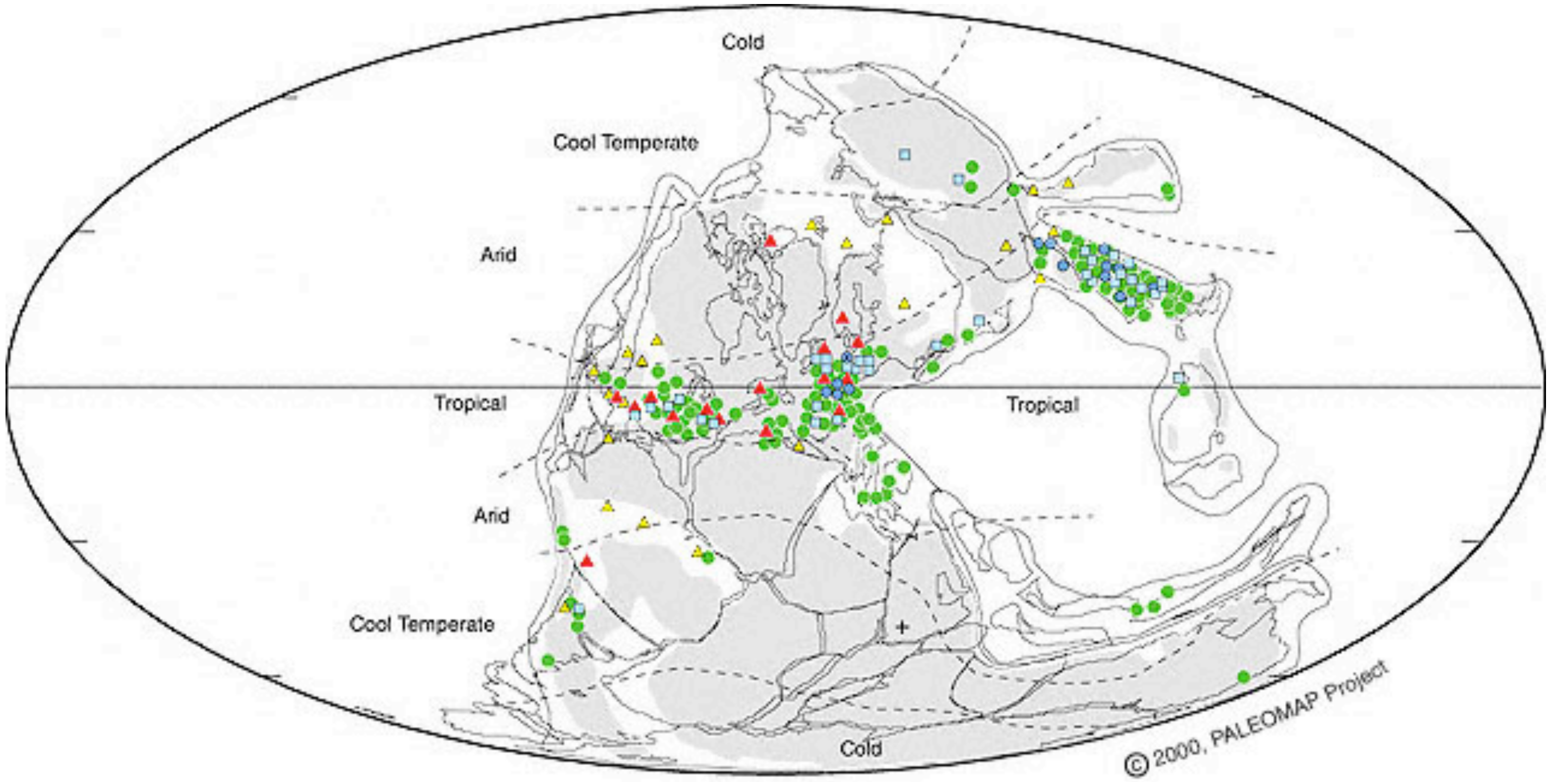
“Greenhouse Earth” periods:

- Late Paleocene-Early Eocene (6040Ma) - warm climates extend further north than today: England a tropical jungle! Palm trees in Alaska
- Late Cretaceous (100Ma-65Ma) -ocean temps rose > 5°; tropics widespread
- Triassic/Jurassic (250-140Ma) - warm climates, even at the poles

“Icebox Earth” periods

- Late Pliocene-Pleistocene (5Ma-present) - we are still in a global cool period
- mid-late Carboniferous (320-290Ma)- glaciers in southern hemisphere up to 45º
- Late Ordovician (460-440Ma) - glaciers over continents N & S of equator
- Late Precambrian (1Ba-550 Ma) - “Snowball Earth”…..glaciers at the equator

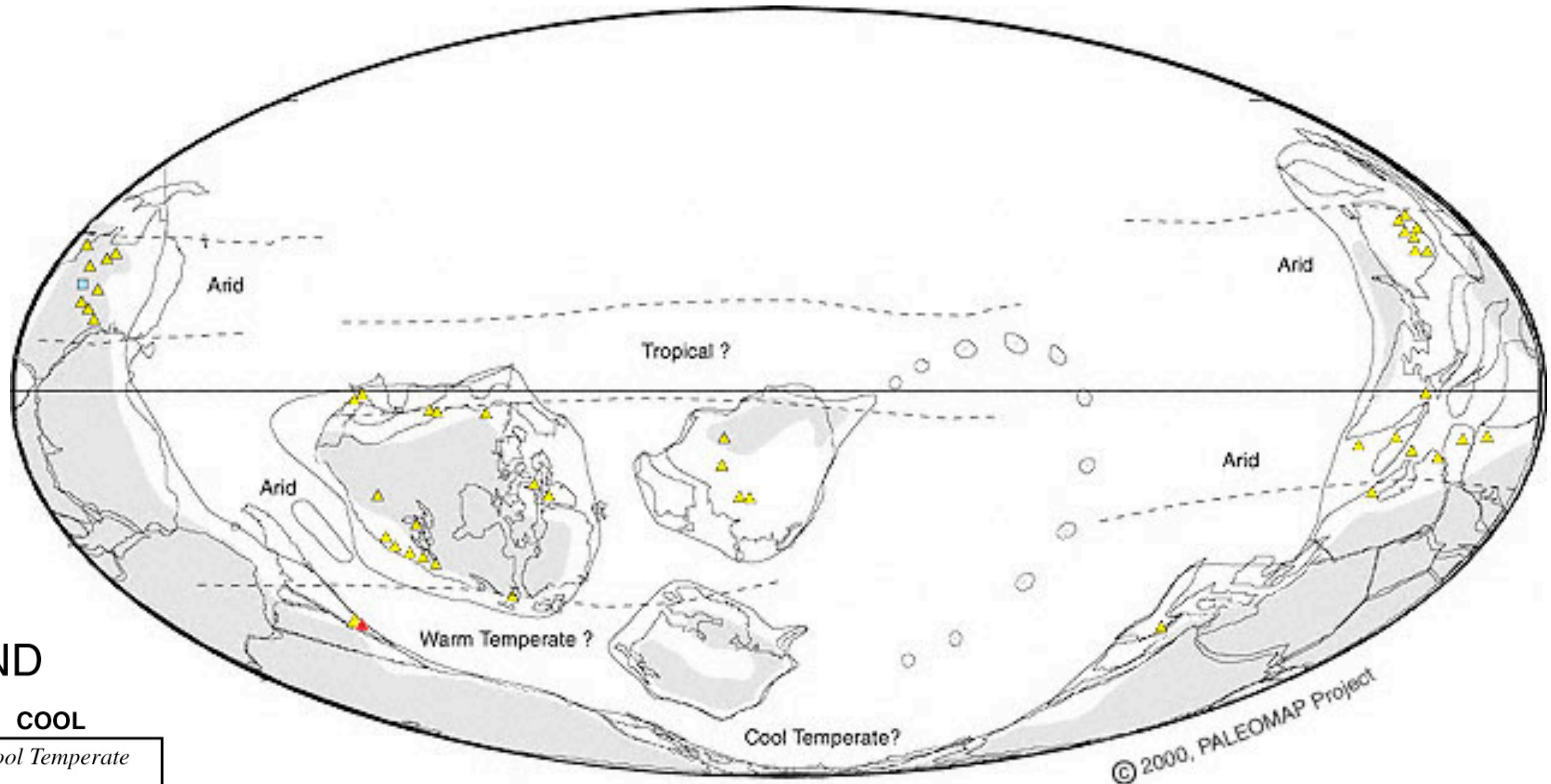
In addition to overall heating and cooling latitudinal climate zones can be compressed (not spaced out like today)



Upper Carboniferous (Gzelian)

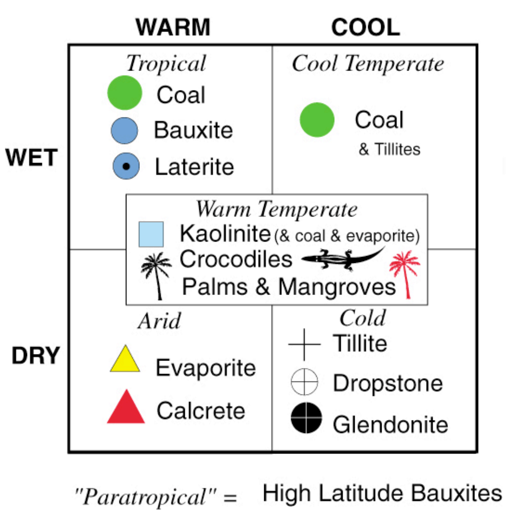
Zonal compression can result from changes in the movement of heat from the equator to poles

Hypothesize about the Cambrian climate of VT



Middle & Upper Cambrian

LEGEND



Take away points..

- What is a “climate proxy?”
- What are examples of:

  geochemical proxies?

  biological proxies?

  lithologic proxies?

When you see how paleoclimate reconstruction for a geologic period, can you describe the various techniques used to create it?