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Biogeochemical cycles
and environmental inference

Reading
Chapter 10

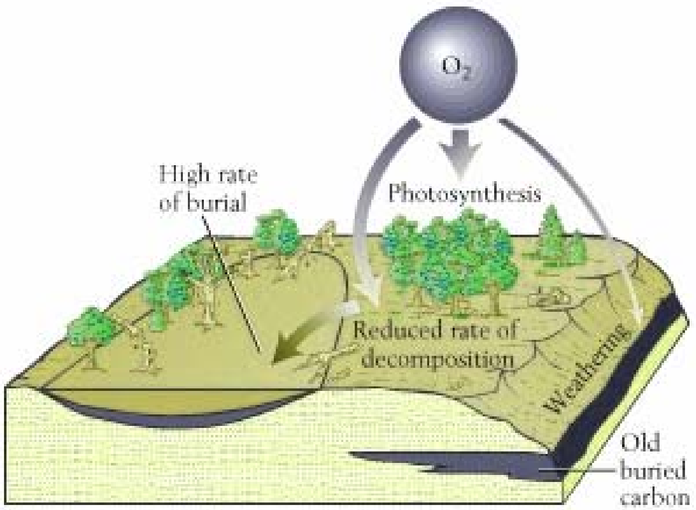
Chemical cycles

Many chemicals move in huge cycles through earth systems

Reservoirs.- chemicals that are bound up in a particular space. (e.g., carbonate platforms are reservoirs of carbon and oxygen).

Biomass.- the combined body mass of living organisms, animal and plant. Biomass is an important reservoir for some chemicals.

Flux.- movement of chemicals into or out of a reservoir.



Negative feedback.- interactions that keep the size of a chemical reservoir stable.

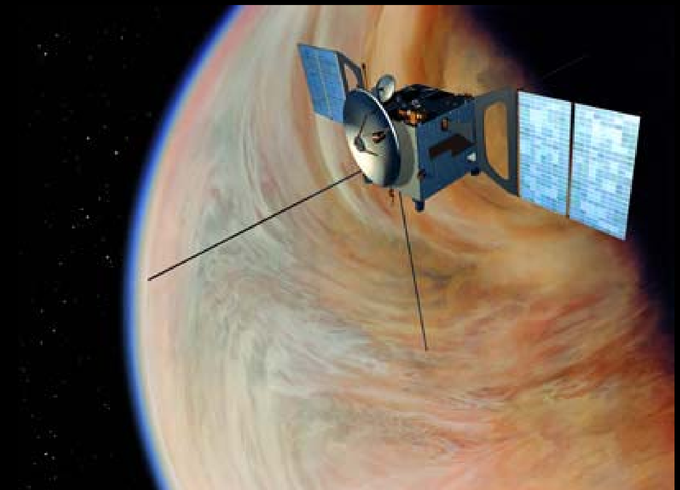
Positive feedback.- interactions that promote flux once it begins.

Budget.- the sum total amount of the chemical in all of its reservoirs combined.

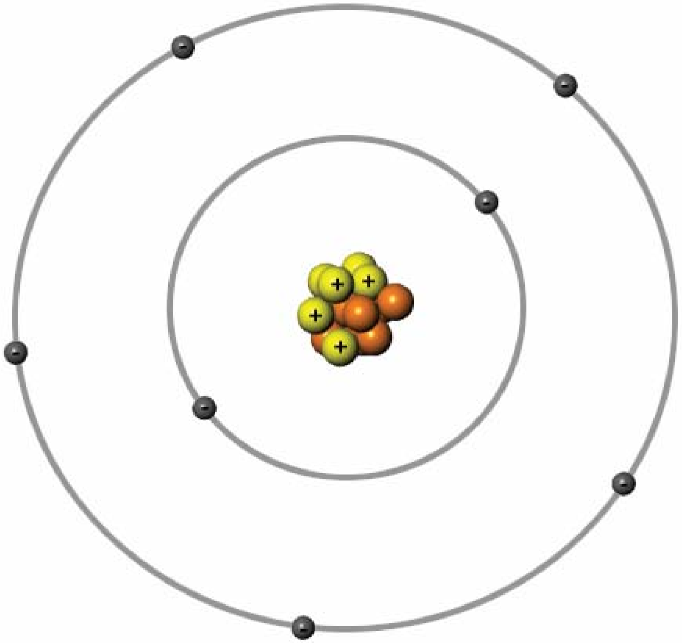
Total budge of elements for a planet does not usually change significantly through time, especially at the level of particular elements.

Comparative atmospheric compositions of selected gases

Venus:	**96.5% CO_2**	3.5% N_2	
Mars:	**95.3% CO_2**	2.7% N_2	0.13% O_2
Earth:	78.1% N_2	20.95% O_2	**<1% CO_2**



Biogeochemistry is largely the study of change in stable isotopes, whose relative abundance is affected by many geological, biological and environmental processes.



Atomic Number. - The number of protons in the atom. The number of protons defines the identity of the element.

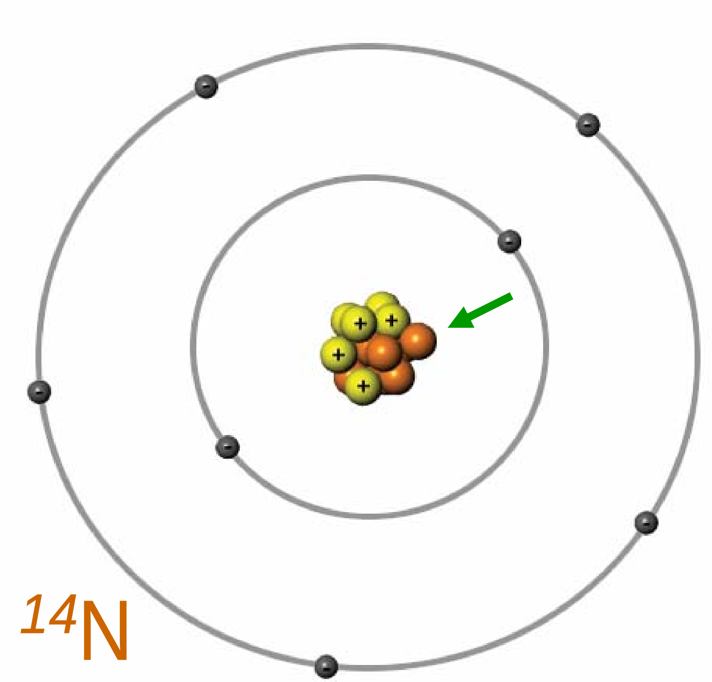
Atomic Weight. - sum of the elements protons and neutrons in the nucleus.

Isotope. - two or more versions of an element with the same number of protons but a different number of neutrons.

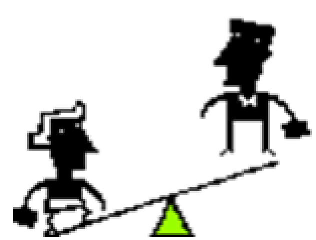
Stable isotopes. - Number of protons and neutrons stable through time.

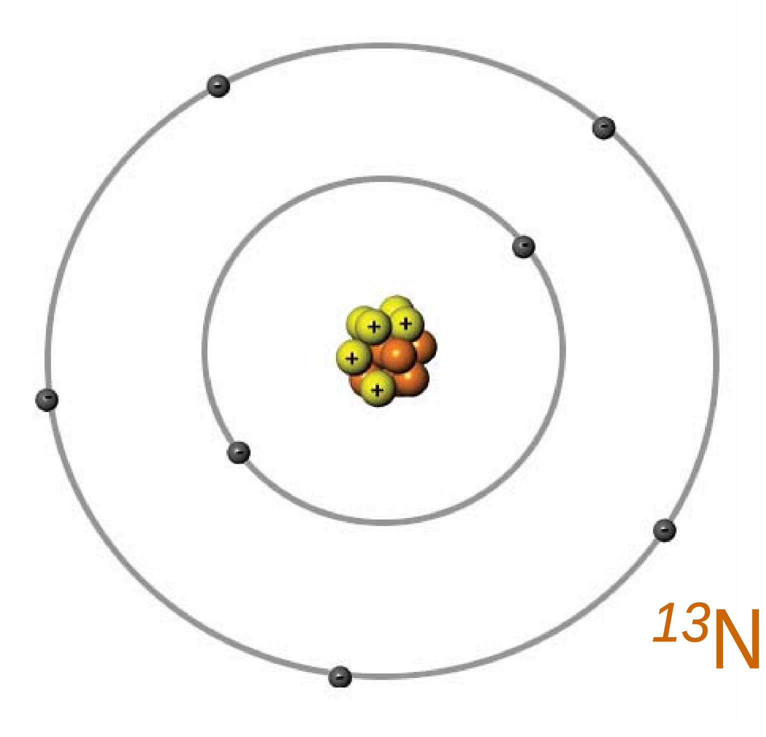
Non-stable or radioactive isotopes. - spontaneously lose neutrons through radioactive decay.

Two stable isotopes of nitrogen



Atomic number = 7
Atomic weight = 14



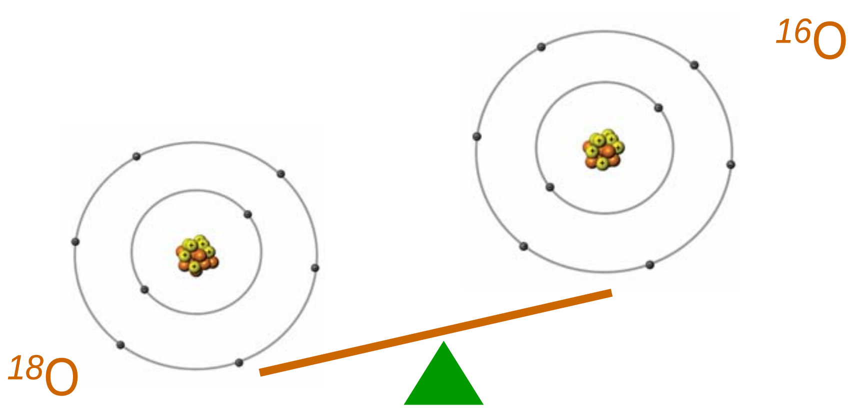


Atomic number = 7
Atomic weight = 13

Fractionation

The difference in atomic weights of isotopes can result in differential movement of each isotope along the paths of the elements geochemical cycle.

Example: $H_2{}^{16}O$ is lighter than $H_2{}^{18}O$ and so evaporates more readily than its counterpart.



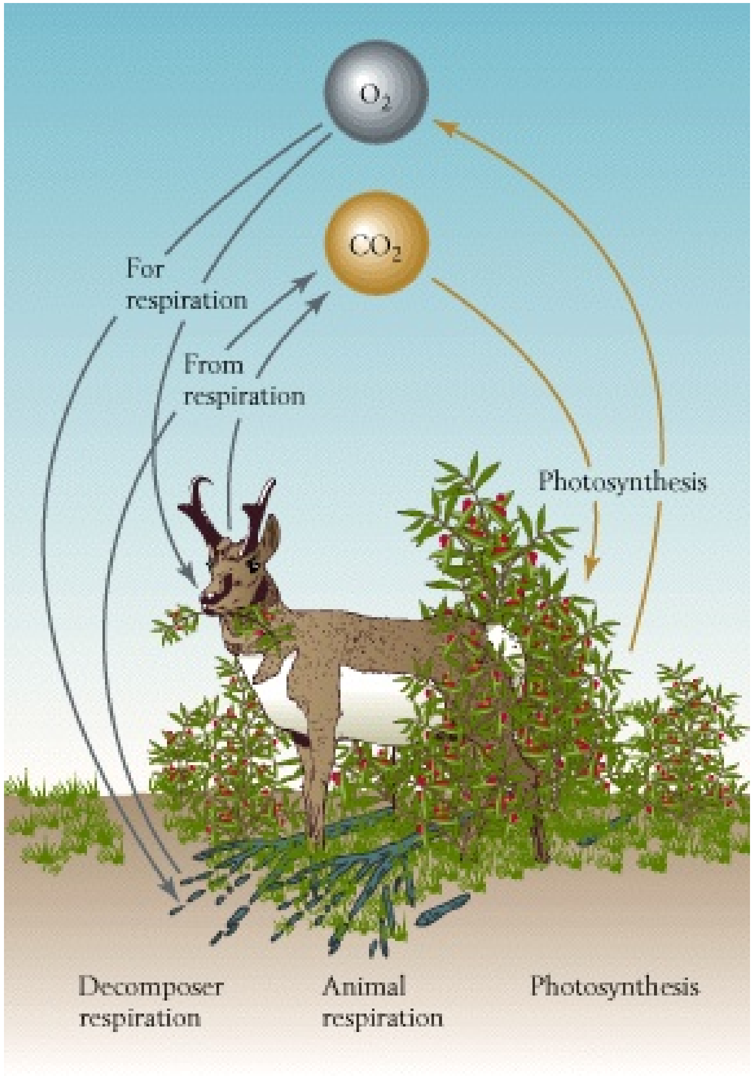
Unequal flux of isotopes is called *fractionation.*

Carbon and Oxygen Cycles

CO_2 and O_2 are parts of several biogeochemical cycles.

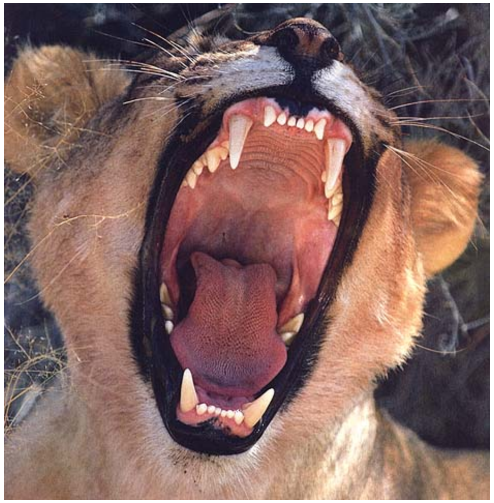
Both carbon and oxygen have stable isotope variants.

Evaporation, biomass, photosynthesis, and carbon and carbonate deposition are important components of their cycles.



Atmospheric carbon and oxygen are mostly controlled by organisms

Metabolic respiration uses O_2 and produces CO_2 as a byproduct



Photosynthesis binds CO_2 using energy from sunlight, retaining the carbon and releasing the O_2

The total biomass of plants and animals are necessarily in sync.

The fate of the dead…

Dead plants (and animals) are

(1) *Eaten.* Their carbon is passed to animals.

(2) *Decompose.* Their carbon is released back into the environment and eventually the atmosphere.

(3) *Buried.* Their carbon is stored in a geological reservoir and cannot return to the atmosphere until the rocks are weathered.

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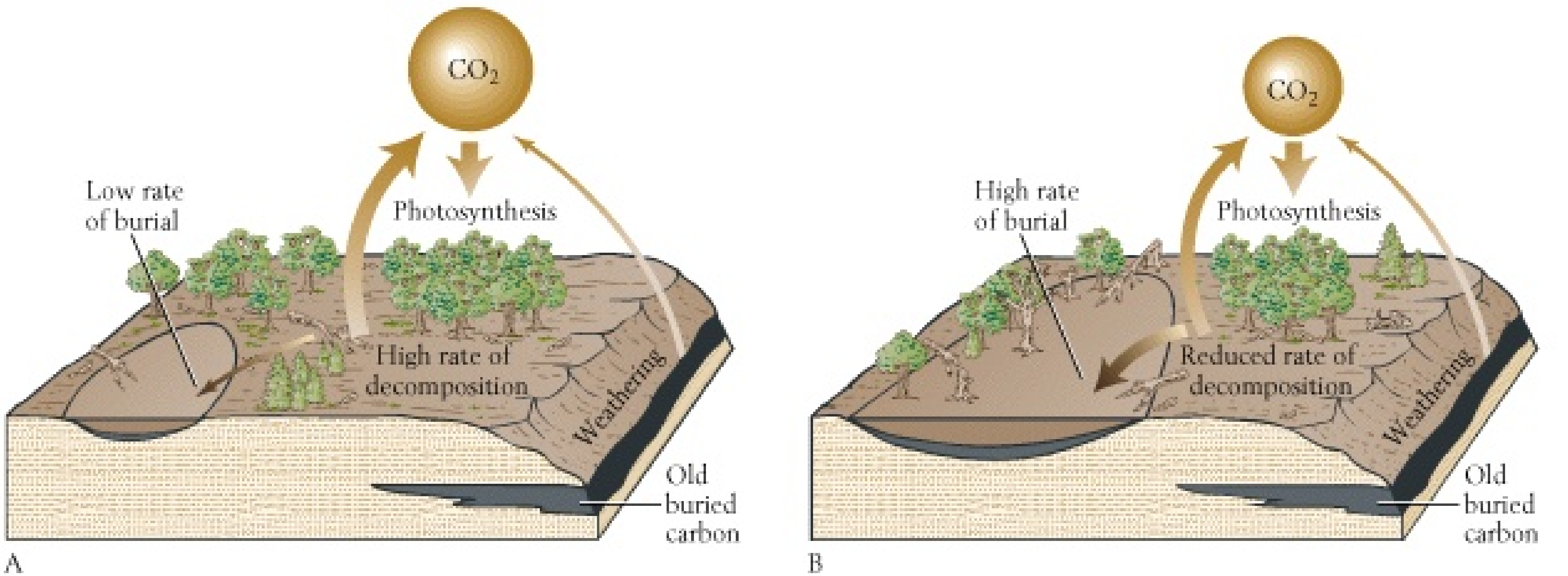
The Effects of Plant Burial on Carbon

Normally rate of burial of organically bound carbon is roughly equal to the rate at which it is released by weathering.



Low rate of burial,
increase in atmospheric CO_2

High rate of burial,
decrease in atmospheric CO_2

Weathering of carbonates also decreases atmospheric CO_2

Plant burial happens most frequently in anoxic water environments

Cold water (northern lakes, glacial lakes, deep cold sea water)

Swamps and bogs

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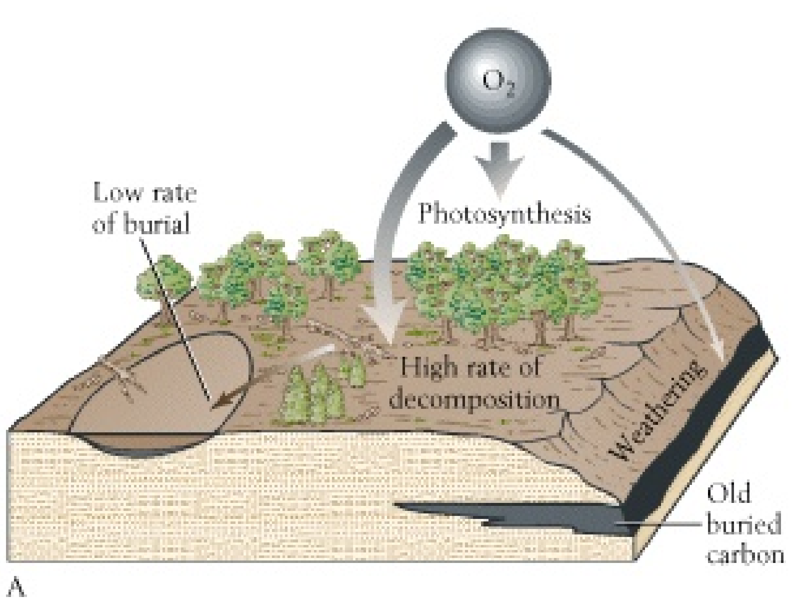
The Effects of Plant Burial on Oxygen

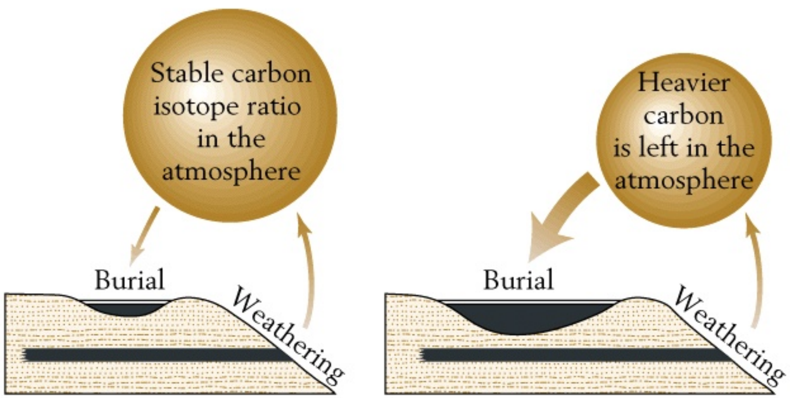
Decomposition uses oxygen to combine with stored carbon to produce CO_2



Low rate of burial,
decrease in atmospheric O_2

High rate of burial,
increase in atmospheric O_2

Carbon Isotopes, fractionation, and the carbon cycle



A Burial rate of carbon balances weathering rate

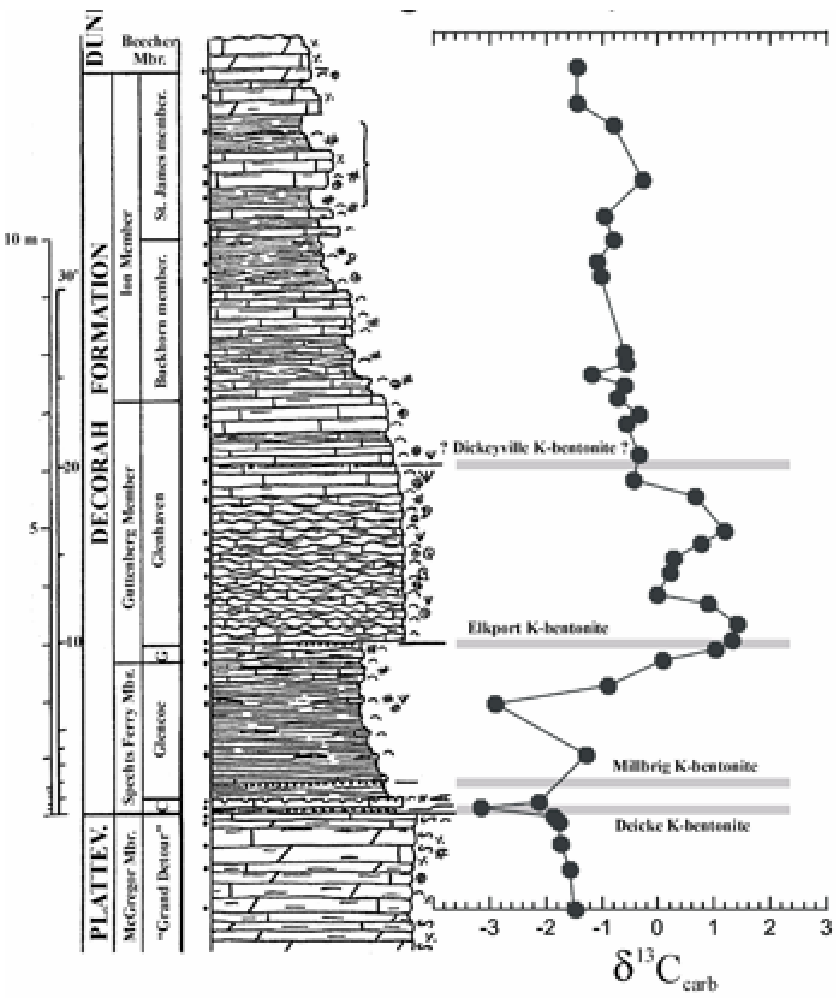
B Burial rate of carbon exceeds weathering rate

- ^{12}C is found in greater abundance than ^{13}C in the atmosphere
- Plants preferentially take up ^{12}C during photosynthesis, depleting ^{12}C relative to ^{13}C in the atmosphere
- Normally decomposition returns ^{12}C at the same rate it is extracted, creating an atmospheric balance
- In times of burial, however, ^{12}C is buried and so the proportion of ^{13}C in the atmosphere increases

Distribution of carbon isotopes in sedimentary rocks indicates the proportion of CO_2 and O_2 in the past

Measuring fractionation

Delta (δ) values in stable isotope geochemistry



δ is the relative proportion of a given isotope in a rock or fossil compared to a standard.

The ratios of stable isotopes can be measured in rocks, fossils, sediments, organic remains, etc.

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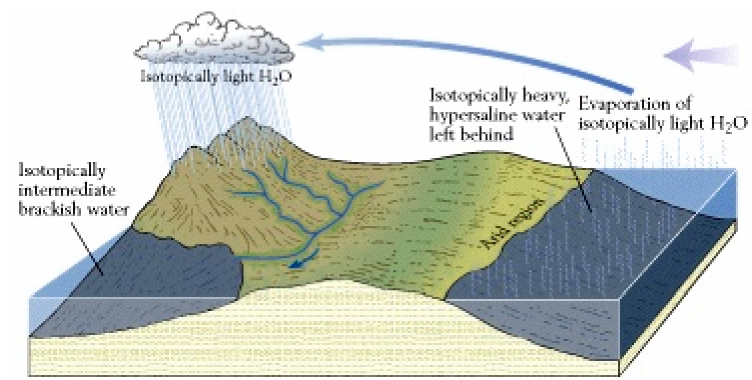
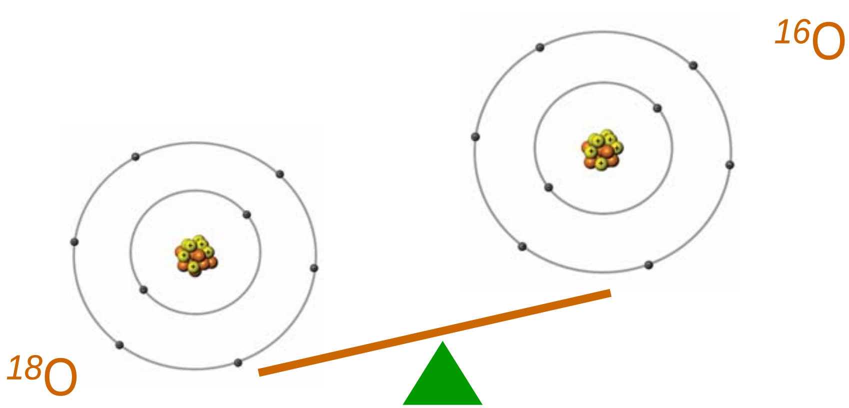
Oxygen isotopes, temperature and rainfall

Evaporation preferentially vaporizes H_2O composed of ^{16}O isotopes:

Seawater is enriched in ^{18}O
Rainfall is enriched in ^{16}O





In warm times, evaporation is greater so the proportion of ^{18}O increases in sea water

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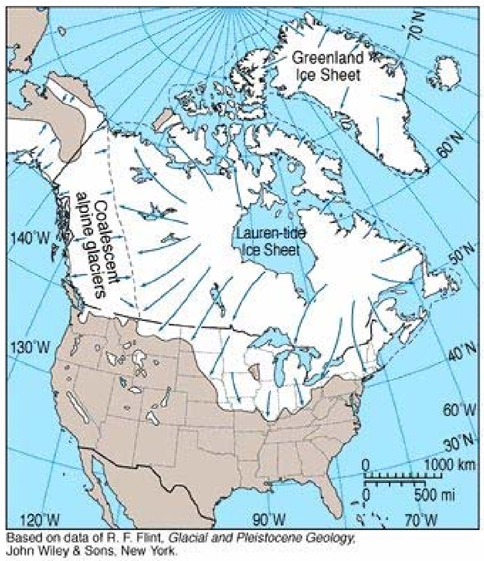
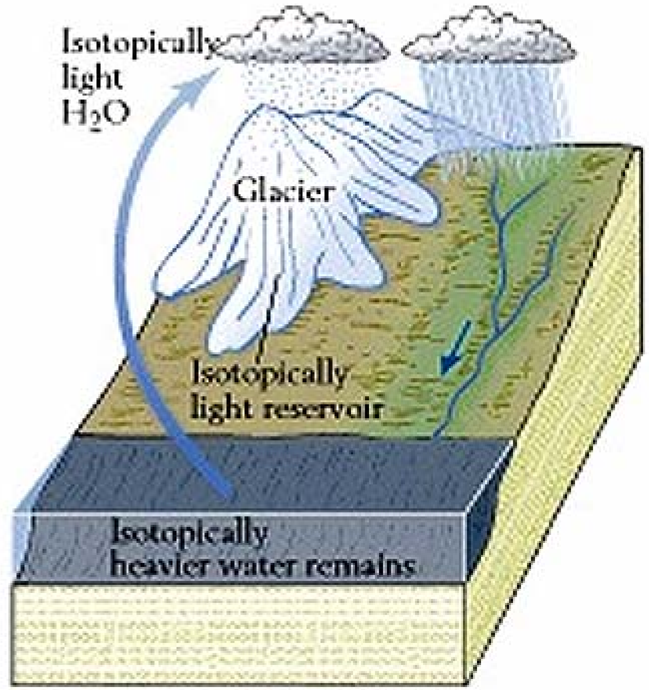
Glaciers have opposite effect

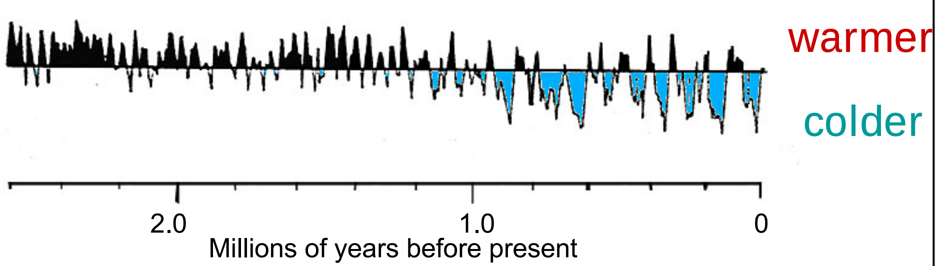


Based on data of R. F. Flint, *Glacial and Pleistocene Geology,* John Wiley & Sons, New York.

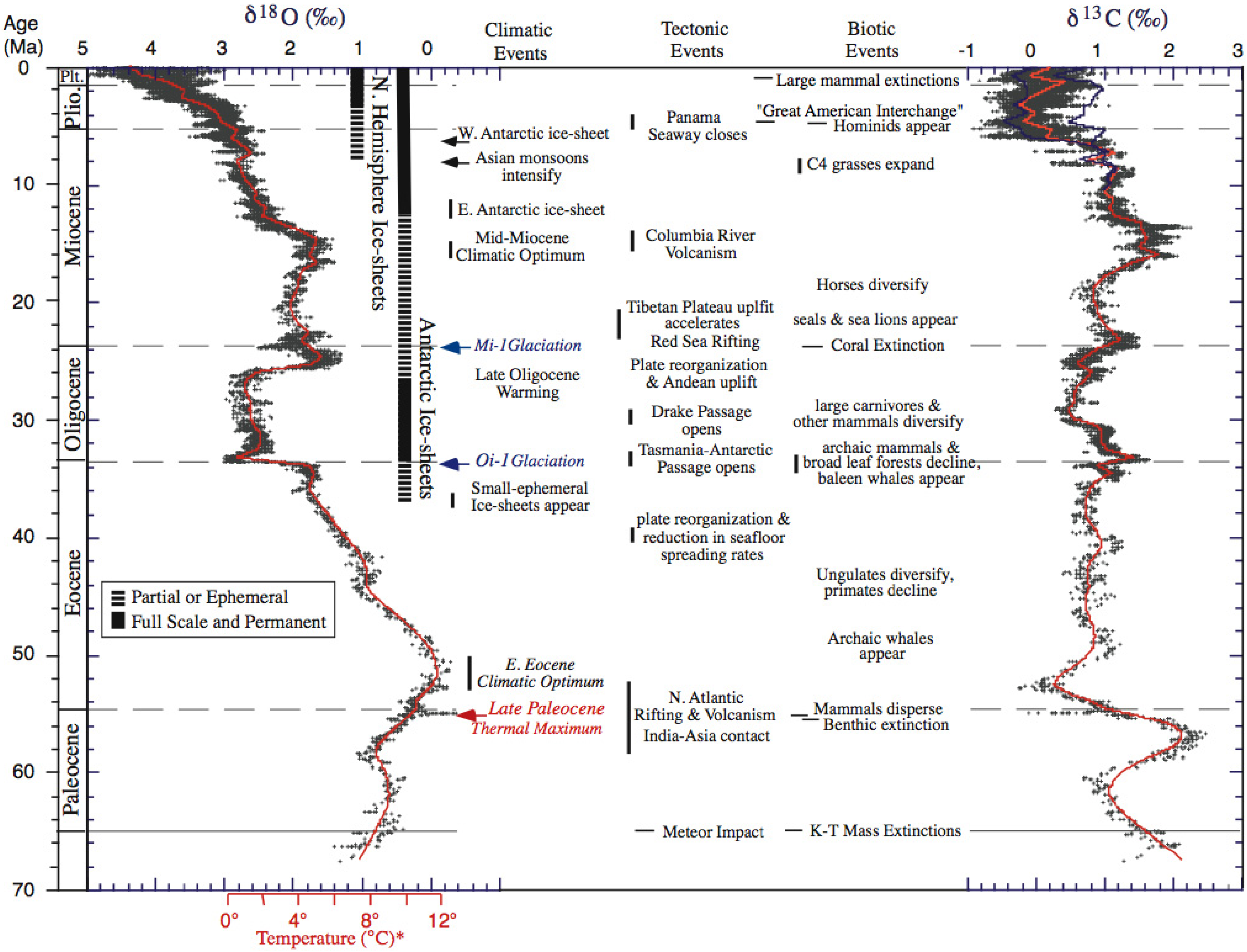
Glaciers bind rain water and also contribute to enrichment of **^{18}O** in sea water during cold periods



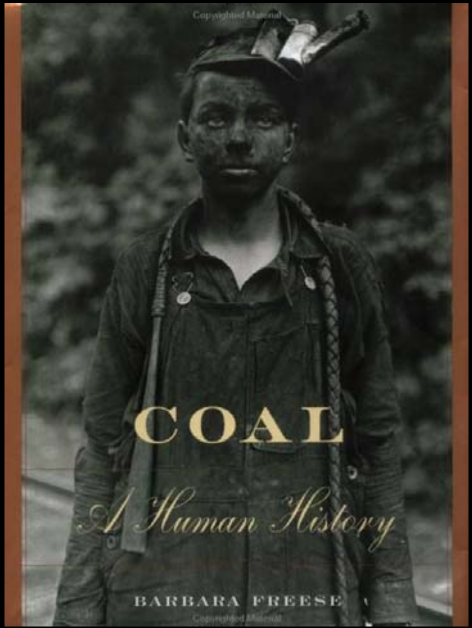
Global temperature during the Pleistocene



A Record of Cenozoic Environmental History

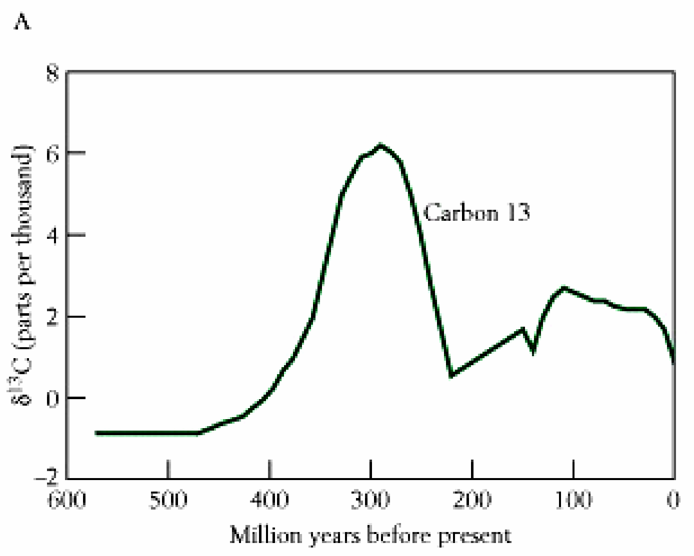


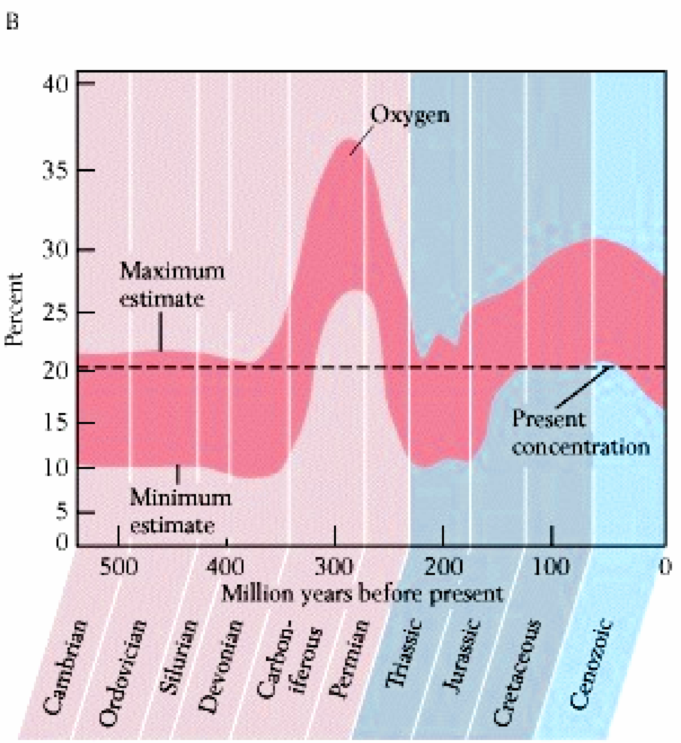
The Carboniferous
Mississippian and Pennsylvanian Times

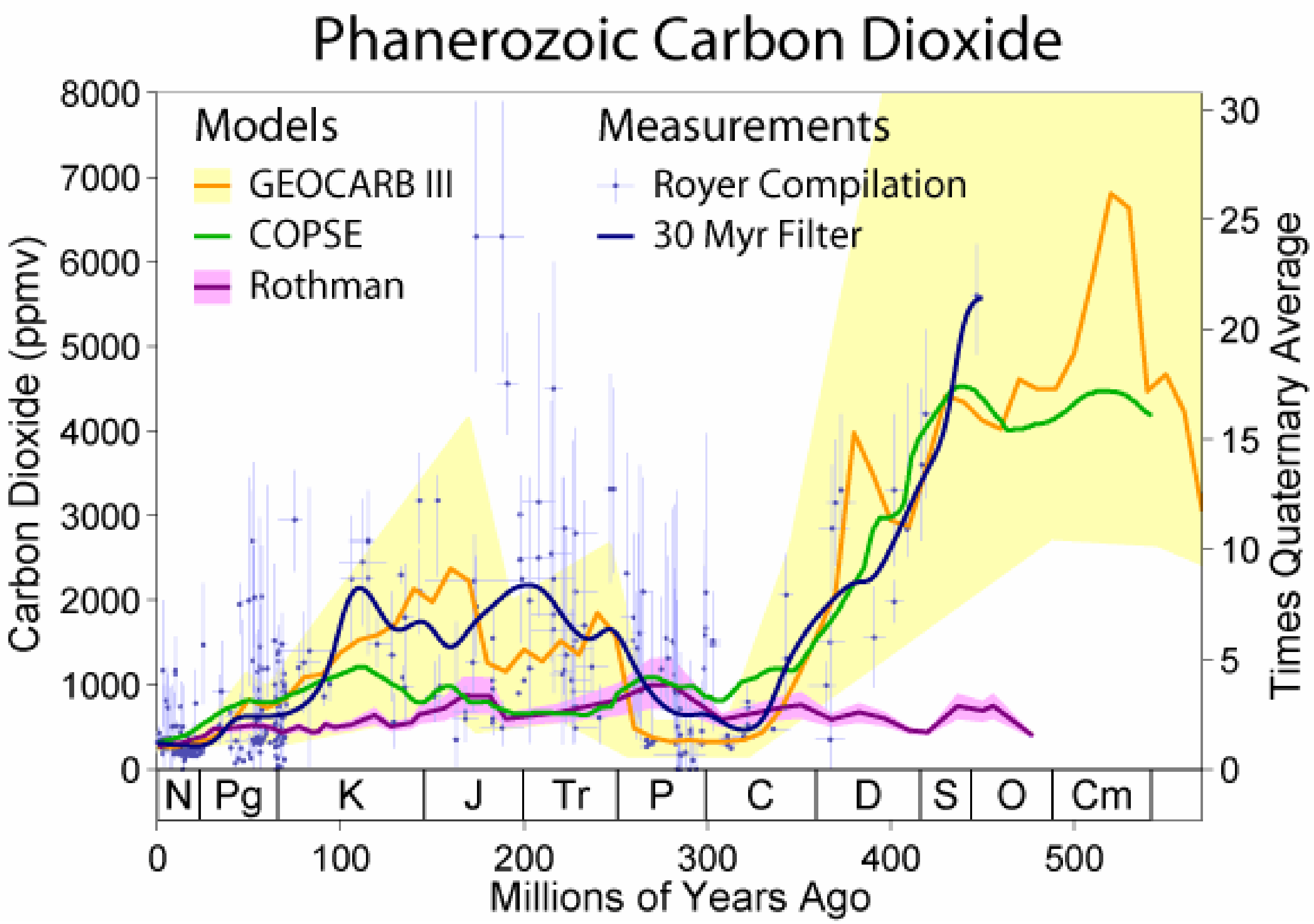


Burial in anoxic swamps increased ^{13}C in atmosphere because light ^{12}C was buried with the plants

Burial of carbon increased O_2 concentration in atmosphere



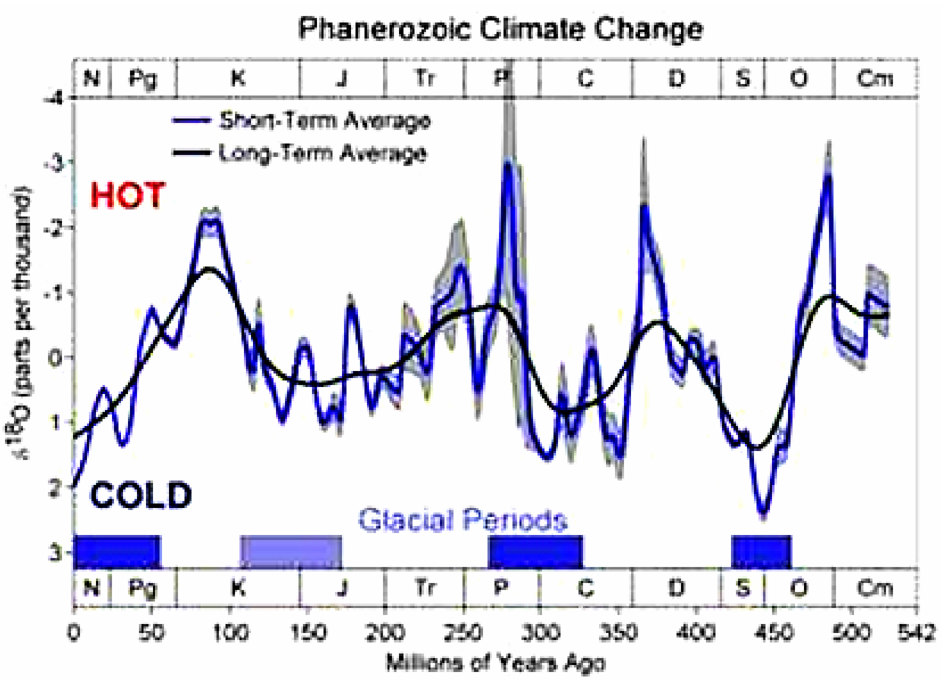




Plants reduced CO_2 in the earth's atmosphere
Reduced CO_2 resulted in cooling (no 'greenhouse effect')c

Phanerozoic ^{18}O changes

Temperature



Increasing diversity of plants through early Phanerozoic increased the O_2 in the atmosphere and decreased the CO_2

Warm, tropical temperatures in early Carboniferous (Mississippian) resulted in large carbonate platforms in the shallow seas and huge forested swamps on land.

Plants reduced CO_2 in the earth's atmosphere, but were being buried in anoxic swamp conditions. These became the Carboniferous coal deposits that are widespread around the world.

Reduced CO_2 resulted in cooling (no 'greenhouse effect'), which brought on major ice age, the coldest in earth's history.

The effect was climate change and lowered sea levels.

The effect on marine life

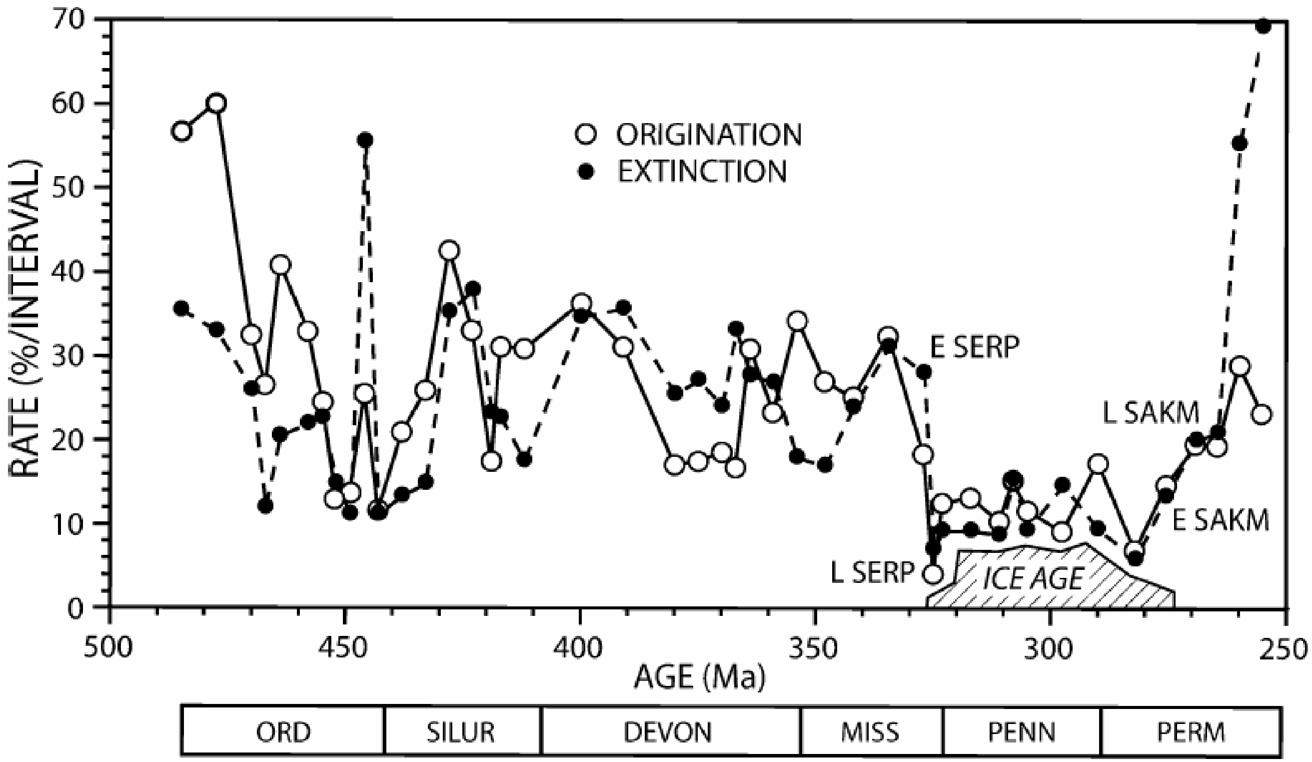


Figure 2. Rates of origination and extinction (percent per interval) for marine invertebrate genera from Ordovician through Permian time (periods as in Fig. 1). Interval abbreviations: E SERP and L SERP, early and late Serpukhovian; E SAKM and L SAKM, early and late Sakmarian.