Cycles in the Phanerozoic

- Evolutionary trends: extinctions, adaptive radiations, diversity over time
- Glaciations
- Sea level change
- Ocean chemistry
- Atmospheric CO_2

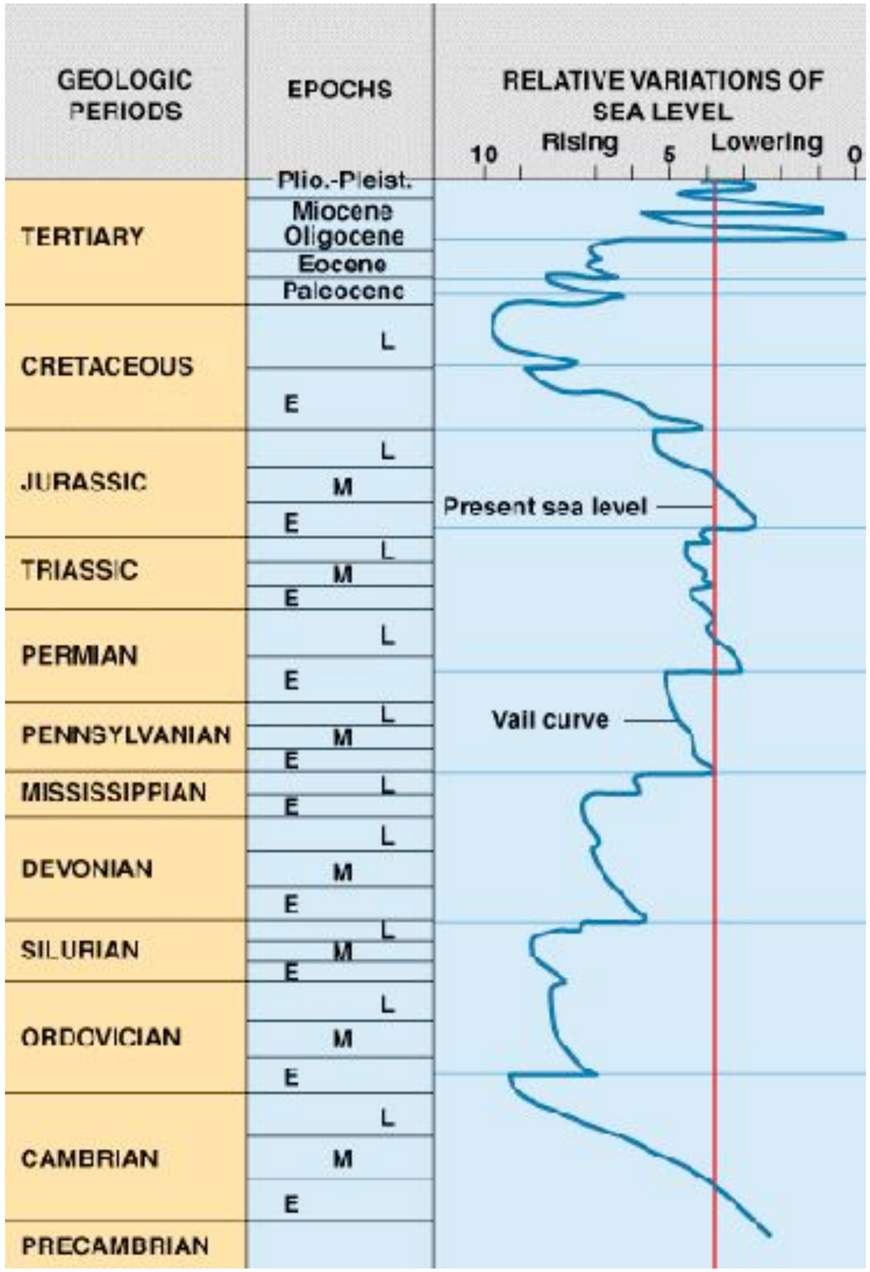
biosphere

- Mass extinctions in the…..you need to know these from lab
- Major adaptive radiations: the **Cambrian** (calcareous exoskeltons/shells); **mid Ordovician** (benthic invertebrates), **lower Silurian** (benthic invertebrates), **Mid-Late Devonian** (reef builders, fish), **early Carboniferous** (tetrapods, flora), **early Permian** (marine invetebrates, tetrapods), **Triassic** (marine invertebrates, tetrapods),**mid Jurassic** (reefs, marine reptiles), , **mid Cretaceous** (marine plankton, gymnosperms), **early Tertiary** (mammals, angiosperms), **mid Tertiary** (modern reefs, mammals, grasses) the obvious ones you need to know are those that follow the major mass extinctions

Biosphere, cont.

- Diversity over time (see lab graph; discussion of diversity/modern extinctions from this same lab)

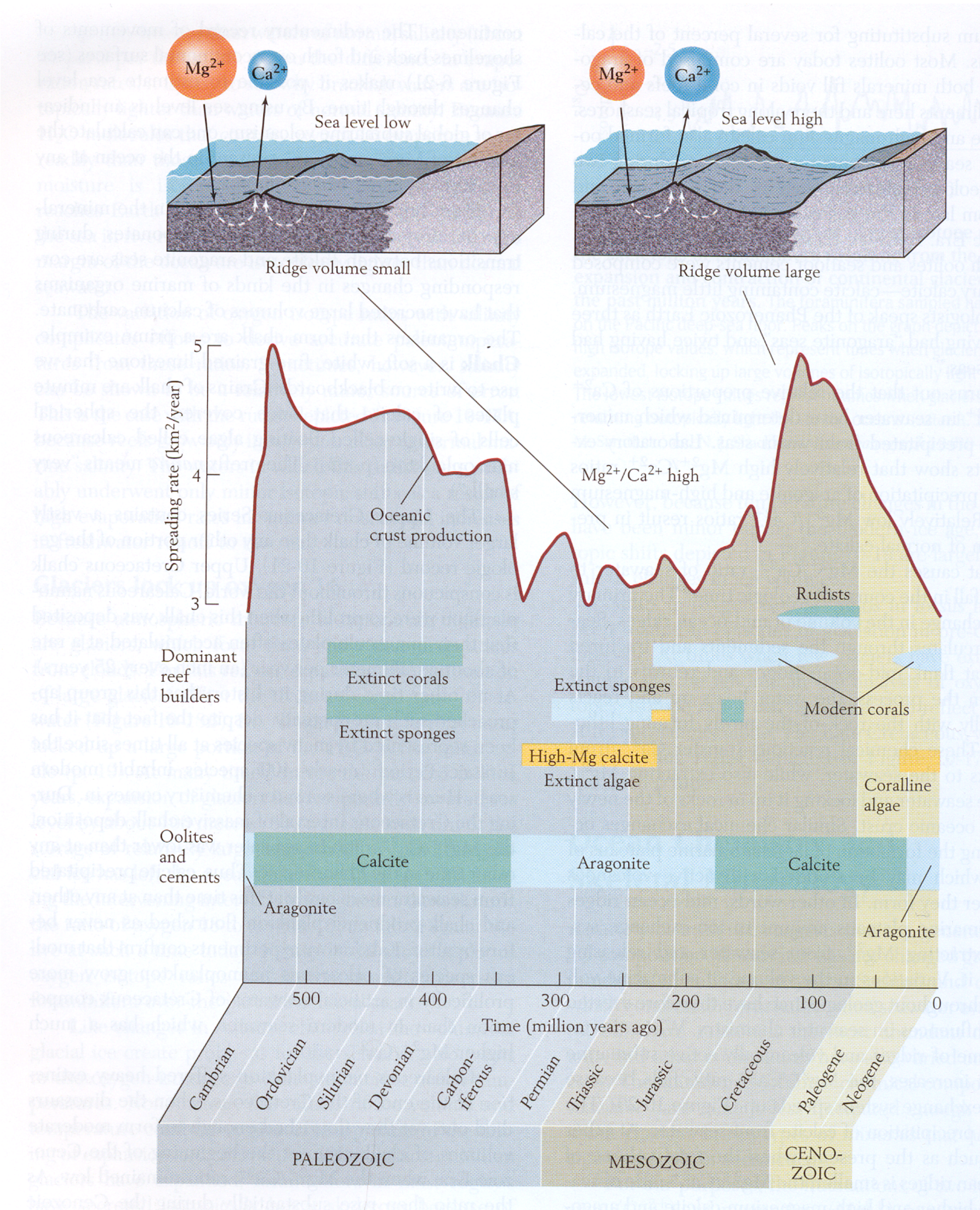
Sea level change over time



What controls global sea level?

Exam question: what is the impact of sea level on evolutionary trends (in both the marine and terrestrial environments)?

Ocean chemistry



Although overall ocean chemistry has been stable since the Proterozoic, there has been variation in the abundance of Mg and Ca as a function of sea floor spreading rates.

When sfs rates are high and the mid-ocean ridges are large, there is a *decrease* in the Mg^{+2} /Ca^{+2} ratio in seawater. Mg^{+2} is removed from sea water in contact with hot magma at the mid-ocean ridges, Ca^{+2} is released into the hot water.

"so what?" with fluctuating Mg/Ca ratios?

- It controls what minerals marine organisms can use to build their shells. When the ratio of Mg^{+2}: Ca^{+2} is high (low rates of sfs), aragonite is the mineral that forms. This favors animals that make aragonite shells, like brachiopods, and many extinct corals and sponges
- When the ratio of Mg^{+2} to Ca^{+2} is low (hi rates of sfs), calcite is the mineral that forms. This favors animals that make calcite shells, like modern corals and clams

Exam question: what is the relationship between sea floor spreading And evolution of certain groups of marine animals?

One major period in Earth history of "calcite seas"

- The evolution of calcareous nannoplankton - the tiny marine organisms that secrete calcite shells in the Cretaceous…they were so abundant in the Cretaceous seas that major chalk deposits formed (the White Cliffs of Dover). "*creta*" = Latin for chalk

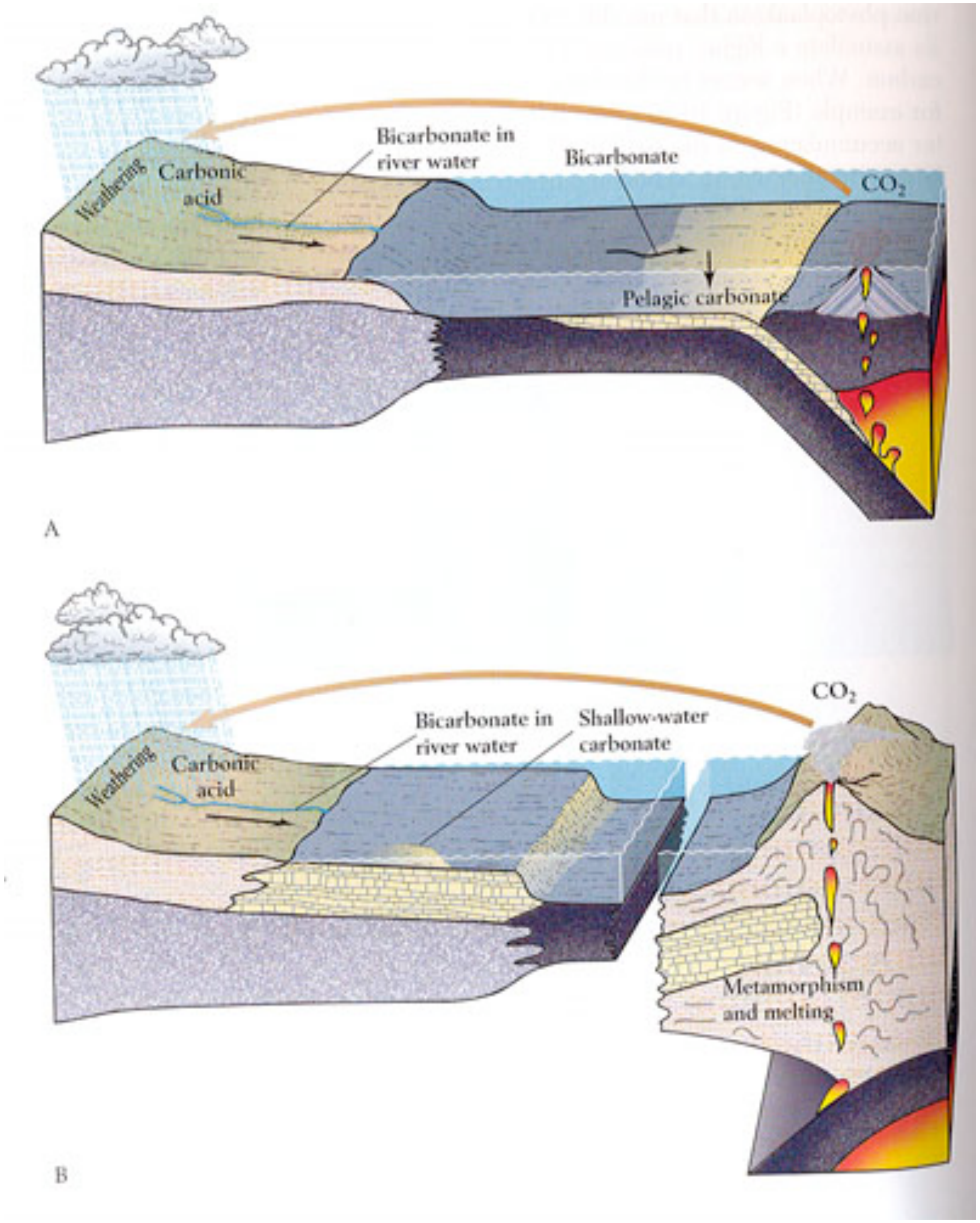
Major glaciations

- Quaternary
- Carboniferous
- Late Devonian
- Late Ordovician
- Late Precambrian (Neoproterozoic)

The carbon cycle

What can fluctuations in atmospheric carbon dioxide levels tell us about the biosphere?

How the lithosphere cycle is linked to the biosphere cycle

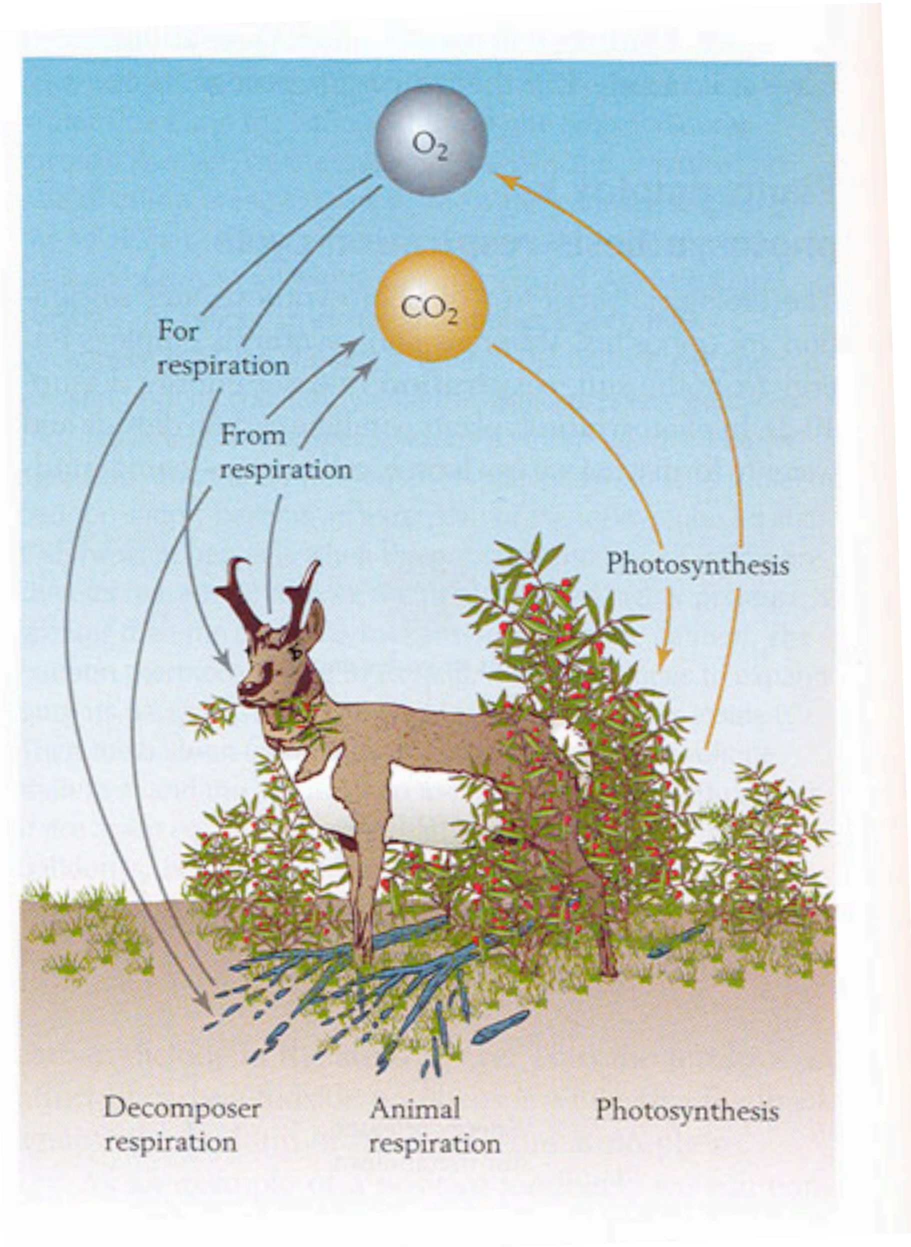


How plate tectonics controls the composition of the atmosphere. Subduction of ocean crust leads to release of CO_2 back into the atmosphere through the eruption of volcanoes. CO_2 gas mixes with H_2O in the atmosphere and produces weak "acid rain" that weathers rocks, forming sediment. River water contains the by-product of weathering, HCO_3, which is returned to the sea where it is taken up as limestone on the sea floor and recycled at plate collisions.

What this diagram doesn't show is the very important step of storing carbon in the biosphere.

How we trace the pathway of carbon: Carbon isotopes

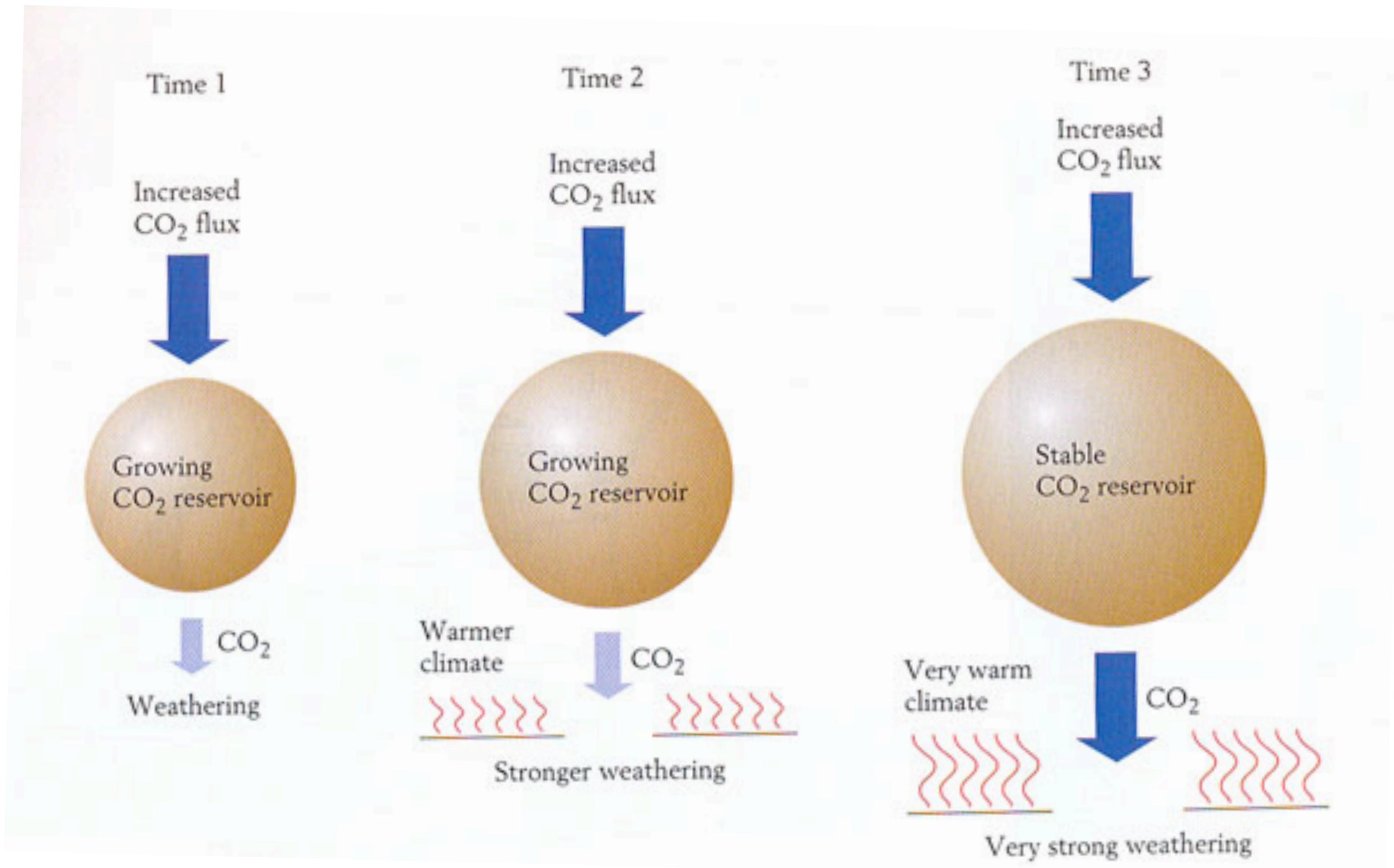
- Carbon has 3 isotopes: 2 stable (C_{13} and C_{12}) and one unstable (C_{14}).
- The stable isotopes of carbon are selectively taken up (fractionated) in organic material, thus organic carbon predominantly uses the light C_{12}. High rates of plant growth lead to extraction of C_{12} from the atmosphere with its resulting enrichment in C_{13}.
- Burial of this light carbon removes C_{12} from the system (just like ice stores light O_{16}).
- Weathering preferentially removes light C_{12} also.



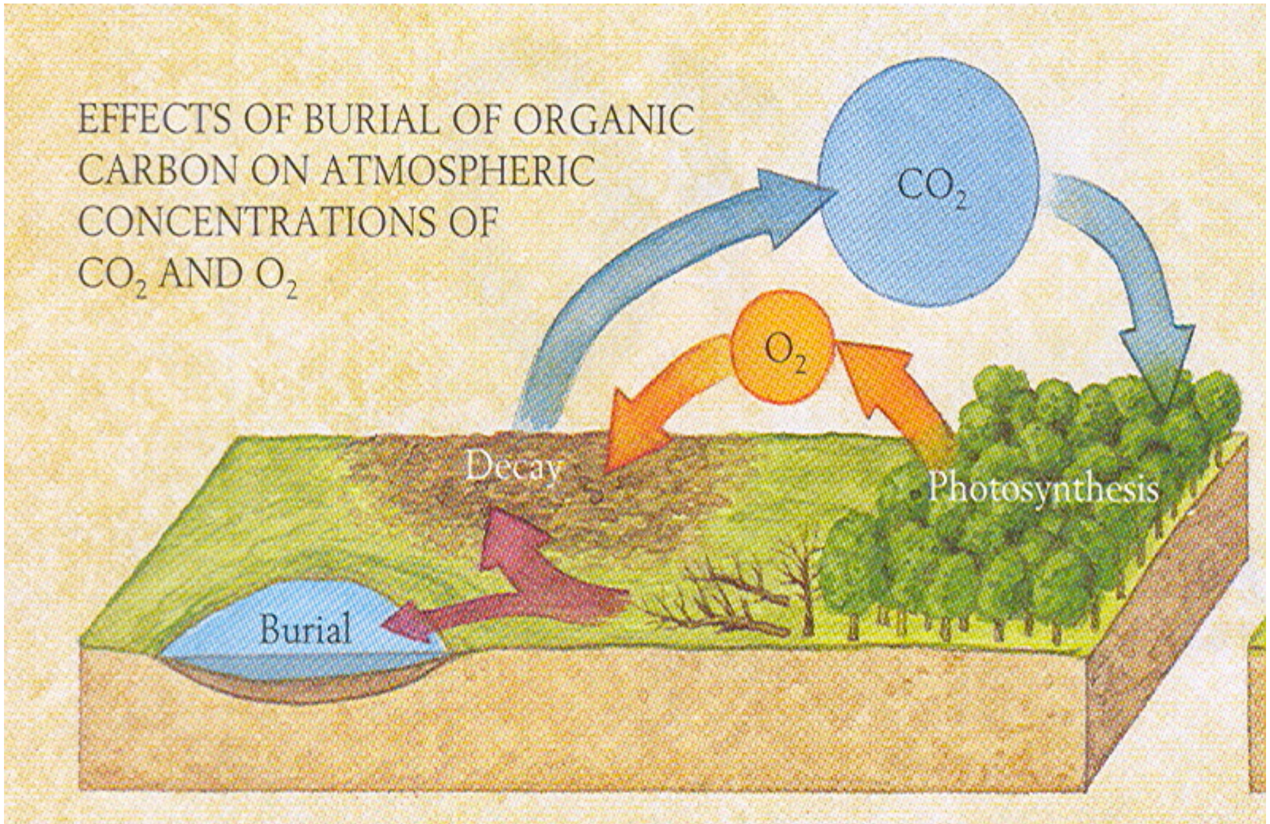
Plant photosynthesis removes CO_2 from the atmosphere and returns O_2. Animal respiration removes O_2 and returns CO_2. Thus the system stays in equilibrium

Photosynthesis removes CO_2 from the atmosphere and creates sugar CH_20.

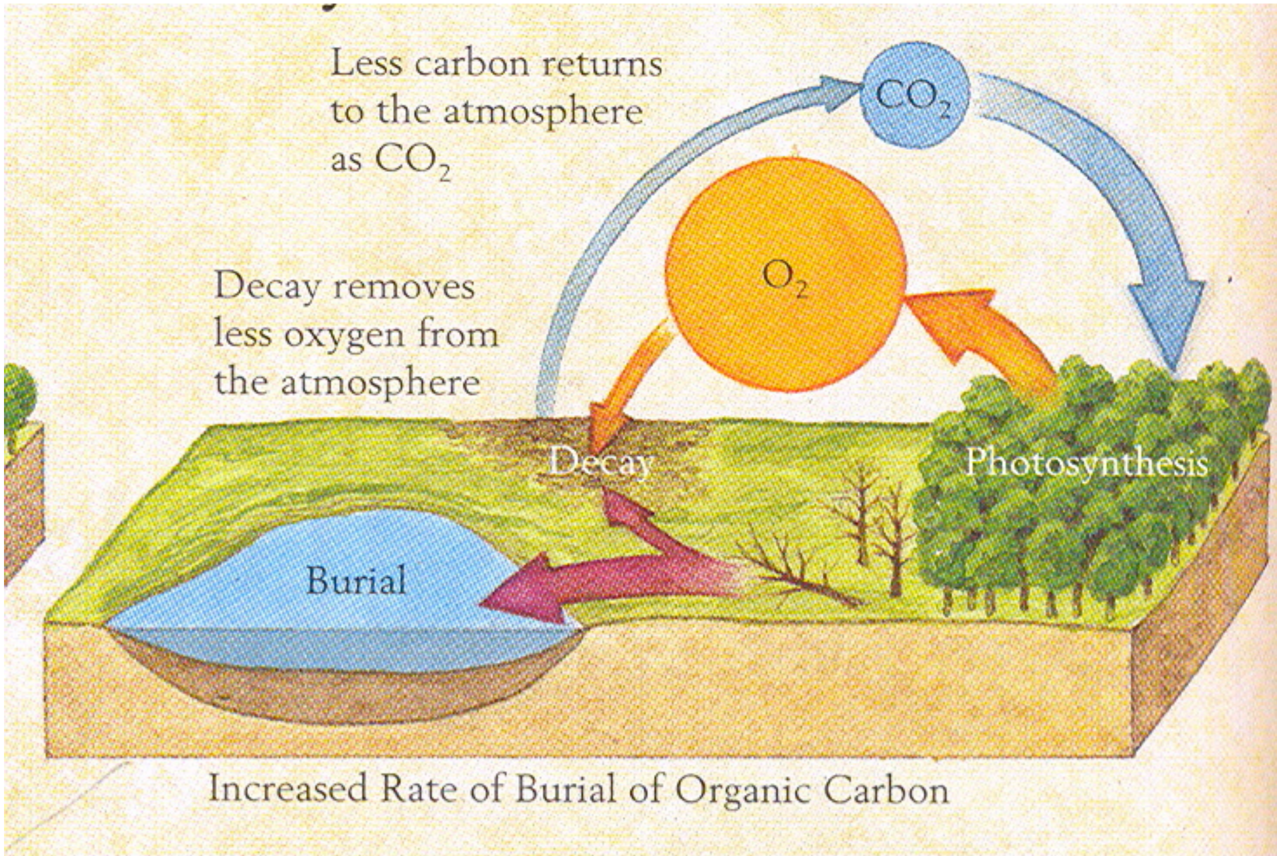
Respiration is a form of oxidation, and sugar is burned, or metabolized, to create energy.



Closed systems ultimately reach equilibrium: in the example shown here increased CO_2 to the atmosphere (left) increases weathering rates (middle) but the extraction of CO_2 as a result of weathering "brakes" the system from accelerating. Without interference, the system would stay in equilibrium, in other words, levels couldn't expand indefinitely.



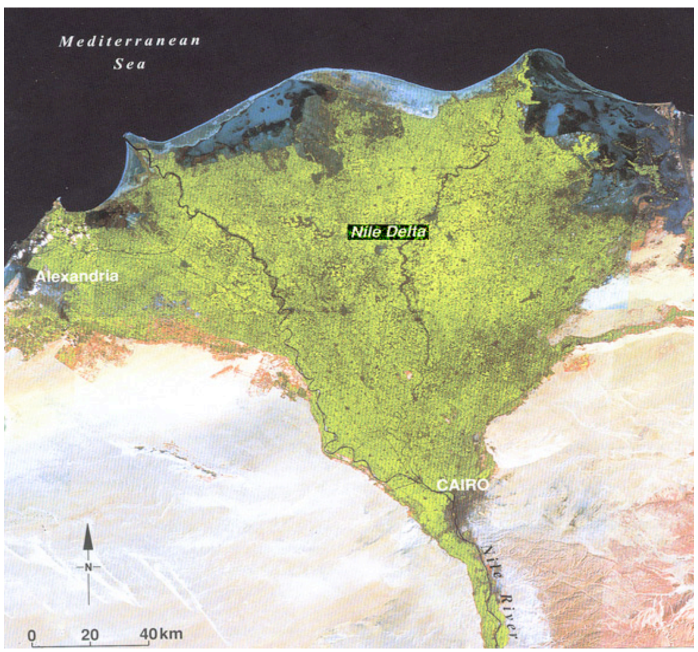
Organic life (plants, animals) store carbon in their tissues. When they die, this material decays - in which case the carbon is oxidized and returned to the atmosphere **OR** it is buried - for example, plant material in swamps.



If the rate of burial of organic carbon is greater than its rate of decay, then carbon will not be oxidized back into the atmosphere, but will remain sequestered, or removed, from the atmosphere as coal, petroleum or limestone. This will reduce the amount of atmospheric carbon dioxide.

Over geologic time, how have burial rates of organic carbon changed?

- When sea level is high, coastlines flood, and swamps, estuaries are abundant = opportunities for burial of lots of plant material
- When sea level is high, more limestone is deposited ($CaCO_3$)
- When climates are warm and moist, more plant growth



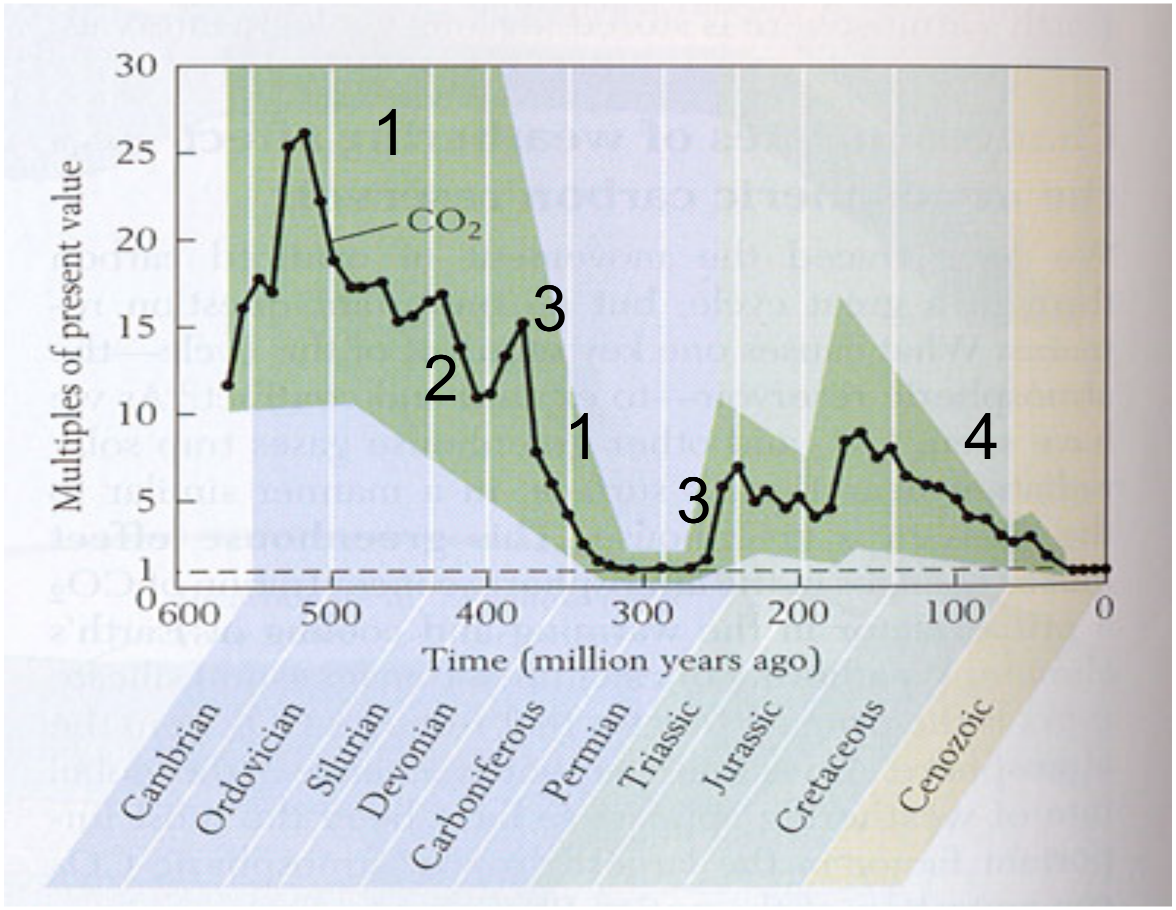
Over time, how do we increase extraction rates of atmospheric CO_2?

When mountains are uplifted, more surface area is produced for atmospheric weathering….

$CO_2 + H_2O \rightarrow H_2CO_3$

H_2CO_3 is a weak acid that chemically reacts with rock to break down the rock and create new minerals

When rates of plate movement are high = increased volcanic activity and CO_2 emissions



1= incr in weathering from evo of land plants

2= incr in burial of C

3= decr in weathering- no mtn building

4= weathering of Andes/ Himalayas

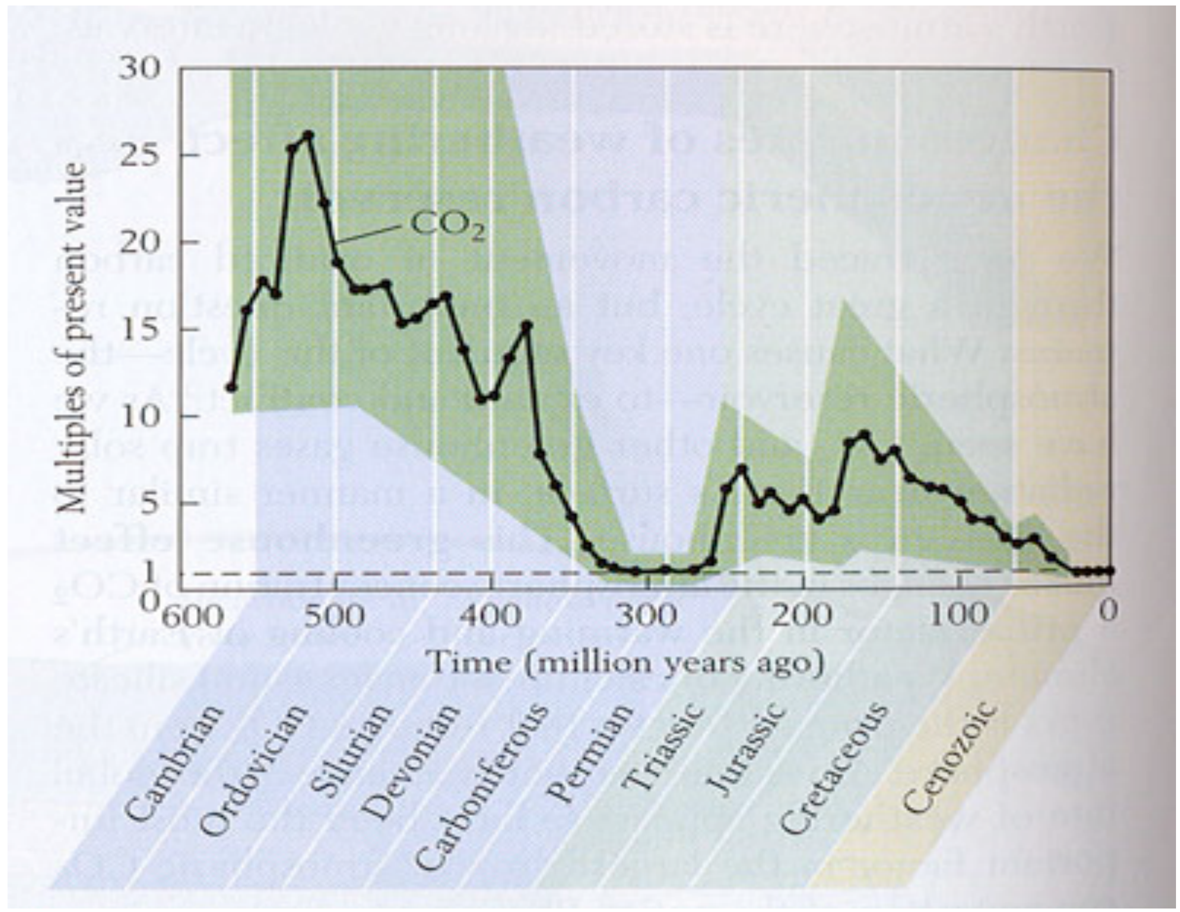
A plot of atmospheric CO_2 levels over geologic time. The Y axis is "multiples of the present day atmospheric CO_2 levels." The X axis is geologic time. The graph shows that in the Paleozoic Era, atmospheric CO_2 levels were 25+ times greater than today! Graph is based on **modeling** the carbon cycle.

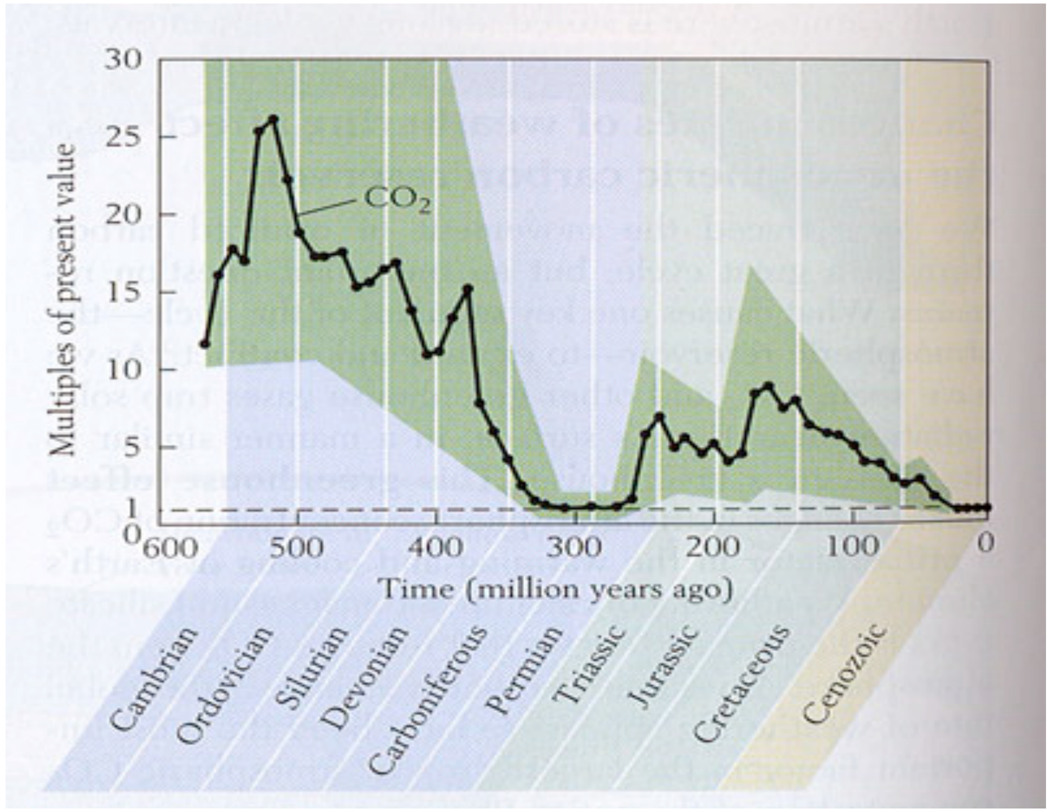
Exam questions:

How do we interpret some of the changes we see?

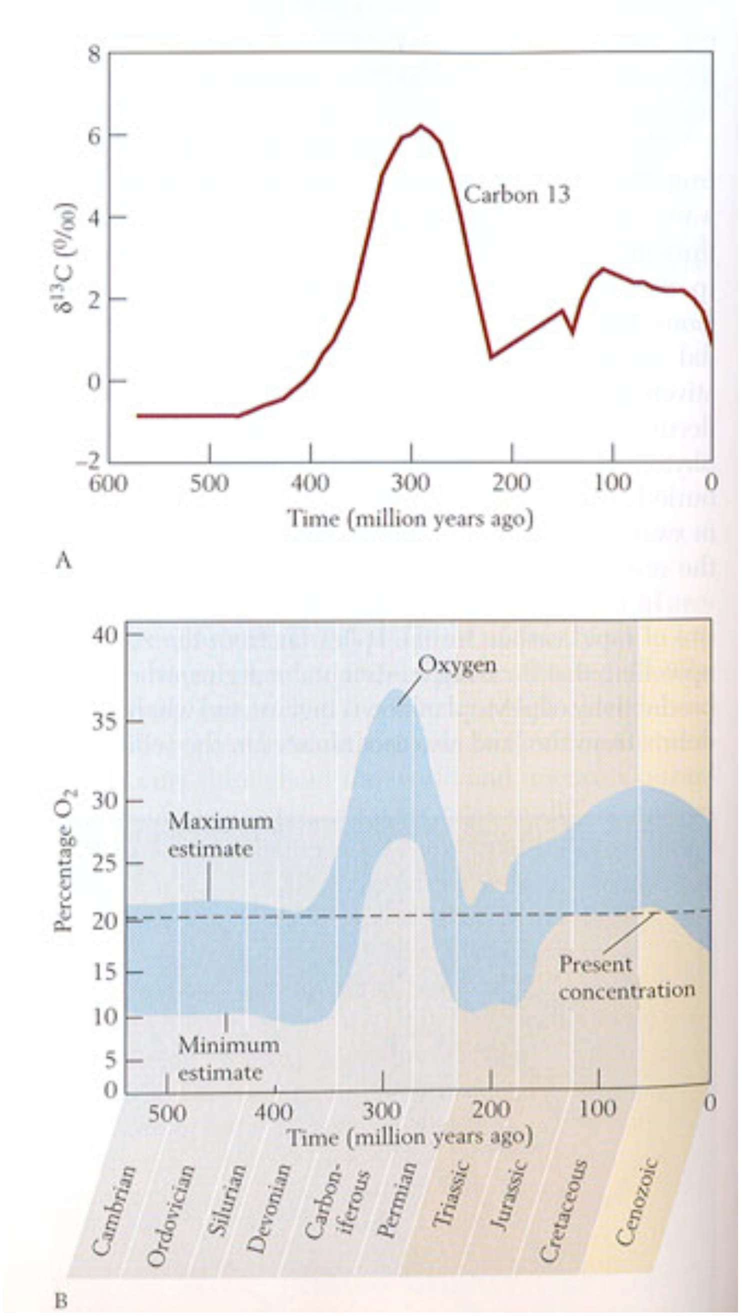
1. Why is the level of atmospheric CO_2 rise in the Cambro-Ordovician?
2. Why does it decrease through the Paleozoic?
3. Why is it so low in the early Mesozoic?
4. Why does it increase again in the Cenozoic, and then decrease to present day levels?

What causes removal of atmos CO_2? What causes its production?





The stunning Paleozoic decr in CO_2 reflects huge increase in weathering rates as plants diversify on land plus uplift of mtns; low C values in late Carboniferous reflect very high burial rates of C followed by little mtn-building in Permian. Modest rise in the Mesozoic from volcanic/tectonic activity during breakup of Pangea and warm dry climate with little weathering. Decreasing levels through late Mesozoic/Cenozoic due to incr deep water limestone formation (evolution of calc.marine organisms) and increasing weathering rates from uplift of Himalayan Mtns.



Tracking C_{13} from limestone enables us to model atmospheric carbon.
Carbon burial rates, which are shown to be very high at the end of the Paleozoic (much light C_{12} is sequestered in buried plants). C_{13} is also high during the Cretaceous, another time of coal formation. Rates drop through the Cenozoic as buried C_{12} is returned to atmosphere through uplift and weathering

A model for atmospheric O_2 levels suggest that they will fluctuate as the inverse of atmospheric CO_2. Note broad band of uncertainty

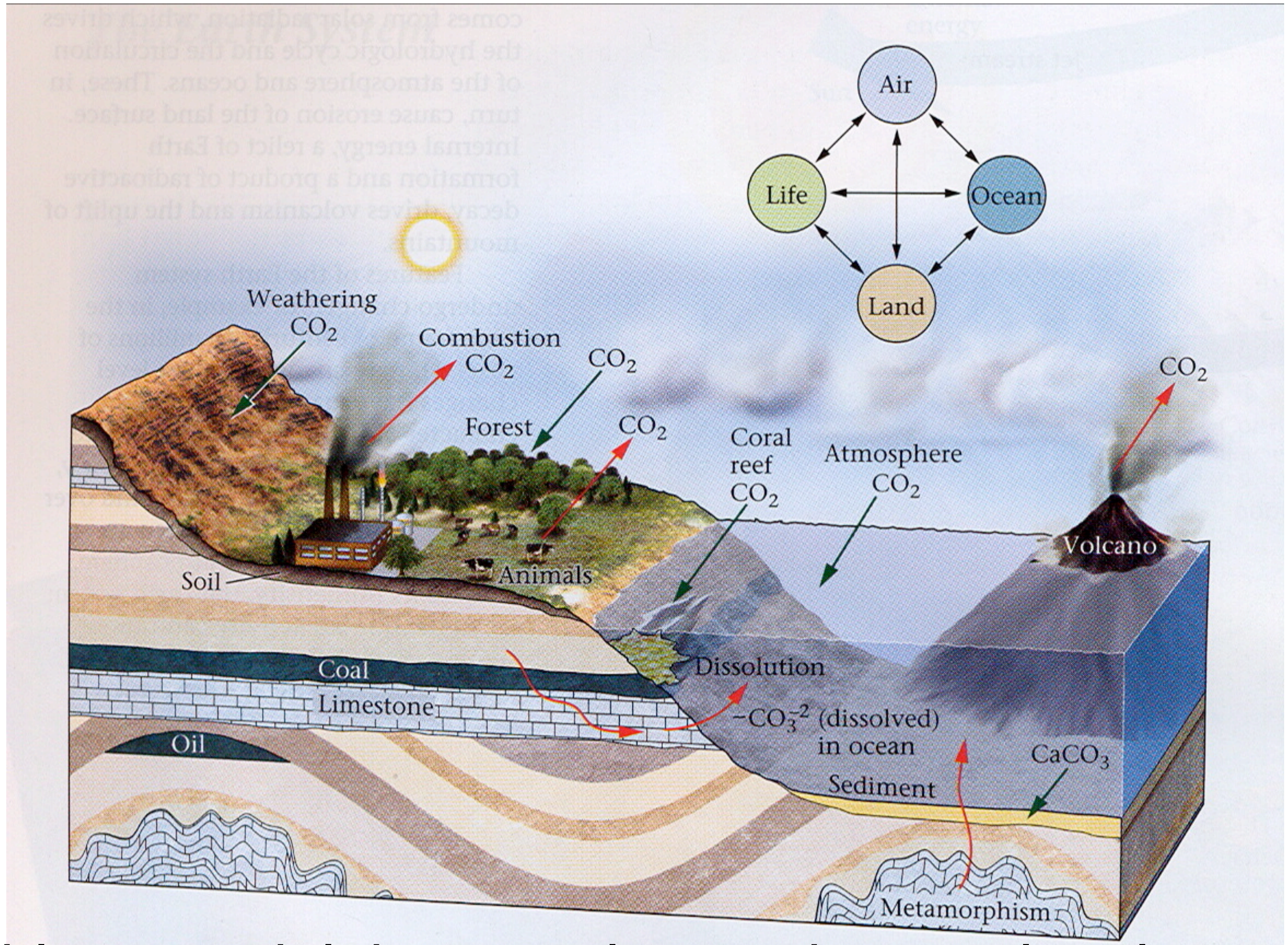
How do we increase the amount of carbon sequestered in organic material and out of the atmosphere?

- Increase the amount of plant material (plant trees)
- Increase the surface area of the Earth under cultivation
- Maintain healthy coral reef growth and ocean ecosystems in general

How do we increase the amount of carbon buried, and not oxidized back into the atmosphere?

- Don’t cut and burn trees (deforestation)
- Don’t burn garbage
- Don’t burn fossil fuels (coal and petroleum are complex carbon molecules from decayed organic life)
- New technologies for ocean sequestation

The Carbon Cycle



You should be able to model the complete carbon cycle: plate tectonics PLUS changes in the biosphere, and predict how changes in the various reservoirs would influence atmospheric CO_2 levels