Week 11 Assessment – available thru Friday, Nov. 5, 8 pm
Homework 3 available at web site (Due Wed. Nov. 10)

Quick summary of last time (see lecture notes from Nov. 1)

Relative concentrations of dissolved CO$_2$, bicarbonate, and carbonate ion in ocean waters

Carbon burial and oxygen (p 159-162)
The Inorganic Carbon Cycle – the Ocean

Diffusion between atmosphere and ocean

Uptake/cycling by sediments

“anorganic” should be “inorganic”
This figure depicts how the relative abundances of these different ions shift as the pH changes. Note that at the current ocean pH of about 8, bicarbonate ion is the most abundant (there is almost 20 times as much $\text{HCO}_3^-$ as there is $\text{CO}_3^{2-}$ and dissolved $\text{CO}_2$ combined).
The atmosphere/ocean inorganic carbon cycle

Figure 8-16

We measure these:
- Atmospheric CO₂
- Oceanic CO₂ (H₂CO₃)
- Marine carbonate sediments
- Carbonate sedimentary rocks

We estimate these from samples and calculations:
- Silicate weathering
- Carbonate weathering
- Sea-floor dissolution
- Carbonate weathering
- Chemical equilibration
- Air-sea exchange
- Precipitation of CaCO₃
- Volcanism

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If there are vertical gradients in the concentration of CO$_2$ in water, then surface ocean waters can be out of equilibrium (i.e., they are adjusting to the gradients). Upwelling brings relatively high CO2 to the surface (‘sources’) and biologically active surface waters are low in CO$_2$. 

Figure 8-13
How can we tell the difference between CO$_2$ produced by fossil fuel burning and that which occurs naturally?

Air in the upper atmosphere is constantly being exposed to high-energy radiation from the sun and from sources outside the solar system. Some of these ‘cosmic rays’ react with nitrogen to form a carbon atom that is radioactive ($^{14}$C, or “carbon 14”). Normal carbon weighs 12 g/mole, $^{14}$C weighs 14 g/mole.

A gram of living carbon (that has formed recently from carbon dioxide in the atmosphere) will contain about 50 billion atoms of $^{14}$C. Once that carbon is no longer being replenished by atmospheric carbon (i.e., once the organism dies), after about 5730 years only half of the $^{14}$C will remain (~25 billion atoms). After another 5730 years, only half of that will remain (~12.5 billion atoms). By taking the ratio of $^{14}$C to total carbon atoms, then, scientists can estimate when that object stopped living. After 110,000 years, a gram of once-living carbon will have no more $^{14}$C atoms. Thus, any once-living object that has been dead for more than 100,000 years will contain no $^{14}$C. This is often referred to as ‘old carbon,’ as opposed to ‘young carbon’ which will trigger a signal on a geiger counter because it contains some radioactive carbon.
Back to our figure. As we have burned fossil fuels, the $^{14}\text{C}/^{12}\text{C}$ ratio in our atmospheric reservoir of $\text{CO}_2$ has decreased over time as we have diluted the air with $\text{CO}_2$ that is low in $^{14}\text{C}$. 

The concentration of $^{14}\text{C}$ in the atmosphere has decreased with the burning of fossil fuels depleted in $^{14}\text{C}$. 

![Graph showing the decrease in Relative $^{14}\text{C}$ concentration over time from 1700 to 1950.](image)
So what the color contours in this figure represent are the amounts of ‘fossil-fuel’ derived CO₂ in ocean water samples. CO₂ that has been diluted by the products of fossil-fuel combustion (low in \[^{14}\text{C} \] ), appears red.

From the figure, we can trace the path of CO₂ as it dissolves in water, and we can see how fast the CO₂ mixes into the water, since we know that we have only been burning fossil fuels for 100 years or so. This allows us to track regions of deep water formation!
Back to the organic carbon cycle.

Let’s look at the long-term portion.

Residence time = \(
\frac{10,000,000 \text{ Gt}}{0.05 \text{ Gt/y}}
\) 

= 200,000,000 y
Back to the organic carbon cycle.

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$= 200,000,000 \text{ y}$

Remember – photosynthesis uses up CO$_2$, but produces O$_2$.

If photosynthesis and respiration/decay are roughly in balance, shouldn’t the amount of O$_2$ in the atmosphere be similar to the amount of biomass?
For every CO$_2$ taken up by photosynthesis, one O$_2$ molecule was produced. There are 200,000 parts per million (ppm) O$_2$ in the atmosphere.

\[ \text{CO}_2 + \text{H}_2\text{O} \rightarrow \text{H}_2\text{CO} + \text{O}_2 \]

Note that 400 ppm of CO$_2$ in the atmosphere is equivalent to 800 Gt of carbon (that’s the weight of all the C atoms in atmosphere)

If it took the equivalent of 200,000 ppm of CO$_2$ to make 200,000 ppm of O$_2$, 400,000 Gt of organic carbon must have been produced. Where is it?

Living biomass = 500 Gt
Soils (formerly living plants/animals) = 2500 Gt
‘Fossil’ organic carbon = 20,000

Total = 23,000 Gt

This is still not enough!
It is estimated that there is over 10,000,000 Gt of carbon tied up in rocks (some even estimate that it’s as much as 70 million Gt!). This is carbon that was thought to once be living on the surface, but eventually got buried by the changing surface. Such a process would have been very slow – hundreds of millions of years if it took occurred at a rate that is similar to the rate at which organic carbon is buried today.

Note that 10,000,000 Gt of buried carbon, all traced back to a photosynthetic origin, would imply that an equivalent of 5,000,000 ppm of O₂ (of 5 times the current mass of the atmosphere!) would have been produced. If so, where did all this oxygen go?

Into rocks! See Chapter 11 (page 217)
Summary - one way to estimate the amount of organic carbon that is buried in the earth is to add up all the sources of O$_2$ (that which is in the atmosphere and that which is estimated in the rocks as oxides – e.g., iron oxides)

Of course, such estimates are crude. They certainly aren’t accurate to factors of 2 – and probably not to factors of 10. But they aren’t off by factors of 1 million!
Another interesting thing to consider is what would happen if we burned all the readily available organic carbon on Earth.

Burning living biomass (500 Gt) would generate 250 ppm of CO$_2$ (for a total of 650 ppm) and decrease O$_2$ from 20.8% to 20.7750%.

Burning organic carbon in soils (2500 Gt) would generate another 1250 ppm of CO$_2$ (for a total of 1850 ppm) and decrease O$_2$ from 20.7750% to 20.65%.

Burning all the estimated fossil fuels (20,000 Gt) would generate 10,000 ppm of CO$_2$ (for a total of 11,850 ppm), and decrease O$_2$ from 20.65% to 19.65%.

So, you can see that we have the ability to increase CO$_2$ to toxic levels (1000 ppm is considered harmful) without barely affecting oxygen levels!