Ocean Carbon Chemistry Problems
EART254 – The Climate System
Due Tuesday, April 21, 2009

**Problem #1:** Assume the ocean is well represented by two reservoirs, a surface water reservoir and a deep water reservoir. Here is the information you will need about each reservoir:

| | SURFACE OCEAN RESERVOIR | DEEP OCEAN RESERVOIR |
|---|---|---|
| VOLUME | Upper 100 m equals 2.5% of global ocean | 100 – 4000 m equals 97.5% of global ocean |
| Temperature | 20˚C | 2˚C |
| Salinity | 35 | 35 |
| [DIC] | ? | ? |
| [Alk] | ? | 2390 μmol/kg |
| pH | 8.14 | 7.98 |
| $[HCO_3^-]$ | ? | ? |
| $[CO_3^=]$ | ? | ? |
| [CO2*] | ? | ? |
| pCO2 | 303 ppmv | ? |

Here are the equilibrium constants that you'll need (see carbon chemistry notes for more information about each equation).

| | For T = 20˚C, Sal = 35 | For T = 2˚C, Sal =35 |
|---|---|---|
| $-\log K_0$ | 1.489 mol $kg^{-1}$ $atm^{-1}$ | 1.235 mol $kg^{-1}$ $atm^{-1}$ |
| $-\log K_1$ | 5.882 mol $kg^{-1}$ | 6.080 mol $kg^{-1}$ |
| $-\log K_2$ | 9.035 mol $kg^{-1}$ | 9.346 mol $kg^{-1}$ |

Assumptions that you should make for this problem:

[Alk] is not significantly affected by photosynthesis and respiration.
Alkalinity is conserved (no river input or output into sediments).
All $CaCO_3$ formed at surface dissolves at depth.
All organic carbon formed at surface dissolves at depth.
Organic matter composition: P:N:C = 1:16:106 (Redfield ratio)
$CaCO_3$ composition: C:Ca = 1:1
Biogenic transfer of carbon from surface to deep: Every 1 C in $CaCO_3$ is accompanied by 4 C in organic matter.

STATE any other assumptions that you make.

A. Make calculations to fill in the questions marks in the table.

B. Calculate the amount of carbon that must have been transferred from the surface to the deep reservoir in the form of $CaCO_3$.

C. Calculate the amount of carbon that must have been transferred from the surface to the deep reservoir in the form of organic carbon.

D. Is the deep water carbon inventory consistent with the biologically related carbon transfers that you calculated? If not, then what other process might influence deep water carbon concentrations? How important is this other process?

**Problem #2:** This problem demonstrates what happens to deep water when it upwells, warms, and stimulates biological productivity. For this problem, we will also take into account the influence that changes in phosphate [$HPO_4^{2-}$] and nitrate [$NO_3^-$] have on [Alk]. Also, assume that the warming and biological production occur much faster than air-sea gas exchange.

Imagine the parcel of deep water that upwells has these initial properties:
Temp = 1 ˚C
[$HPO_4^{2-}$] = 2.2 µmol/kg
[DIC] = 2300 µmol/kg
[Alk] = 2406 µmol/kg

A. When parcel of water moves to surface it warms to 20˚C. What is its $pCO_2$?

B. Next let's isolate what occurs as organic matter is produced, causing [DIC] and [Alk] to change. Organic matter production occurs until all $HPO_4^{2-}$ is used up. Calculate how much $pCO_2$ changes due to organic matter production.

C. What are the relevant Revelle and Alkalinity factors at this location?

D. Next let's isolate what occurs as $CaCO_3$ is produced, causing [DIC] and [Alk] to change. Assume that the carbon removed due to $CaCO_3$ production is 25% of that removed due to organic matter production. Calculate how much $pCO_2$ changes due to $CaCO_3$ production.

E. Is the water parcel a sink or source of $CO_2$ to the atmosphere?

**Problem #3:** This is a very simplified look at how the ocean chemistry buffering might work in response to anthropogenic release of carbon. Assume a well mixed reservoir with pre-anthropogenic values for [DIC] of 2250 µmol/kg, and [$CO_3^=$] of 100 µmol/kg.

So far, 223 PgC have been added to the atmosphere due to anthropogenic activity. Imagine that after adding an additional 500 PgC, no more is added. Assuming 25% of all anthropogenic carbon is sequestered into the terrestrial biosphere, let's see what happens to the other 75%.

Assume that 75% of total anthropogenic carbon is free to enter the ocean at high latitudes.

A. Calculate the new pCO2 of the ocean, and therefore of the atmosphere in equilibrium with the high latitude ocean.

B. Calculate the new [CO3=].

C. What is the new depth of the lysocline immediately after the carbon mixes into the ocean? (Before there is time for calcite production/dissolution and therefore [Alk] to adjust to changes in ocean carbon chemistry).

D. Given the new depth of the lysocline, what changes in the carbon chemistry of the ocean would you expect to occur next. What would happen over 1000's and 10,000's of years?