SIO 40 Fall 2007 Homework 4 **Due Nov 2nd**

This homework covers materials presented in lectures 10, 11, and 12 as well as the accompanying reading assignments for those lectures (see syllabus). These are primarily short answer questions. In most cases, a few sentences should suffice. Please try to answer all questions in the space provided, use the back of the page if you have to. Be careful to answer each part of multi-part questions. **Note:** Homeworks will be graded on the basis of a *random subset* of these questions – so your best strategy will be to answer all the questions to the best of your ability.

1) What are the sources of the heat that drives large-scale convection in the Earth's mantle and outer core?

Main sources of heat come from: 1) residual heat from the energy released during the initial formation of the Earth by accretion 4.6 billion years ago; and 2) the radioactive decay of long-lived isotopes within the Earth (eg. uranium , potassium, thorium isotopes).

2) Explain the difference between a convergent and divergent (spreading) plate boundary, and give an example of where each type is located on the surface of the Earth today.

A divergent boundary is where two tectonic plates are moving apart and new crust is forming, such as at the mid-ocean ridges in the Atlantic Ocean. Plates come together at convergent margins. When one of the two convergent plates is an oceanic plate, as in the far western Pacific, it gets subducted under the continental plate. When two continental plates converge, as where the Indian-Australian plate is colliding with Asia, uplift creates mountain ranges.

3) Why are sedimentary rocks so abundant at the Earth's surface when igneous rocks (eg. primary minerals like olivine) make up most of the crust?

Igneous rocks weather once they are exposed at the surface of the Earth's crust, gradually degrading to form sedimentary rocks. Thus igneous rocks are uncommon at the Earth's surface because they are unstable to weathering, while sedimentary rocks are abundant because they are the products of weathering reactions.

4) Name two processes (chemical reactions) which result in the consumption of atmospheric O_2 during the weathering of black shales. Which of these weathering reactions results in significant acid production?

Two processes that consume O_2 during weathering of black shales include

1) oxidation of organic matter

$$CH_2O + O_2 \rightarrow CO_2 + H_2O$$

2) pyrite oxidation

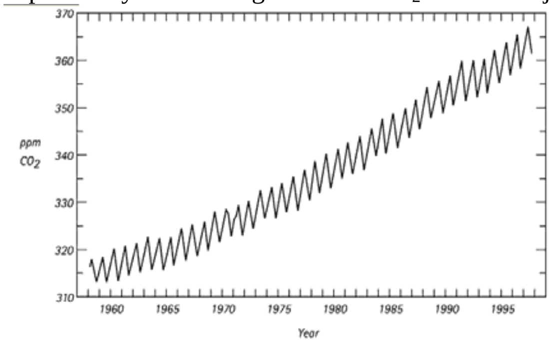
$$4FeS_2 + 8\,H_2O + 15O_2 \rightarrow 2Fe_2O_3 + 16H^+ + 8SO_4^{2-}$$

Of the two reactions, pyrite oxidation produces the most acid, although the production of metabolic CO_2 via respiration can also increase soil acidity.

5) What does the circulation of the Hadley cell have to do with the location of tropical rainforests and deserts in North and South America? Which of these two terrestrial biomes is more productive?

In the Hadley circulation cell, warm moist air rises at the equator and loses a lot of its moisture as precipitation. This area of high rainfall near the equator corresponds to the location of most of the world's tropical rainforests. The dry air then moves to higher latitudes and comes back down to the surface as cool, dry air. The lack of moisture in the air as it descends tends to create a relatively dry climate in the region around 30° North and South. This corresponds to the location of most of the world's deserts, in the region around 30° latitude. The rainforests are the most productive terrestrial biome on Earth and are far more productive than the deserts, the least productive terrestrial biome.

6) We know, from measurements of the concentration of CO_2 in the Earth's atmosphere, that the concentration is going up. The most famous example of this is the "Keeling curve", shown below. This record of CO_2 increase was obtained from continuous measurements made at Mauna Loa in Hawaii by Charles Keeling (of UCSD!). Can you explain why the Keeling curve for CO_2 has such a jagged, "sawtooth" – type pattern of increase?



The sawtooth pattern is a result of the seasonal cycling of photosynthesis and respiration in the terrestrial biosphere. This causes marked uptake of CO_2 in the summer. The cycling is especially visible in this record because Mauna Loa is in the northern hemisphere, and the greatest amount of continental landmass and accompanying terrestrial biomass is also in the northern hemisphere.

7) What is the turnover time for oceanic primary producers vs. terrestrial primary producers? How is this significant to the global distribution of primary production?

The turnover time of marine biomass is weekly, versus about 20 years for terrestrial biomass. This is significant to the global distribution of NPP because the faster turnover of marine biomass allows oceanic NPP to be about equal to terrestrial NPP, even though the marine biomass is about 1000x less (by mass basis) than terrestrial.

8) What is the biological organic carbon pump in the ocean and how is the efficiency of this pump affected by the structure of the oceanic food web?

Phytoplankton photosynthesis removes CO_2 from seawater and sequesters it in the form of organic carbon, some of which can be removed from the surface ocean by the vertical flux of sinking material. This process tends to decrease atmospheric CO_2 by drawing down CO_2 in ocean surface waters. The "classical food web" (ie. big diatoms to copepods to fish, etc.) is much more efficient at generating vertical flux (and thus pumping CO_2 out of surface waters) than a food web based on small phytoplankton and small grazers.

9) What is the relative timescale for each of these processes in terms of the carbon cycle? Use numbers, not just words.

a) Atmosphere/upper ocean exchange 1-10 yrs
b) Terrestrial forest/atmosphere exchange less than 1 yr
c) Deep ocean/surface ocean exchange more than 100 yrs
d) Ocean sediment/atmosphere exchange more than 100 yrs (really millions of years)
e) Terrestrial soil/atmosphere exchange 10 - 100 yrs

10) How does the solubility pump work to move CO_2 from the atmosphere into the deep ocean? in what regions of the ocean does this happen?

CO_2 is more soluble in cold, high latitude waters, causing an influx of CO_2 from the atmosphere into the surface ocean in these locations. Formation of deep water (sinking of cold, dense water masses) moves the CO_2 dissolved in surface waters into the deep ocean. Once sequestered in the deep ocean, CO_2 is generally prevented from exchanging with the atmosphere by a cap of warm, less-dense surface water. In this way atmospheric CO_2 can be sequestered over long (100-1000 year) timescales.

11) Limestone (carbonate) weathering does not lead to the net removal of carbon dioxide from the atmosphere. Why not?

Carbonate weathering on land ($CaCO_3 + H_2CO_3 \rightarrow Ca^{2+} + 2HCO_3^-$)
is exactly balanced by carbonate precipitation by organisms in the ocean ($Ca^{2+} + 2HCO_3^- \rightarrow Ca^{2+} + 2H_2CO_3$), such that there is no net removal of CO_2 from the atmosphere when these two processes are considered together.

12) Why is plate tectonics critical to the maintenance of an atmosphere-ocean reservoir rich in carbon?

Plate tectonics is responsible for the subduction of $CaCO_3$ sediments deposited on oceanic plates at convergent margins. Once the $CaCO_3$ sediment reaches a significant depth in the mantle, the sediment undergoes metamorphic reactions at high temperature and pressure. Carbonate metamorphosis is one such reaction which results in the release of CO_2 from $CaCO_3$ mineral phases. This CO_2 which is released into the mantle is eventually released back into the atmosphere by volcanic eruptions or reactions at ridge crest spreading centers. This addition of CO_2 back into the atmosphere is important for counter-acting the long-term removal of CO_2 from the atmosphere by silicate weathering, and thus preserving carbon in the atmosphere-ocean reservoir.