CARBON BUDGET

Adapted from Rosenthal, Environmental Science Activities

The cycling of carbon through photosynthesis and respiration is only part of the global cycling of carbon. Geochemical processes also contribute to carbon cycling. Biological processes transfer carbon between organisms and the environment; geochemical processes transfer carbon between sedimentary rocks and the atmosphere, oceans and living organisms. Biological processes are relatively short term, occurring over years to hundreds of years while geochemical processes work on a time scale of millions of years.

Carbon occurs primarily as carbon dioxide (CO_2) in air and water, organic carbon (proteins, fats, carbohydrates, and nucleic acids) in living and dead organisms, and carbonate ions (CO_3^{-2}) in water, rocks, shells, and bones. To understand how these are connected in a cycle, it is useful to think in terms of sources, sinks, and fluxes. Sources are carbon emitters; sinks are carbon absorbers; fluxes are flows of carbon between sources and sinks. A source may also be a sink. For example, the atmosphere is a source of carbon dioxide for photosynthesis, but it is also a sink for carbon released during respiration, burning, and decay.

Because carbon dioxide is a greenhouse gas, scientists are concerned that continued increases in atmospheric carbon may lead to global climate change.

In this activity you will model the carbon reservoirs and fluxes and consider what might happen to the increasing carbon dioxide produced by human activities.

Table 1: Carbon Reservoirs

Reservoir	Carbon in Gt
Ocean surface	1,000
Ocean life	6
Organic material in ocean	1,000
Deep ocean water	38,000
Ocean sediments	3,000
Sedimentary rocks	100,000,000
Soil	1,600
Fossil fuels	4,000
Living land organisms	600
Atmosphere	750

Table 2: Carbon Fluxes

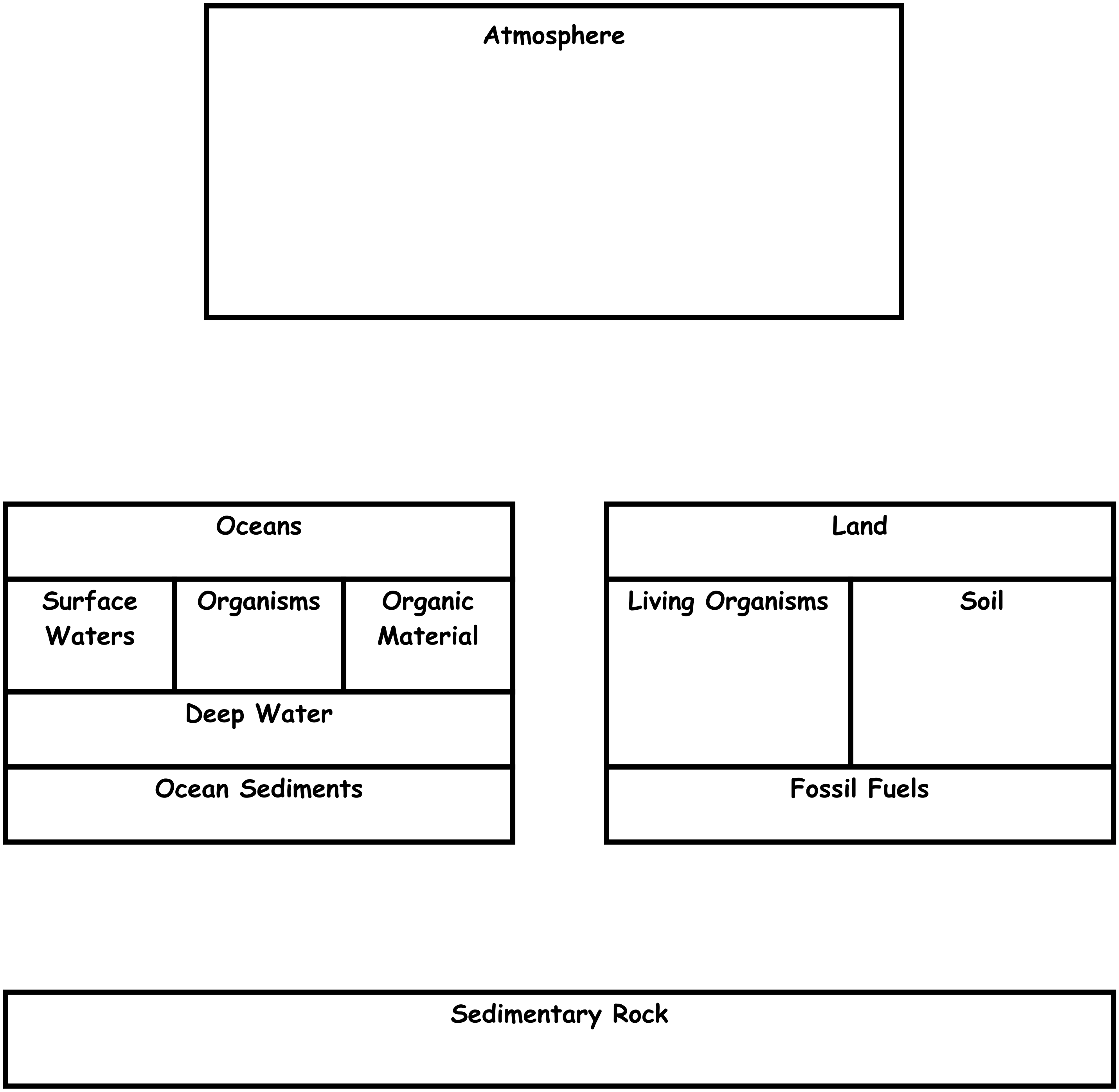
Direction of Movement	Flux (Gt/yr)
Ocean to atmosphere	102
Atmosphere to ocean	105
Ocean surface to deep waters	39
Deep waters to ocean surface	37
Ocean surface to ocean life	28
Ocean life to ocean surface	29
Soil to atmosphere	60
Life on land to soil	60
Life on land to atmosphere	50
Atmosphere to life on land	110
Deforestation to atmosphere	1.6
Fossil fuel combustion to atmosphere	5.4

1. Use the information in the table "Carbon Reservoirs" to complete the diagram of the global carbon cycle. Put the number of gigatonnes of carbon stored in each reservoir in the small boxes in each reservoir. One gigatonne (Gt) equals 1,000 million tones, and 1 tonne equals 1,000 kg.
2. Table 2 shows the fluxes of carbon between reservoirs, measured in gigatonnes of carbon per year (Gt/yr). Add these fluxes to the diagram of the global carbon cycle. **Clearly label each line and indicate the direction of flow.**
3. Calculate the net flux for the atmosphere, the land, and the oceans. **Show your work, including units!** (Recall the law of conservation of matter to check your answer!)
4. The average time that carbon atoms spend in a reservoir is called the residence time. You can calculate residence time by dividing the number of gigatonnes of carbon in the reservoir by the total flux **from** that reservoir. For example, to calculate the residence time of carbon in the atmosphere, divide the total amount of carbon in the atmosphere (750 Gt) by the total flux out (105 Gt to ocean + 110 Gt to life on land).

$$\frac{750\ Gt}{215\ Gt/yr} = 3.5\ years$$

Calculate the average residence time for carbon in living land organisms, for carbon in soil, and for carbon in the ocean. **Show your work, including units!**

Global Carbon Cycle



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Discussion:

5. Which is the largest reservoir of carbon?

   * Which is the second largest?

6. Which processes release carbon into the atmosphere?

   * What human activities release carbon into the atmosphere?

7. Which processes remove carbon from the atmosphere? Which of these processes is the fastest?

8. Which process in this activity is so long that it is not considered part of the cycle in our diagram?

9. What percentage of the total carbon in the land, ocean, and atmosphere (excluding the sedimentary rocks) is in the atmosphere?

   * Considering this answer, why is the level of carbon in the atmosphere considered so important?

10. Scientists monitoring carbon dioxide in the atmosphere estimate that of the 7.1 Gt of carbon dioxide released annually by human activities, approximately 3.2 Gt remain there. Another 2 Gt diffuse into the ocean. How many Gt of carbon are unaccounted for? What are some of the hypotheses to explain what happens to this missing carbon?

Key

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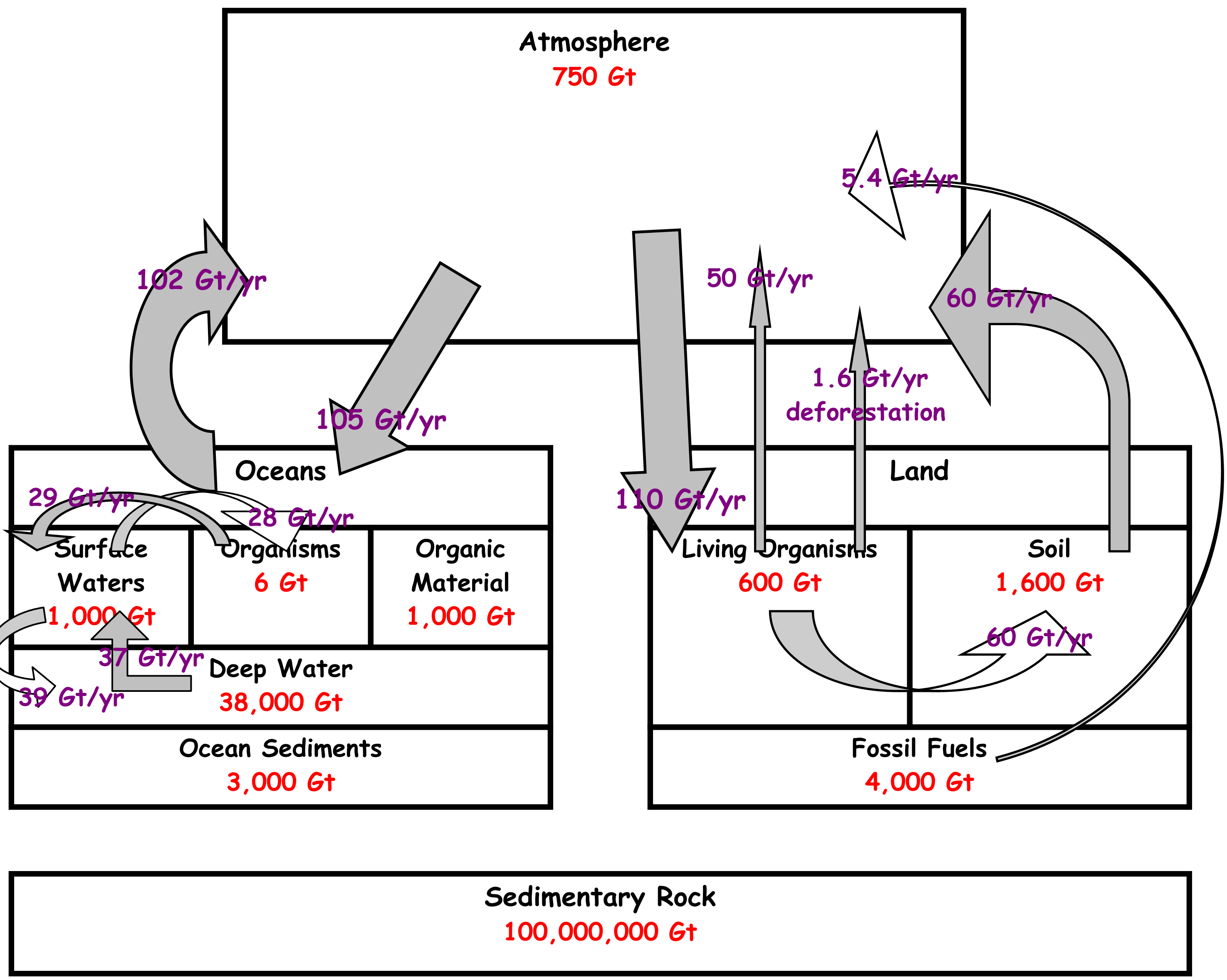
Global Carbon Cycle



3. Calculate the net flux for the atmosphere, the land, and the oceans. **Show your work, including units!** (Recall the law of conservation of matter to check your answer!)

atm	land	ocean
atm = +102 Gt/yr	land = -50 Gt/yr	ocean = -102 Gt/yr
-105 Gt/yr	-1.6 Gt/yr	+105 Gt/yr
+60 Gt/yr	-60 Gt/yr	+3 Gt/yr
+50 Gt/yr	-5.4 Gt/yr	
-110 Gt/yr	+110 Gt/yr	
+1.6 Gt/yr	-7 Gt/yr	
+5.4 Gt/yr		
+4 Gt/yr		

+4 -7 +3 = 0 Gt/yr

Key

4. The average time that carbon atoms spend in a reservoir is called the residence time. You can calculate residence time by dividing the number of gigatonnes of carbon in the reservoir by the total flux **from** that reservoir. For example, to calculate the residence time of carbon in the atmosphere, divide the total amount of carbon in the atmosphere (750 Gt) by the total flux out (105 Gt to ocean + 110 Gt to life on land).

$$\frac{750\ Gt}{215\ Gt/yr} = 3.5\ years$$

Calculate the average residence time for carbon in living land organisms, for carbon in soil, and for carbon in the ocean. **Show your work, including units!**

Residence time for C in living land organisms:

$$\frac{600\ Gt}{60\ Gt/yr + 50\ Gt/yr + 1.6\ Gt/yr} = \frac{600\ Gt}{111.6\ Gt/yr} = 5.1\ yrs$$

Residence time for C in soil:

$$\frac{1600\ Gt}{60\ Gt/yr} = 26.7\ yrs$$

Residence time for C in the ocean:

$$\frac{43{,}006\ Gt}{102\ Gt/yr} = 421.6\ yrs$$

Discussion:

5. Which is the largest reservoir of carbon? **Sedimentary rock**

   * Which is the second largest? **Deep ocean**

6. Which processes release carbon into the atmosphere? **Marine & terrestrial respiration, decay, combustion of fossil fuels & wood, volcanic action, diffusion from ocean to atmosphere, deforestation**

   * What human activities release carbon into the atmosphere? **Burning fossil fuels for heat, transportation, & electricity; deforestation—clearing photosynthesizing vegetation faster than it is replaced**

7. Which processes remove carbon from the atmosphere? Which of these processes is the fastest?
   - Photosynthesis & diffusion from the atmosphere to the oceans remove carbon from the atmosphere.
   - Photosynthesis by algae (phytoplankton) is faster.

8. Which process in this activity is so long that it is not considered part of the cycle in our diagram?
   Geochemical process of sedimentary rock

9. What percentage of the total carbon in the land, ocean, and atmosphere (excluding the sedimentary rocks) is in the atmosphere?

$$\frac{750\ Gt}{750\ Gt + 1000\ Gt + 6\ Gt + 1000\ Gt + 38{,}000\ Gt + 3000\ Gt + 600\ Gt + 1600\ Gt + 4000\ Gt} = \frac{750}{49{,}956} = 1.5\ \%$$

   * Considering this answer, why is the level of carbon in the atmosphere considered so important?
   The amount of CO_2 in the atmosphere influences the amount of heat retained, which may alter global climate. (Increases in carbon dioxide levels in the atmosphere insulate the earth and contribute to global warming.)

10. Scientists monitoring carbon dioxide in the atmosphere estimate that of the 7.1 Gt of carbon dioxide released annually by human activities, approximately 3.2 Gt remain there. Another 2 Gt diffuse into the ocean. How many Gt of carbon are unaccounted for? What are some of the hypotheses to explain what happens to this missing carbon?
    There is 1.9 Gt of carbon unaccounted for that is released annually by human activities. Some hypotheses to explain what happens to this missing carbon is that plants grow faster when there are higher CO_2 levels; or increased CO_2 increases global temperatures which enhance plant growth.