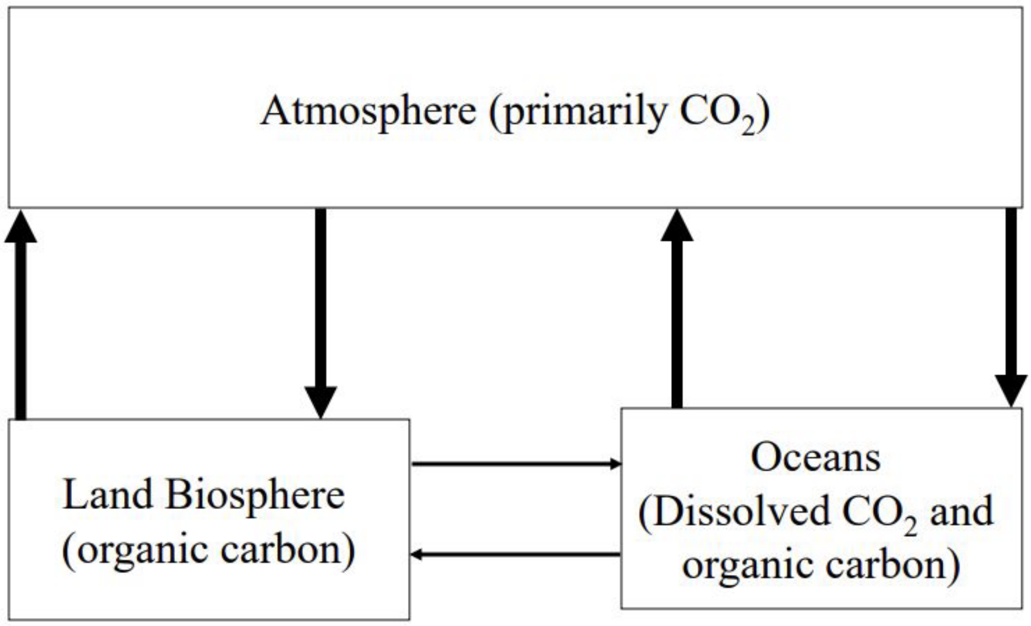
Carbon cycle

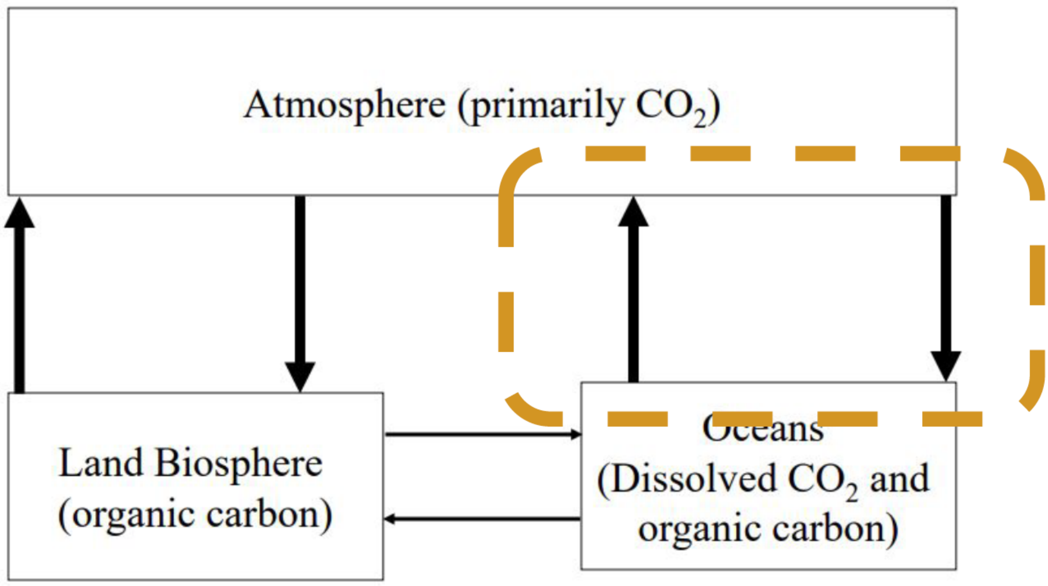
1. Short cycle

1.1. Carbon cycle : Short cycle part 1

SHORT CYCLE



Hydrosphere - atmosphere exchanges



Dissolution of atmospheric CO2 in the ocean and degassing of CO2 from the ocean to the atmosphere

- Exchange of 300 GT of CO2 per year ;
- Residence time = quantity of the element in the reservoir / sum of the flows of contribution in the reservoir.

Video to watch :

Henry's Law and Gas Solubility Explained https://www.youtube.com/watch?v=9JtTpPEesOk

At constant temperature and saturation, the partial pressure in the vapor phase of a volatile solute is proportional to the mole fraction of that body in the liquid solution.

So the higher the temperature, the less CO_2 is soluble, and the more carbon is redistributed to the atmosphere.

For a given amount of carbon in the ocean+atmosphere, the amount of CO_2 in the atmosphere increases if the temperature increases.

CO_2 control : CO_2 balance in the hydrosphere

$$CO_2(g) + H_2O \Leftrightarrow CO_2(aq) + H_2O$$

$$CO_2(aq) + H_2O \Leftrightarrow H_2CO_3$$

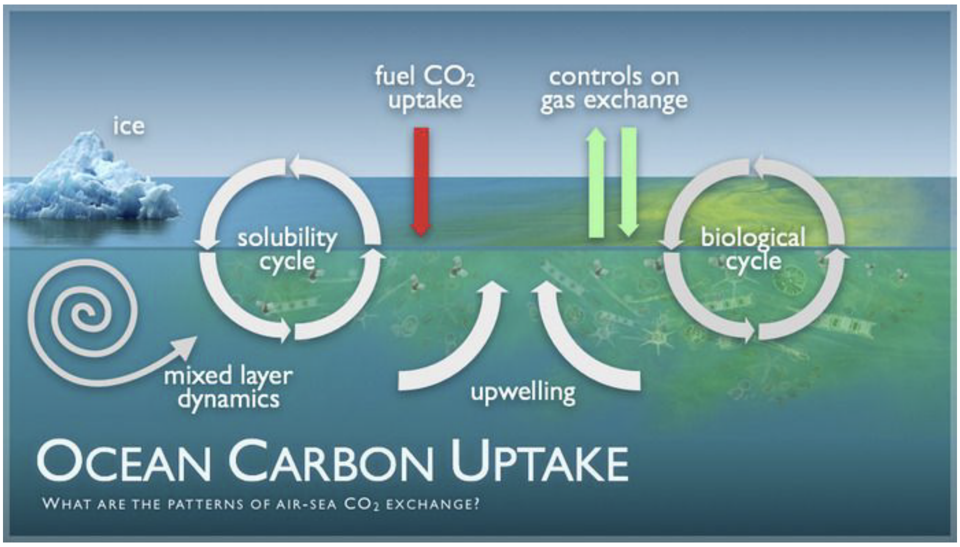
$$Ko = \frac{[H_2CO_3]}{P_{CO_2}}$$

$$H_2CO_3 + \Leftrightarrow H^+ + HCO_3^-$$

$$HCO_3^- \Leftrightarrow H^+ + CO_3^{2-}$$

Ocean pH	Prevailing form
pH<5	H_2CO_3
pH 7-8	HCO_3^-
pH>9	CO_3^{2-}

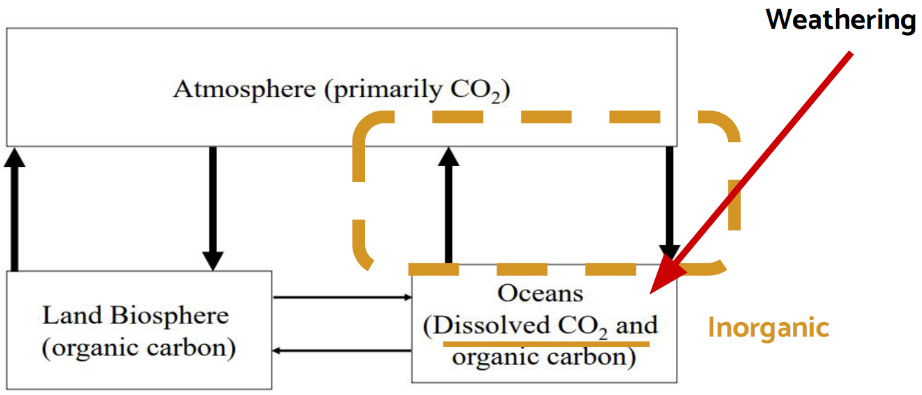
$DIC = [CO_2(aq)] + [H_2CO_3] + [HCO_3^-] + [CO_3^{2-}]$



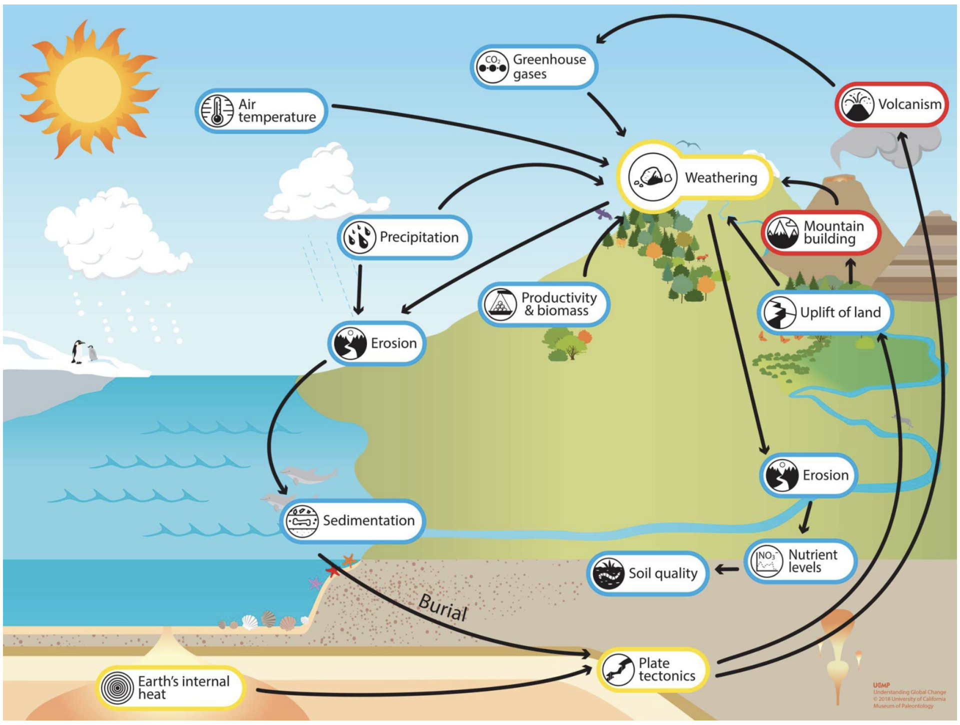
1.2. Carbon cycle : Short cycle part 2

Diversion and leakage in the hydrosphere-atmosphere physical exchanges

There is a diversion of carbon flux from the atmosphere to the ocean through the weathering of rocks.



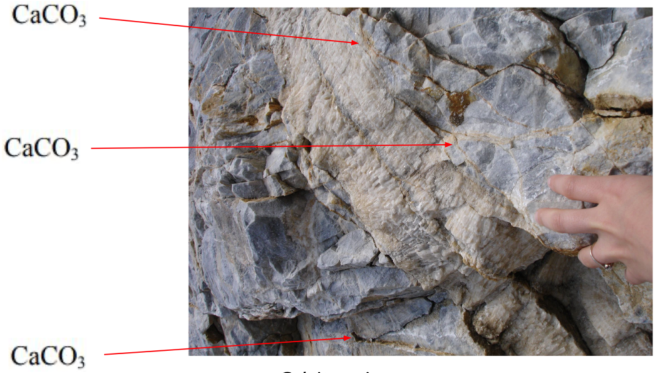
To know more about weathering of rocks : https://www.youtube.com/watch?v=sk B_A2sfBcY



There is a leakage of carbon from the hydrosphere to the lithosphere : the formation of carbonates.

1 Gt of calcite per year.

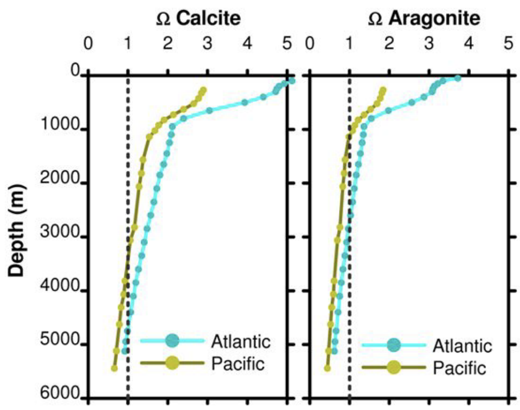
Brow calcite crystals



Calcite veins

Calcium carbonate solubility

$$CaCO_3 \Leftrightarrow Ca^{2+} + CO_3^{2-} \qquad \Omega = \frac{\text{have}}{\text{need for saturation}} = \frac{[Ca^{2+}\text{ present}][CO_3^{2-}\text{ present}]}{[Ca^{2+}\text{ needed}][CO_3^{2-}\text{ needed}]}$$



$\Omega > 1$ Precipitation

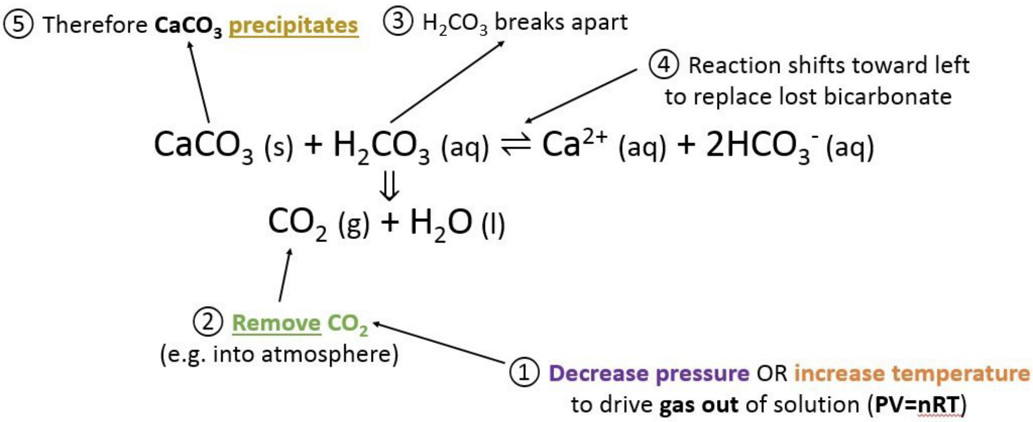
$\Omega = 1$ Equilibrium

$\Omega < 1$ Dissolution

Modern Sea Surface $\Omega \approx$ 2-5

Sea surface is supersaturated with respect to $CaCO_3$, but calcium carbonates are not constantly precipitating.

To precipitate calcium carbonate :



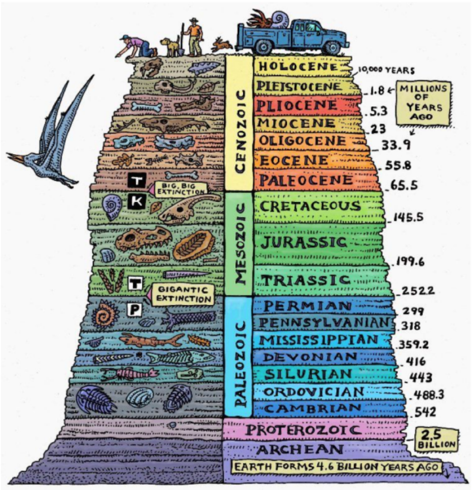
(http://www.luckysci.com)

$$CaAl_2Si_2O_8 + 3H_2O + 2CO_2 = Al_2Si_2O_5(OH)_4 + Ca^{2+} + 2HCO_3^-$$

Anorthite — Kaolinite — bicarbonate ion

with $Ca^{2+} + HCO_3^- \Leftrightarrow CaCO_3 + H_2CO_3$

$$CaAl_2Si_2O_8 + \mathbf{2}H_2O + CO_2 \rightarrow CaCO_3 + Al_2Si_2O_5(OH)_4$$



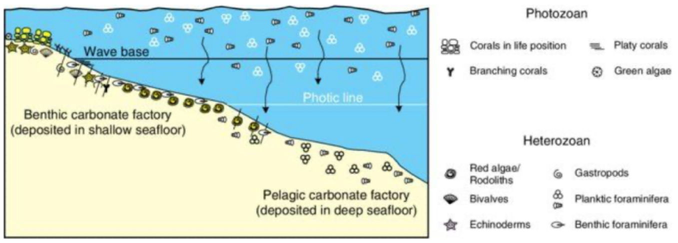
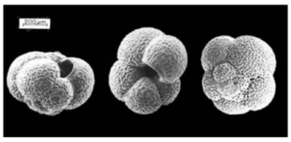


Figure. Main tropical marine biogenic carbonate producers and carbonate factories with respect to water depth.

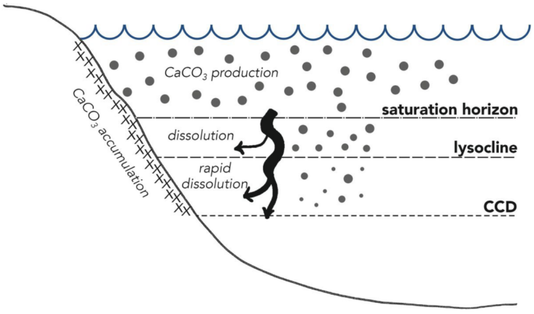
Sgc, Servicio Geológico Colombiano. 2019. « Chapter 9 ». 38. Bogotá: Servicio Geológico Colombiano. https://doi.org/10.32685/pub.esp.37.2019.09.

Coccolithophorales

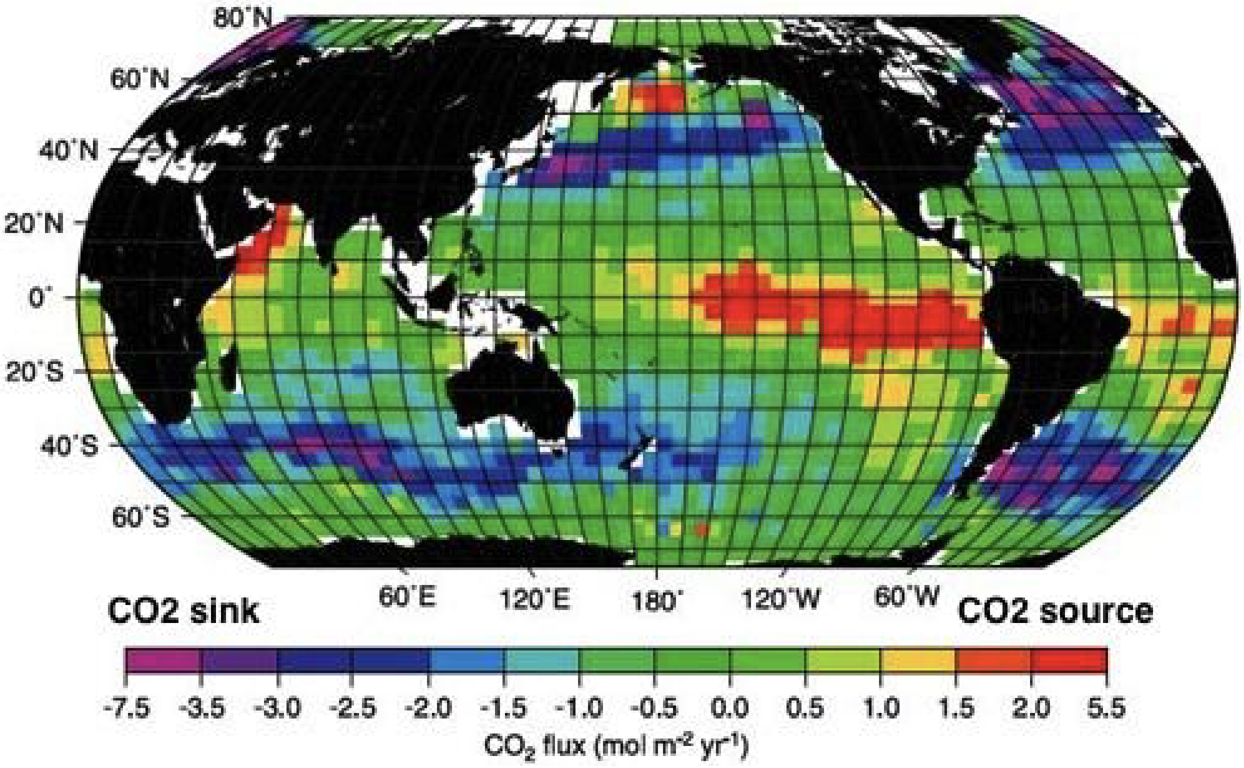


Foraminifera

Corals



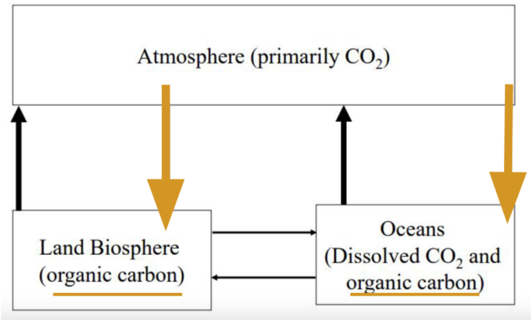
Woosley, Ryan J. 2018. « Carbonate Compensation Depth ». In *Encyclopedia of Geochemistry*, édit par William M. White, 204-5. Encyclopedia of Earth Sciences Series. Cham: Springer International Publishing. https://doi.org/10.1007/978-3-319-39312-4_85.



1.3. Carbon cycle : Short cycle part 3

Photosynthesis and respiration

From atmosphere to biomasse continental and oceanic



Photosynthesis

440 Gt of CO_2 per year, shared equally between the oceans and the continents.

Oxygenic photosynthesis

$$6CO_2 + 12H_2O + \text{light energy} \rightarrow C_6H_{12}O_6 + 6O_2 + 6H_2O$$

carbon dioxide, water → glucose, oxygen, water

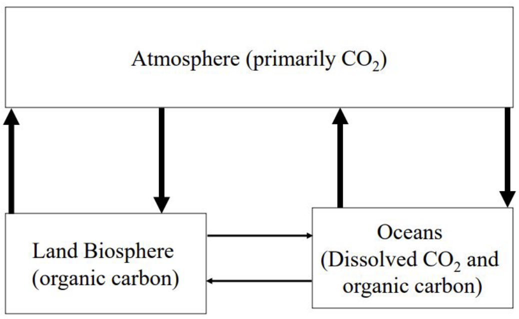
Anoxygenic photosynthesis

$$CO_2 + 2H_2A + \text{light energy} \rightarrow [CH_2O] + 2A + H_2O$$

carbon dioxide, electron donor* → carbohydrate, water

*$H_2A = H_2O, H_2S, H_2$, or other electron donor

From biomass to atmosphere



- Breathing 90°
- Natural combustion 10°

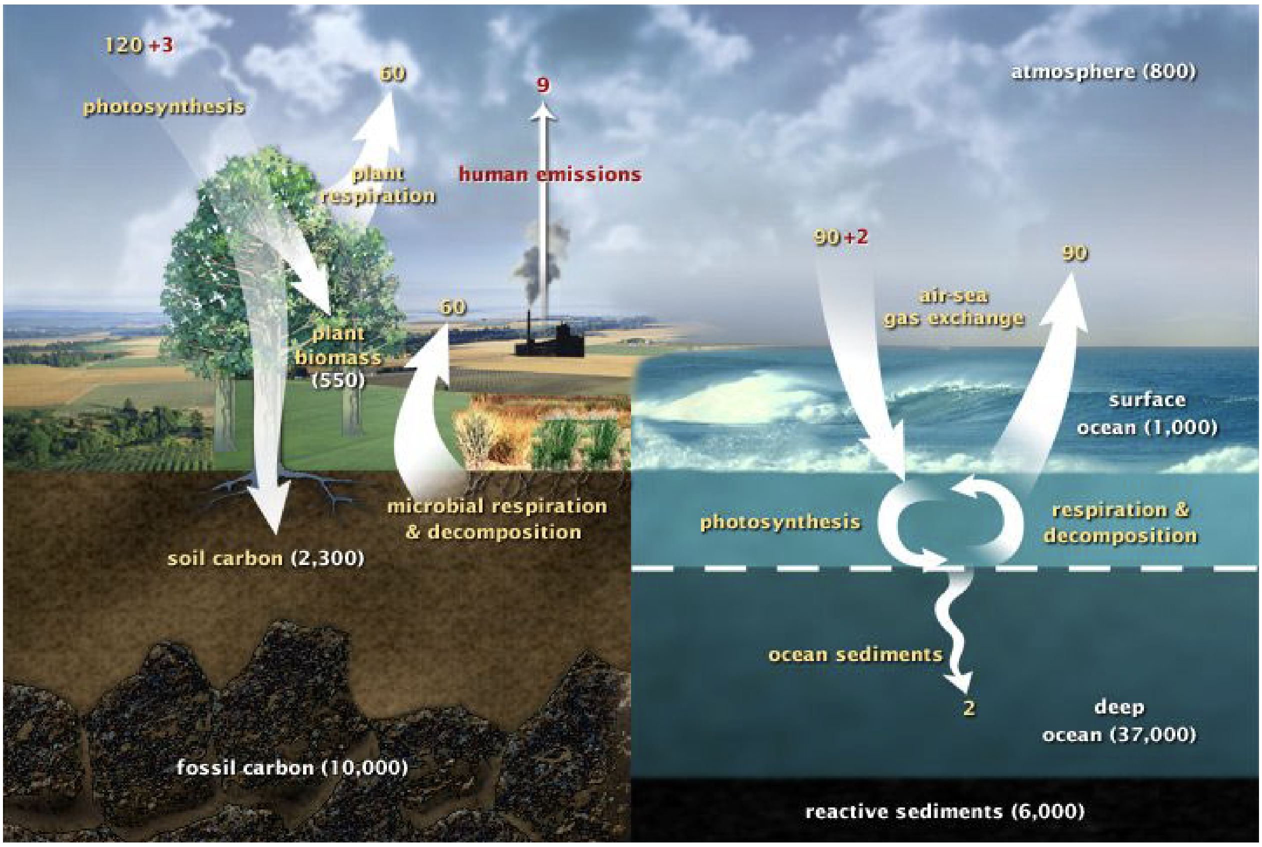
Aerobic respiration chemical reaction :

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6H_20 + 6CO_2 + \textbf{energy}$$

(glucose + oxygen → water + carbon dioxide + energy)

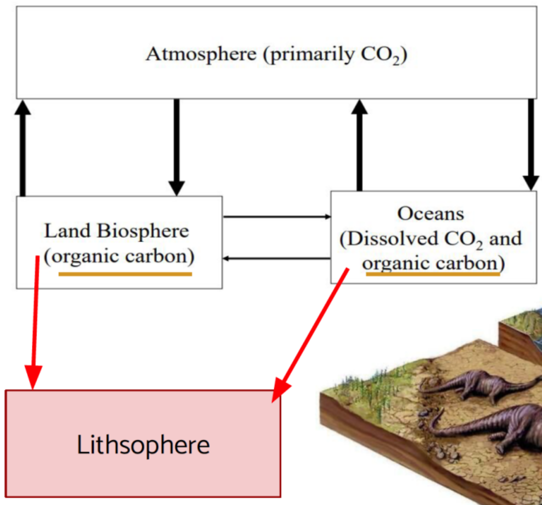
Redox potential [mV]

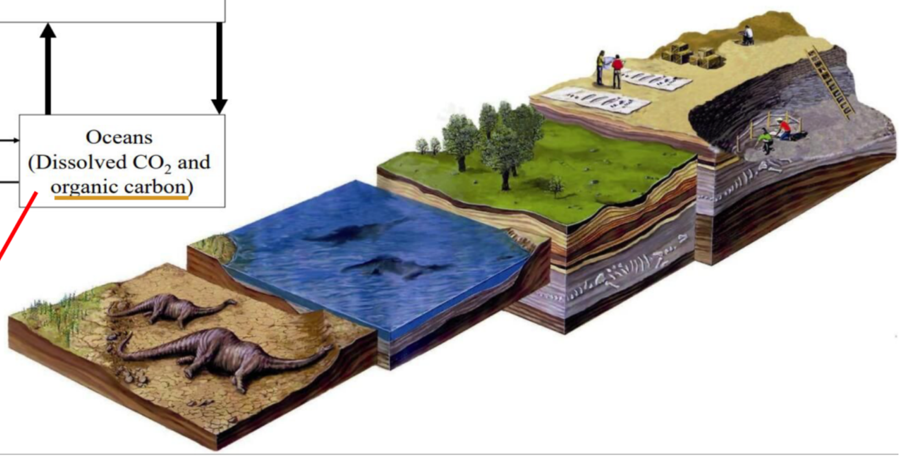
+810	aerobic respiration	$O_2 + 4H^+ + 4e^- \rightarrow 2H_2O$
+750	denitrification (nitrate reduction)	$NO_3 + 6H^+ + 6e^- \rightarrow {}^1/_2\ N_2 + 3H_2O$
+510	mangane (IV) reduction	$MnO_2 + 4H^+ + 2e^- \rightarrow Mn^{2+} + 2H_2O$
+200	iron (III) reduction	$Fe(OH)_3 + 3H^+ + e^- \rightarrow Fe^{2+} + 3H_2O$
- 220	sulphate (IV) reduction	$SO_4^{2-} + 10H^+ + 8e^- \rightarrow H_2S + 4H_2O$
- 240	CO_2 reduction to methane (methanogenesis)	$CO_2 + 8H^+ + 8e^- \rightarrow CH_4 + 2H_2O$



1.4. Carbon cycle : Short cycle part 4

Organic carbon leakage to lithosphere :kerogen formation





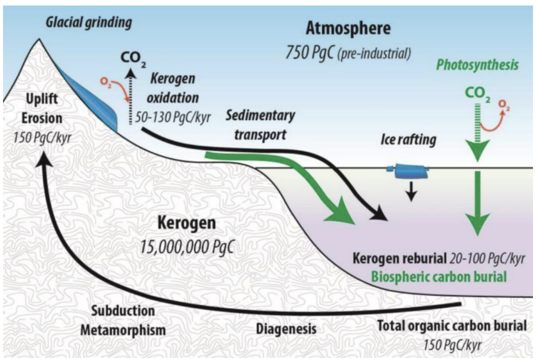
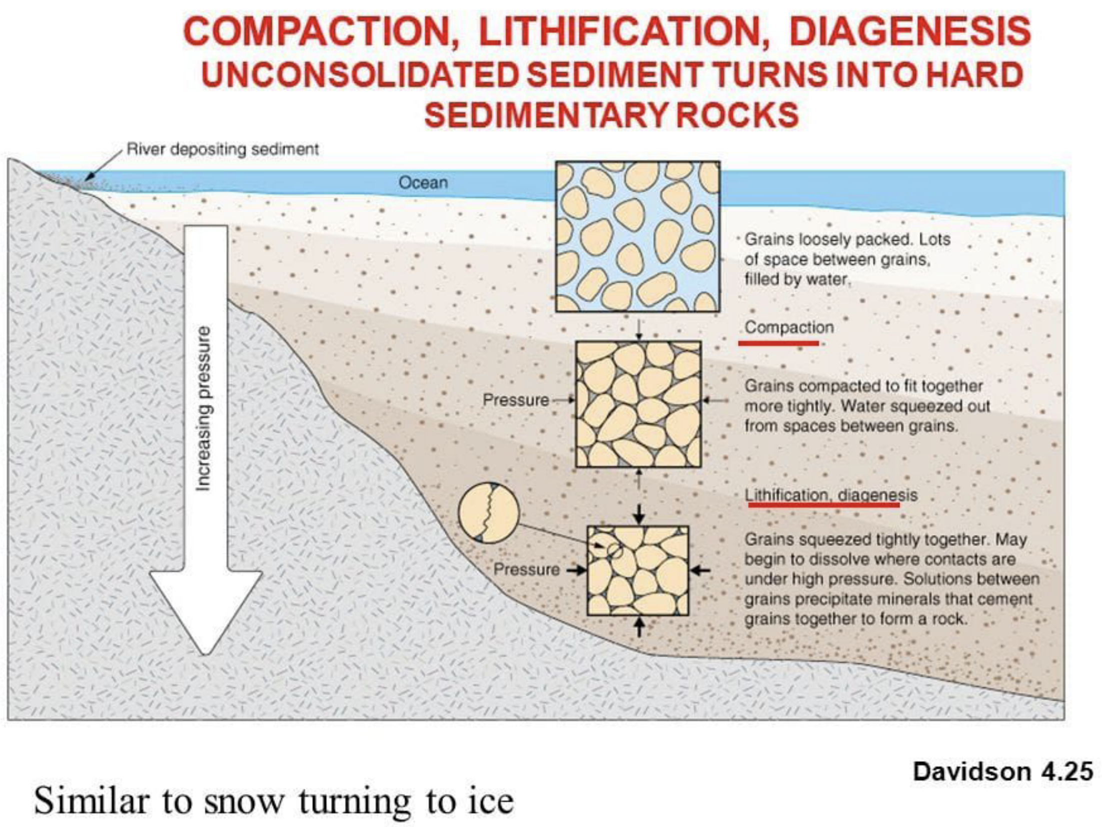
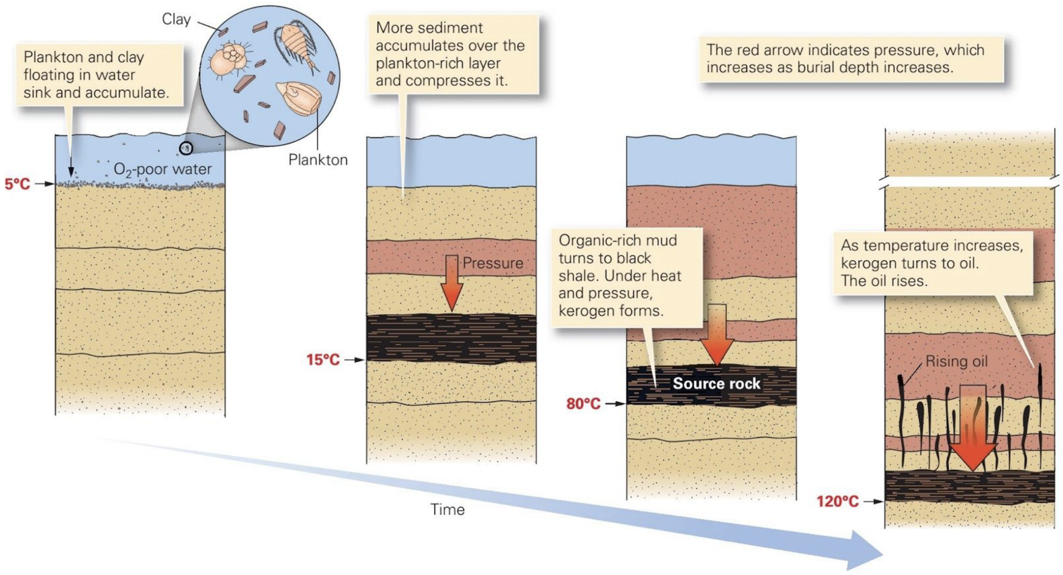
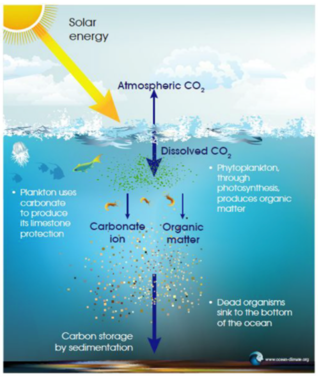


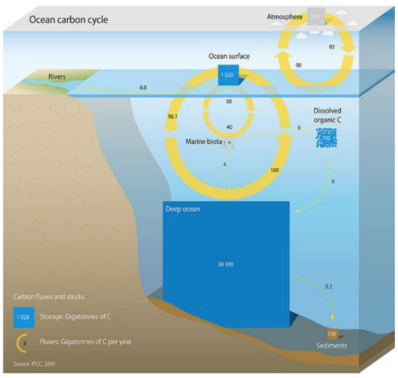
Figure : Organic carbon cycle with the flow of kerogen (black solid lines) and the flow of biospheric carbon (green solid lines) showing both the fixation of atmospheric CO2 by terrestrial and marine primary productivity. The combined flux of reworked kerogen and biospheric carbon into ocean sediments constitutes total organic carbon burial entering the endogenous kerogen pool (Galy et al., 2015; Hedges and Oades, 1997).

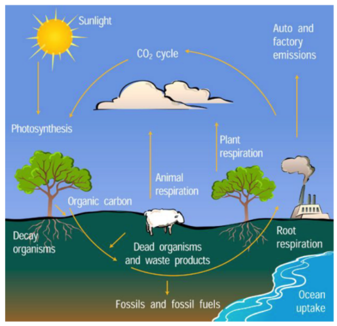




1.5. Conclusion of the short cycle

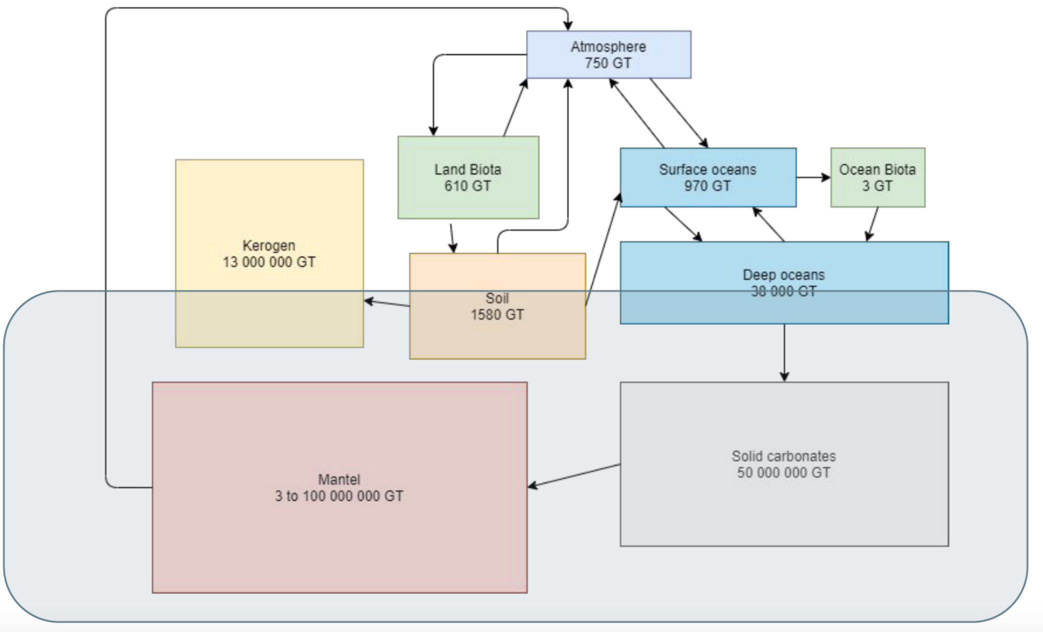


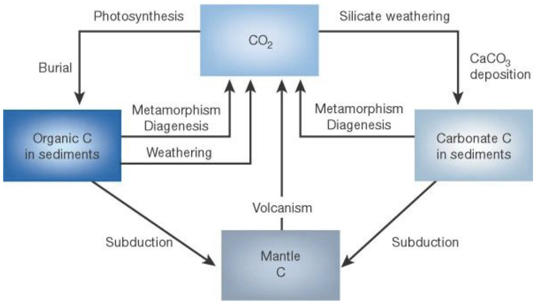




2. Long cycle

Long carbon cycle

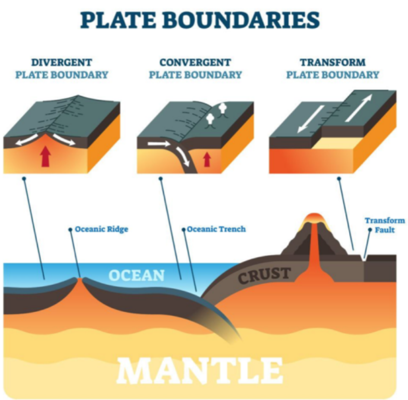


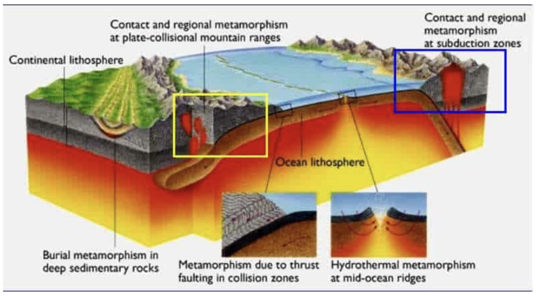


1. $CO_2 + CaSiO_3 <-> CaCO_3 + SiO_2$

2. $CO_2 + H_2O <-> CH_2O + O_2$

Berner, Robert A. 2003. « The Long-Term Carbon Cycle, Fossil Fuels and Atmospheric Composition ». Nature 426 (6964): 323-26. https://doi.org/10.1038/nature02131.





$CO_2 + CaSiO_3 <->CaCO_3 + SiO_2$

Contact Metamorphism Vs. Regional Metamorphism https://www.geologypage.com/

Trap rock forming a characteristic pavement, Giant's Causeway, Northern Ireland (left)

Three Devil's Grade in mid-Moses Coulee , USA (right)

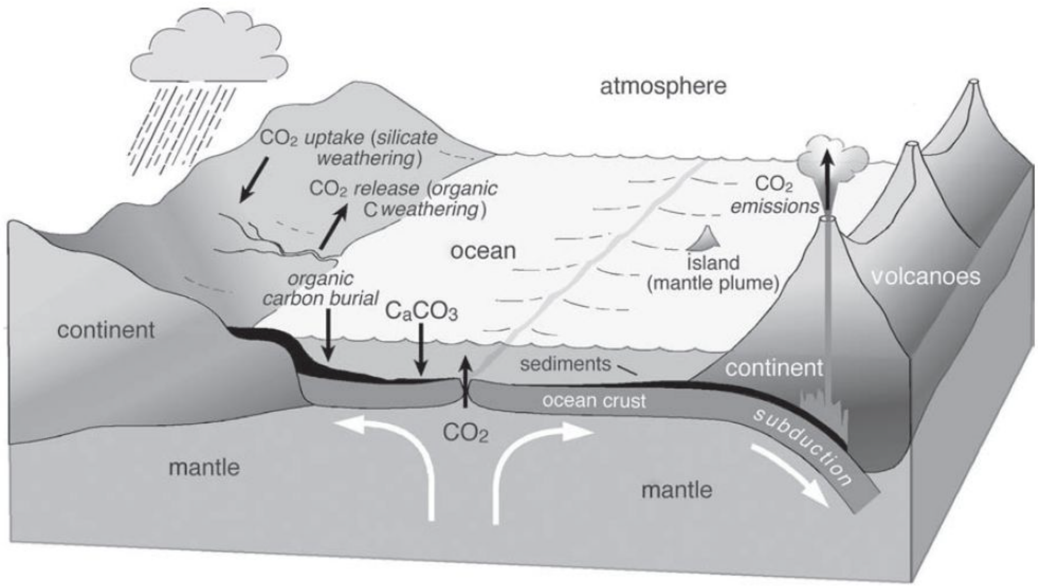


Figure 1.8 Schematic figure of the long-term carbon system involving the exchange of carbon between the atmosphere, ocean and terrestrial systems on geological timescales. Carbon is transferred from the atmosphere to ocean sediments via chemical weathering, where acidic rain reacts with silica rocks, forming calcium and carbonate ions washed out to sea, which precipitate and form calcium carbonate sediments: $CO_2 + CaSiO_3 \rightarrow CaCO_3 + SiO_2$. Subduction of ocean crust below continents leads to eventual melting, releasing carbon dioxide contained within any organic carbon or calcium carbonate in the sediments through volcanic emissions, hydrothermal vents or mantle plumes. For a detailed discussion of the chemical and geological processes, see Berner (1999); drawn by K. Lancaster.