OCN 401

Global carbon cycle I

Systematics and history of the C cycle

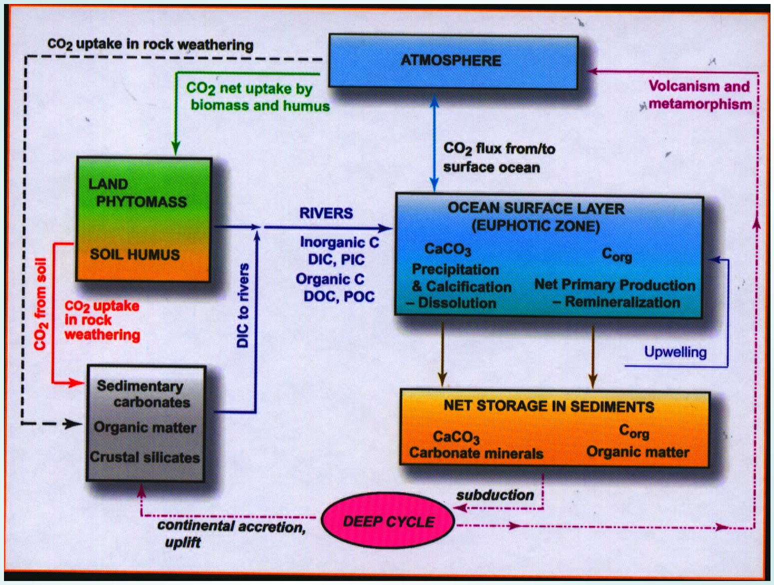
The C cycle is dominated by the processes of:
- Silicate rock weathering
- Organic C production

The major reservoirs of C are:
- Carbonate rocks/sediments
- Organic carbon
- Dissolved inorganic C in seawater

CO_2 is the transfer medium between these reservoirs

The time scales of the processes are:
- Sub-annual to millenia for organic C production
- Thousands to millions of years for the rock cycle

Global carbon cycle involves biomass on land and in the oceans,
the atmosphere, the rock cycle and the physical chemistry of the oceans



Is also linked to the global cycles of oxygen, nitrogen and phosphorous

The oceans contain the largest reservoirs of C

The atmosphere is a holding tank for CO_2

Atmospheric CO_2 levels are controlled by the relative rates of these transfer processes

We will look at the reservoir and transfer processes to see how they regulate climate and the feedback loops that this produces

Carbon reservoir sizes at the Earth's surface

Carbon dioxide is only a small fraction of the reservoir, but its role in photosynthesis, climate regulation and rock weathering make it a critical component of the system

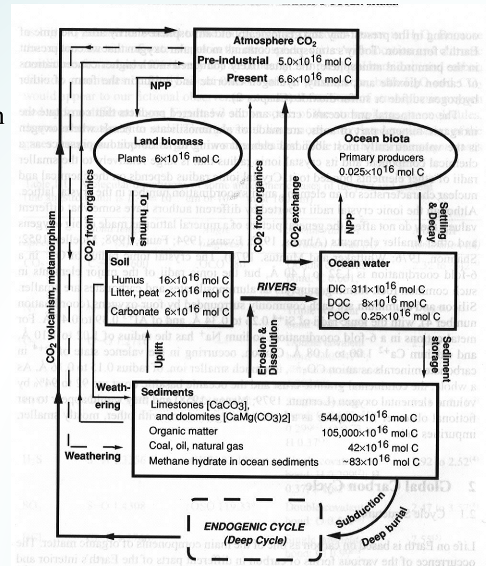


Figure 1.4 Global biogeochemical cycle of carbon. Reservoirs on the Earth surface represent the exogenic cycle. Masses of the major reservoirs are given in Table 1.2. NPP is net primary production, defined in the text. The CO_2 in weathering is shown as taken from the soil (solid line) or from the atmosphere (dashed line). Values of major fluxes are given in Table 1.3. Mass units: 1 mol C = 12.011 g C or 1×10^{16} mol C = 120 Gt C.

The current global C cycle, reservoirs and fluxes in units of 10^{15}g C (and yr^{-1})

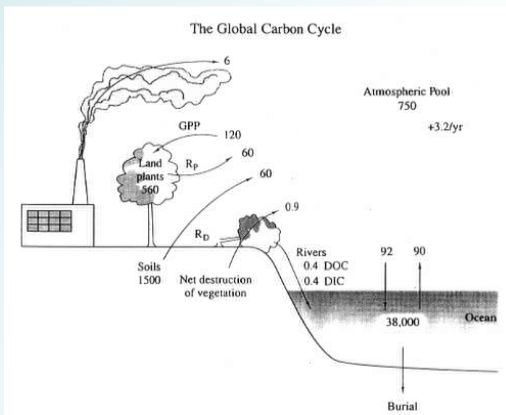


Figure 11.1 The present-day global carbon cycle. All pools are expressed in units of 10^{15} g C and all annual fluxes in units of 10^{15} g C/yr, averaged for the 1980s. Most of the values are from Schimel et al. (1995); others are derived in the text.

Oceanic reservoirs

Listed in order of size:	**g C**
Carbonate sediments	**6.53×10^{22}**
Organic matter in seds	**1.25×10^{22}**
DIC in Ocean	**3.74×10^{19}**
DOC in oceans	**1.00×10^{18}**
Ocean biota	**3.00×10^{15}**

Carbonate sediments in the oceans are the largest reservoir
larger than organic matter reservoir by ~ 4:1
Ocean water is next largest reservoir
Inorganic (DIC) is ~40 x organic ocean reservoir

Land and atmospheric reservoirs

Listed in order of size :

$CaCO_3$ in soils	**7.2×10^{17}**
Land biota	**7.0×10^{17}**
Soil organic matter	**2.5×10^{17}**
Atmosphere CO_2	**6.0×10^{17}**

Soils are next largest reservoir
Living biotic reservoir is ~same as inorganic reservoir
Dead organic matter is 1/3 of the inorganic reservoir
Phytomass ~100 x bacteria and animal reservoirs
Atmosphere is the smallest reservoir, similar to size of all living biomass

The organic C cycle

Transfers between organic reservoirs (on land and in the oceans) can occur on short time scales

Buried reservoirs of organic carbon are large relative to atmosphere

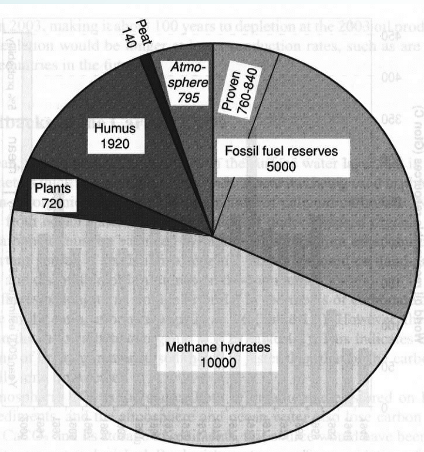


Figure 1.5 Carbon content (gigatons or Gt C) of the major organic carbon reservoirs and as CO_2 in the present-day atmosphere. Fossil fuel reserves are from Kvenvolden (1988, with references to earlier sources). Proven reserves of coal, oil, and natural gas from BP (2004), allowing for variation in the carbon content of different coals. Methane hydrates in oceanic sediments are from Kvenvolden and Laronson (2001). Peat resources are from WEC (2001), and the carbon content of peat is from Shimada *et al.* (2001). Other estimates are from Table 1.3.

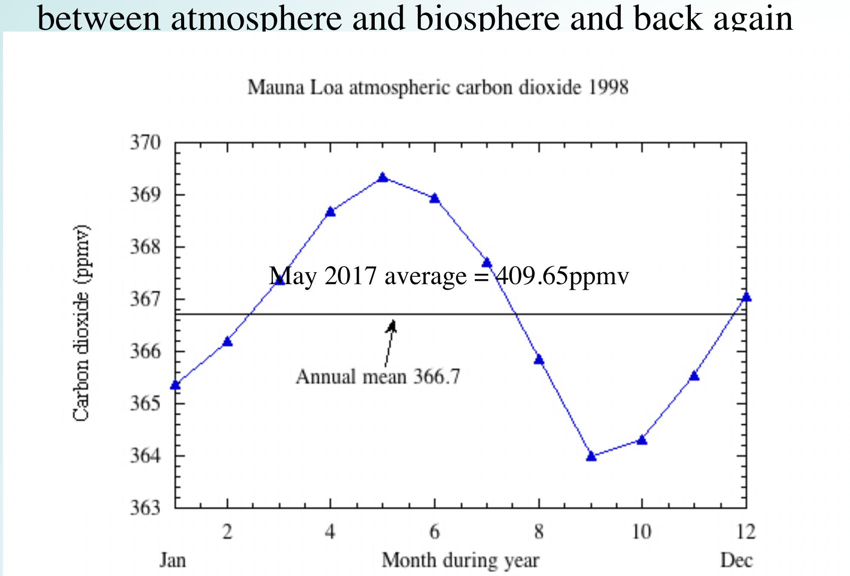
Photosynthesis and respiration

$CO_2 + 2H_2O = CH_2O + H_2O + O_2$

Photosynthesis proceeds to the right, releases oxygen to the atmosphere
Respiration proceeds to the left, consumes oxygen from the atmosphere

Both of these reactions proceed rapidly on annual cycles

Annual cycle of plant growth and death moves CO_2 between atmosphere and biosphere and back again

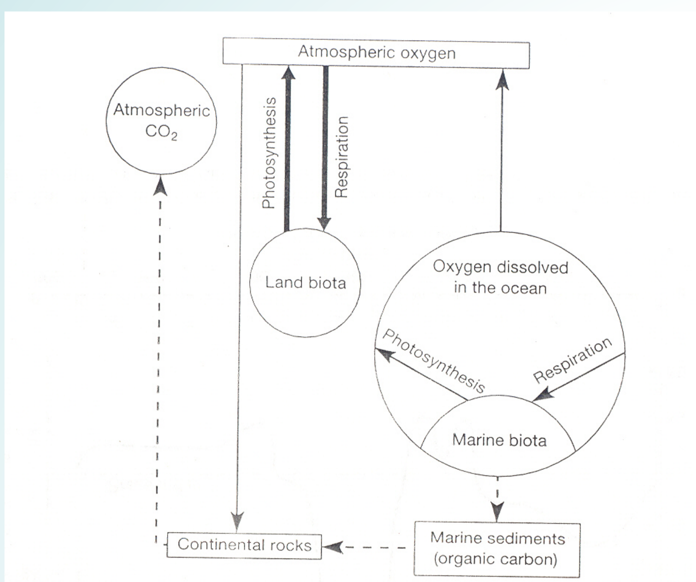


Reactions linking carbon and oxygen

$$C + O_2 = CO_2$$

Under conditions at Earth's surface this reaction proceeds to the right,
Thermodynamics favours CO_2 C and O_2 --lots of Gibbs free energy
But kinetics are slow, activation energy is needed to promote the reaction
The oxidation of carbon is what is happening during the burning of fossil fuels or forest fires

Organic C burial links CO_2 to atmospheric O_2 cycle



The rock cycle

Carbonate and silicate rock cycle

Weathering on land

$CaCO_3 + CO_2 + H_2O = Ca^{2+} + 2HCO_3^-$
$CaSiO_3 + 2CO_2 + 3H_2O = Ca^{2+} + 2HCO_3^- + H_4SIO_4$
Uptake of atmospheric CO_2 during weathering on land, delivery of dissolved form to oceans

Deposition in the oceans

$Ca^{2+} + 2HCO_3^- = CaCO_3 + CO_2 + H_2O$
$H_4SiO_4 = SiO_2 + 2H_2O$
Release of CO_2 during carbonate precipitation

Metamorphic reactions

$CaCO_3 + SiO_2 = CaSiO_3 + CO_2$
Release of CO_2 return to atmosphere via volcanic/hydrothermal activity

$CaCO_3$ weathering on land and reprecipitation in ocean has no net effect on atmospheric CO_2

Weathering of silicates on land and reprecipitation in ocean results in net uptake of atmospheric CO_2

Balance of weathering types affects atmospheric CO_2

Subduction of sediments and volcanic activity returns CO_2 to atmosphere

If no recycling, weathering would remove all CO_2 from atmosphere in ~ 1 million years

Residence time of CO_2 in atmosphere relative to weathering and volcanic input is ~ 6,000 years, i.e. is a long term control

Does not control decadal to century scale changes seen in modern C cycle

Geological history of the C cycle

Long term changes in atmospheric CO_2 driven by rock cycle and biological cycle

Initial high levels of atmospheric CO_2--“Weak” sun

Silicate weathering and carbonate precipitation in ocean reduced atmospheric CO_2 levels

Evolution of life ~3.9 Ga sequestered organic C

Leads to production of oxygen

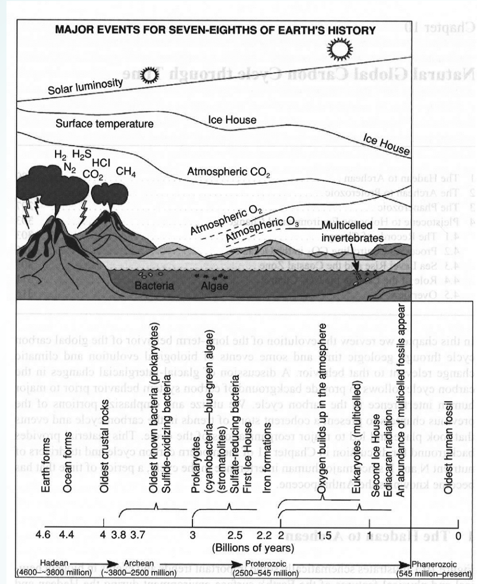


Figure 10.1 Some important atmosphere, ocean and biological trends and events in the history of Earth's surface environment during seven-eighths of geologic time. As free O_2 accumulated in the atmosphere, ozone (O_3) built up in the stratosphere and organisms became less exposed to intense solar ultraviolet radiation (modified from Broecker 1985). Geologic time scale is given in Figs. 1.1 and 7.1.

Initial production of O_2 “used up” by oxidation of Fe in seawater
Terrestrial weathering also consumed early O_2 production
Multi-cellular organisms appear as O_2 levels in atmosphere increase

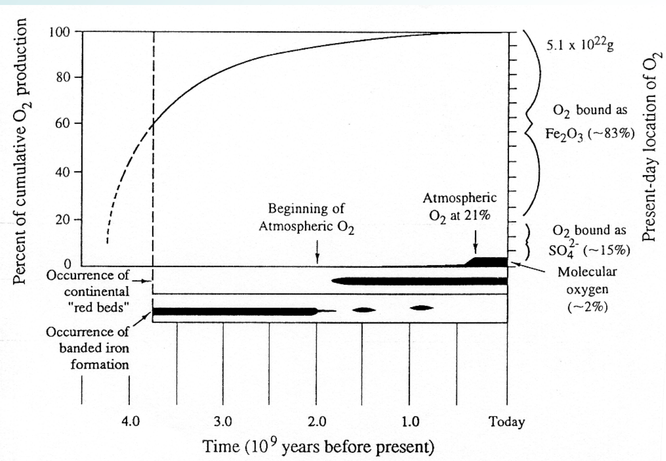
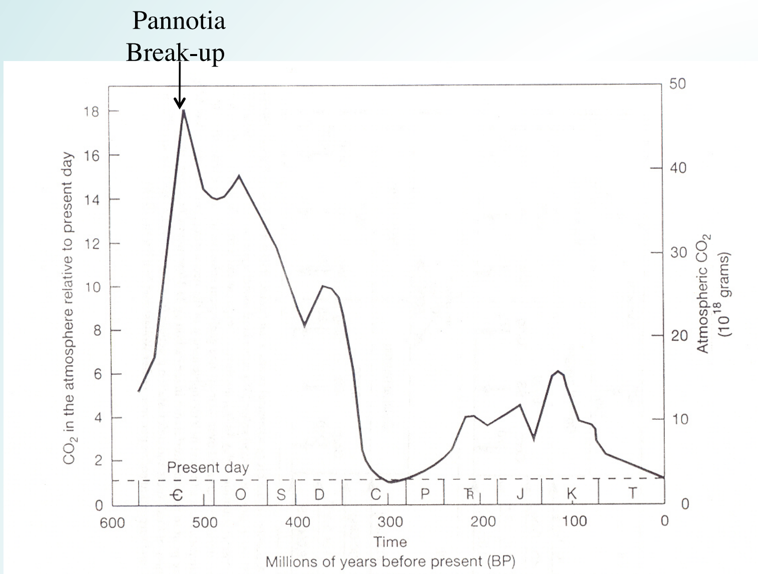
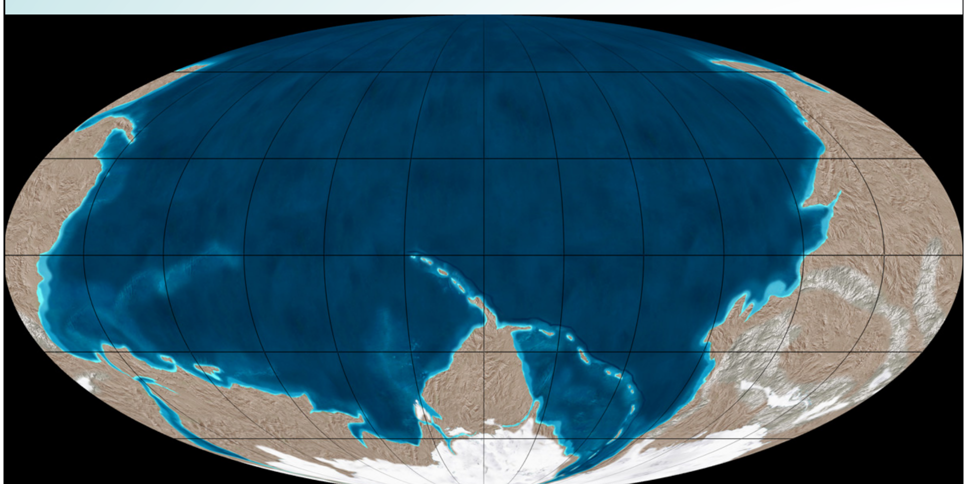


Figure 2.7 Cumulative history of O_2 released by photosynthesis through geologic time. Of more than 5.1×10^{22} g of O_2 released, about 98% is contained in seawater and sedimentary rocks, beginning with the occurrence of Banded Iron Formations at least 3.5 billion years ago (bya). Although O_2 was released to the atmosphere beginning about 2.0 bya, it was consumed in terrestrial weathering processes to form Red Beds, so that the accumulation of O_2 to present levels in the atmosphere was delayed to 400 mya. Modified from Schidlowski (1980).

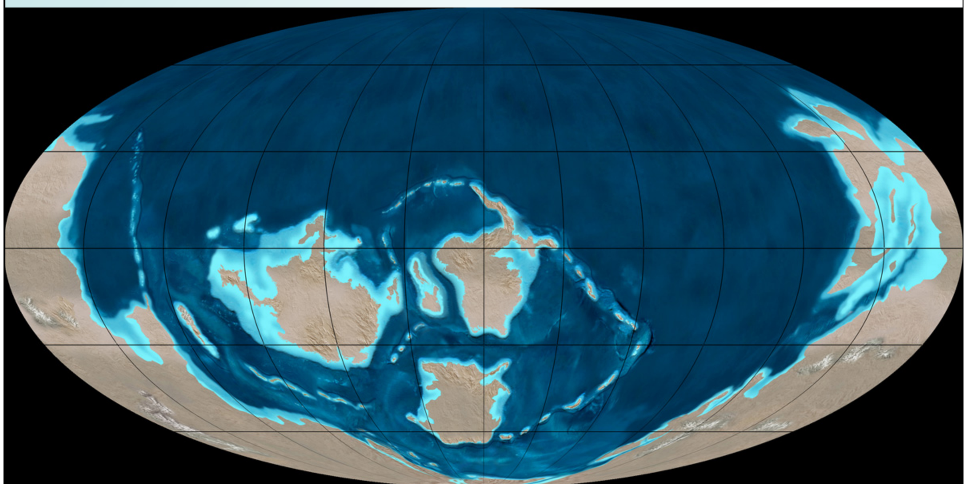
Phanerozoic C cycle
Increase in tectonic activity increases sea level



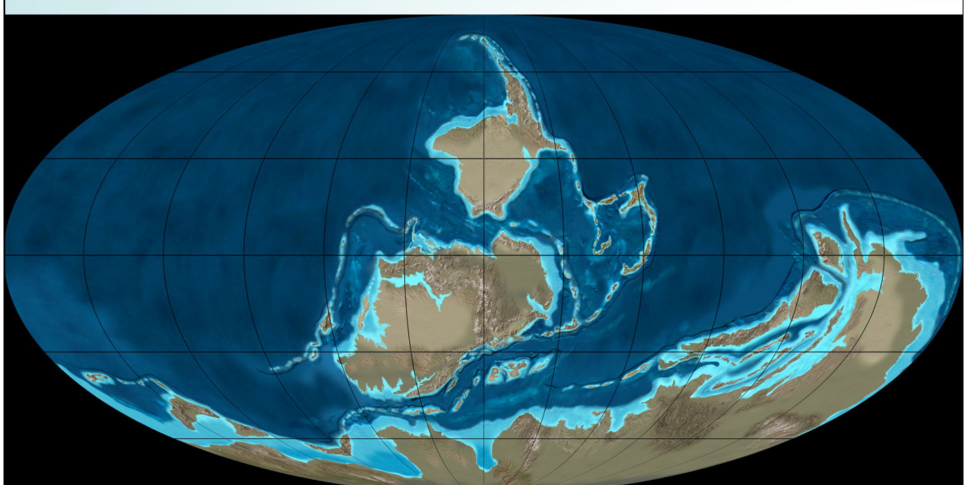
600 mya



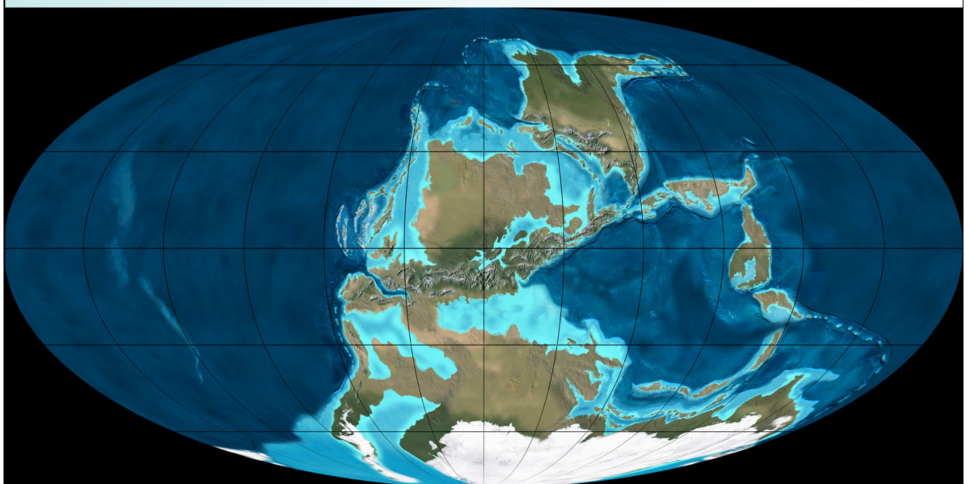
500 mya



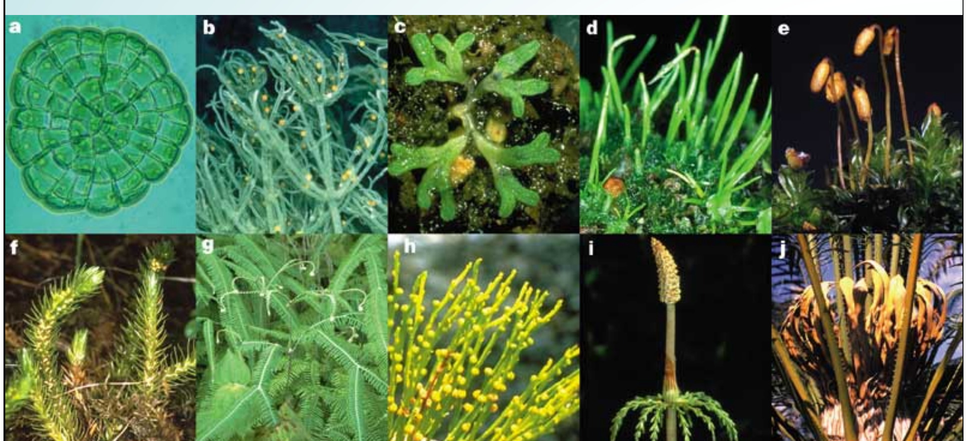
400 mya



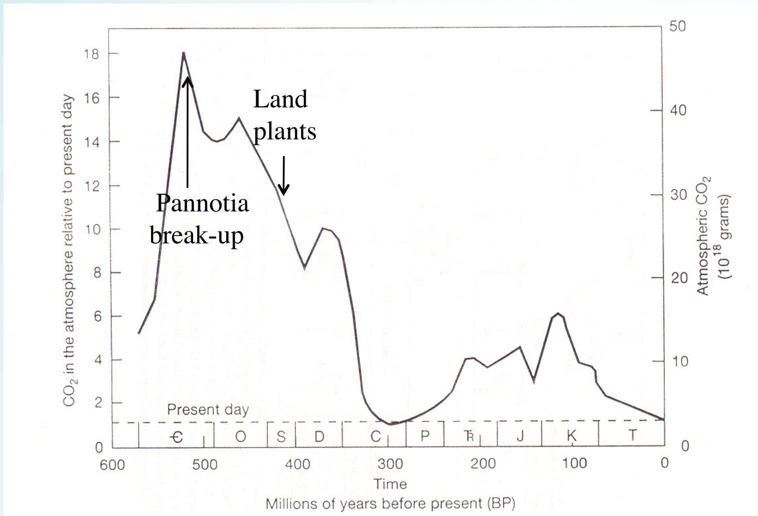
300 mya



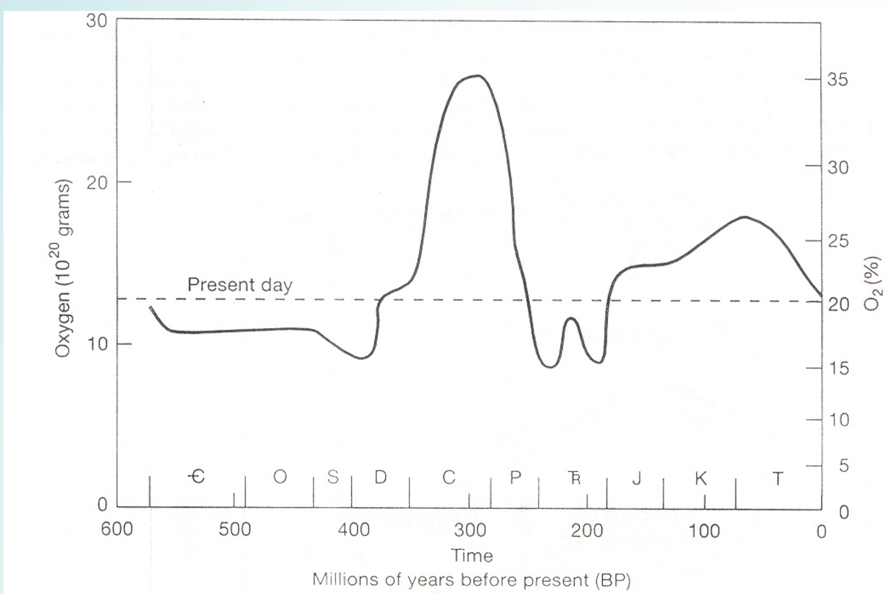
Phanerozoic C cycle
Sea level increase leads to evolution of land plants



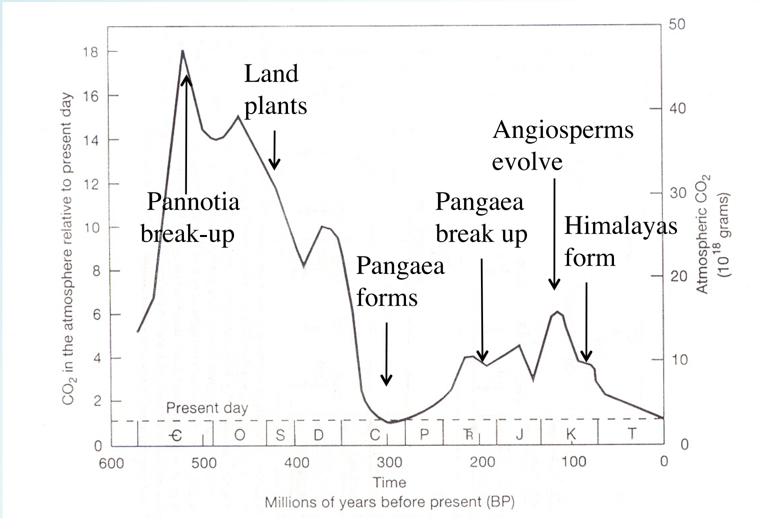
C storage 400-500 Ma 30 x 10^{12} moles C buried in sediments yr^{-1} releases oxygen to atmosphere



O_2 levels in atmosphere track maximum burial of organic C ~ 350 Ma
Microbial processes then pull down O_2 levels as oxidise organic C

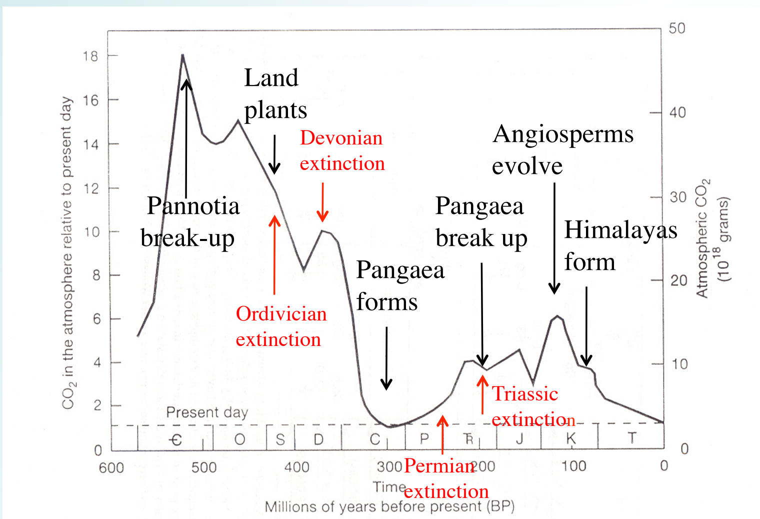


Pangaea forms then breaks up leading to an increase in tectonic activity



Evolution of angiosperms ~ 150 Ma

Deeper roots increase Si weathering rates, leads to drop in atmos CO_2



Phanerozoic C cycle

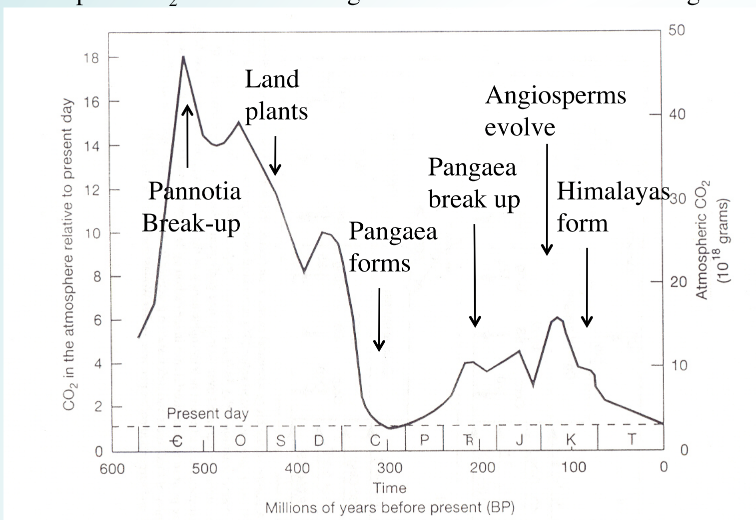
Driven by evolution of land plants - C storage 400-500 Ma

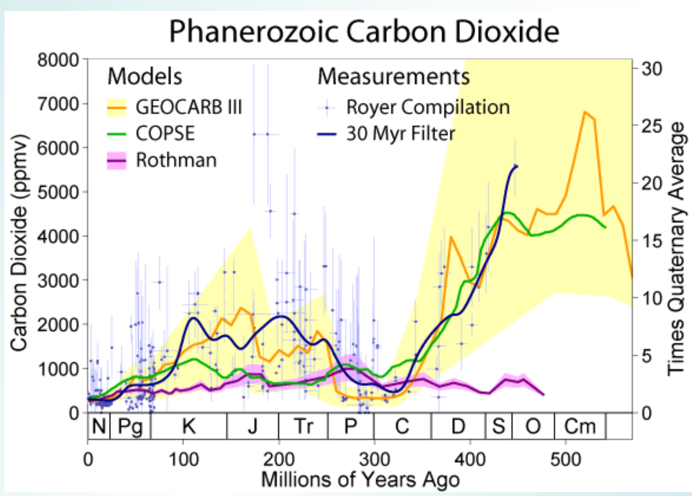
30 x 10^{12} moles C buried in sediments yr^{-1} releases oxygen to atmosphere

Atmos. reservoir O_2 38 x 10^{18} moles, T_r = 1 x 10^6 yrs wrt sedimentary C

Uplift of rocks and weathering of kerogen balances process

Atmospheric O_2 is balance of organic C burial and its weathering





from wikipedia.org