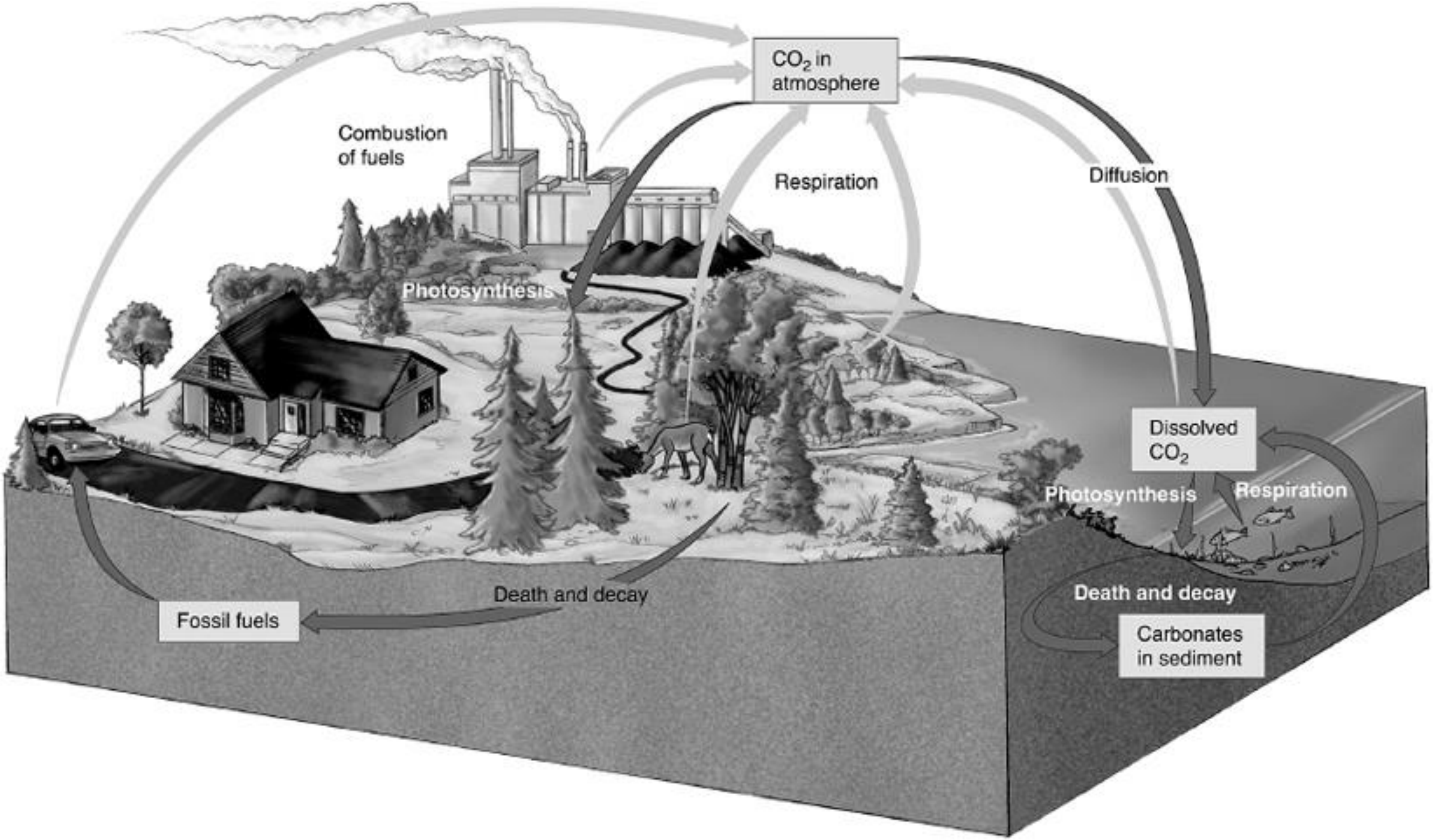
Recap

- ✓ Different layers of atmosphere
  - Thermosphere or Ionosphere
- ✓ Ecosystems
  - Producers
  - Consumers
    - Different types
- ✓ Food chains and Tropic levels
- ✓ Carbon cycle

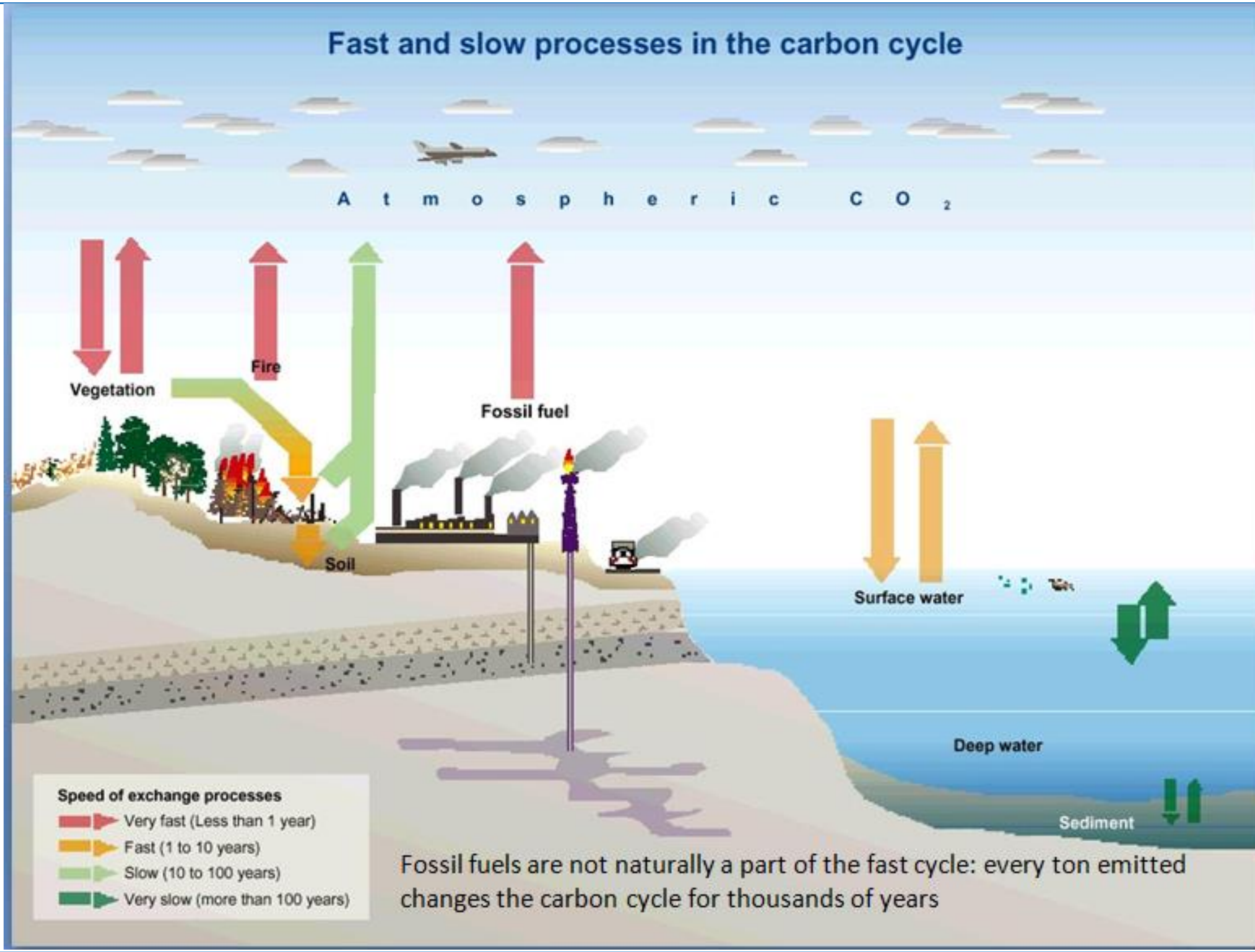
Carbon Cycle

- ✓ Carbon is exchanged between the active pools due to various processes –
  - photosynthesis
  - respiration between the land and the atmosphere
  - diffusion between the ocean and the atmosphere

Carbon Cycle



Carbon Cycle



Fossil fuels are not naturally a part of the fast cycle: every ton emitted changes the carbon cycle for thousands of years

Carbon Pools

✓ Carbon is stored on our planet in the following major pools:

- as organic molecules in living and dead organisms found in the biosphere;
- as the gas carbon dioxide in the atmosphere;
- as organic matter in soils;
- in the lithosphere as fossil fuels and sedimentary rock deposits such as limestone ($CaCO_3$) , dolomite ($CaMg(CO_3)_2$) and chalk;
- in the oceans as dissolved atmospheric carbon dioxide and as $CaCO_3$ shells in marine organisms.

Pool	Amount in Billions of Metric Tons
Atmosphere	578 (as of 1700) - 766 (as of 1999)
Terrestrial Plants	540 to 610
Soil Organic matter	1500 to 1600
Ocean	38,000 to 40,000
Fossil Fuel Deposits	4000
Marine Sediments and Sedimentary Rocks	66,000,000 to 100,000,000

Carbon Cycle

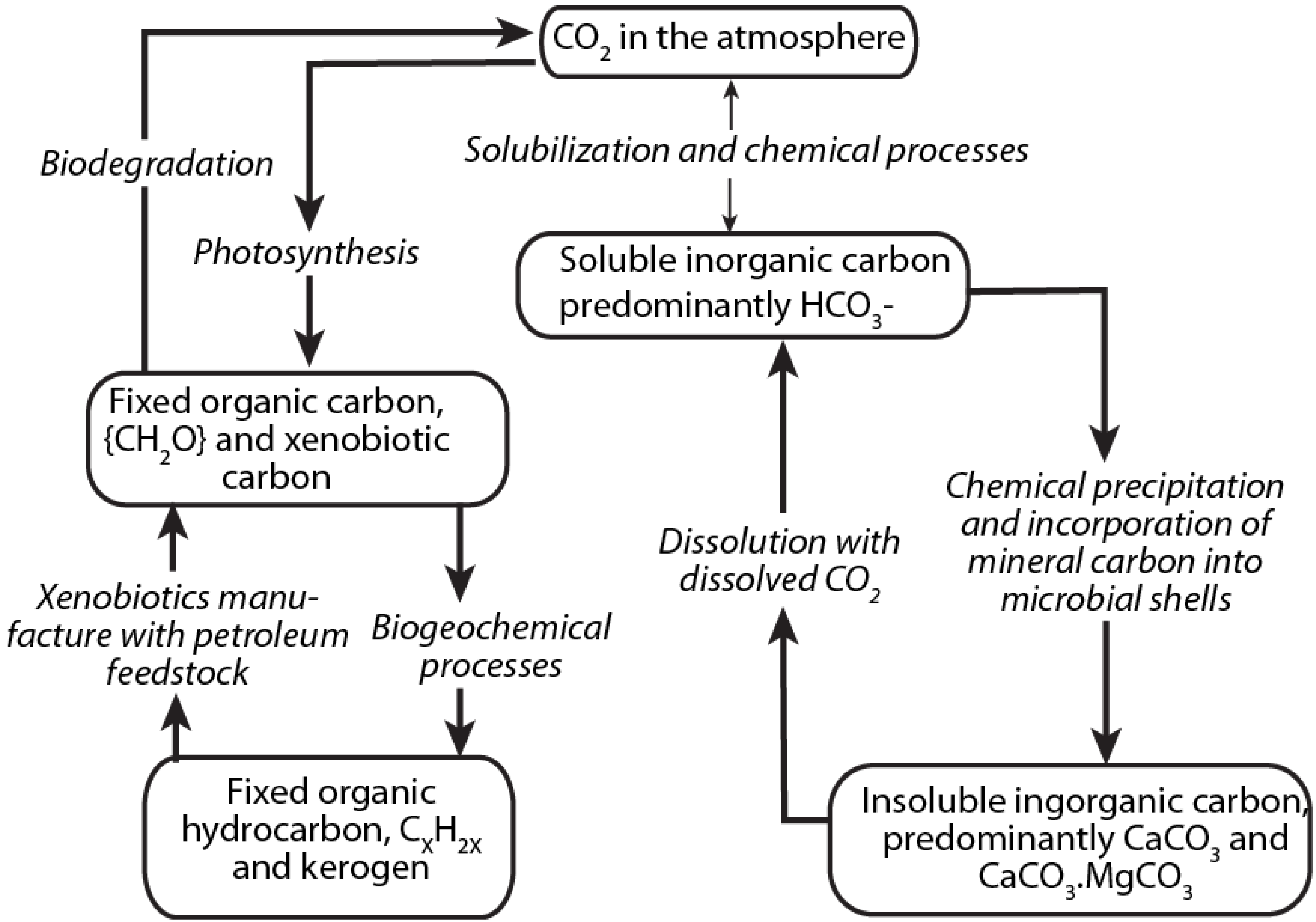
- ✓ Microorganisms are strongly involved in the carbon cycle, mediating crucial biochemical reactions discussed later in this section.

- ✓ Photosynthetic algae are the predominant carbon-fixing organisms in water; as they consume CO_2, the pH of the water is raised enabling precipitation of $CaCO_3$ and $CaCO_3$, $MgCO_3$.

- ✓ Organic carbon fixed by microorganisms is transformed by biogeochemical processes to fossil petroleum, kerosene, coal, and lignite.

- ✓ Microorganisms degrade organic carbon from biomass, petroleum, and xenobiotic sources, ultimately returning it to the atmosphere as CO_2.

Carbon Cycle



Carbon Cycle

✓ Photosynthesis in which algae, higher plants, and photosynthetic bacteria use light energy to fix inorganic carbon in a high-energy organic form

$$\underset{}{\text{Solar energy}} + \underset{\text{carbon dioxide}}{6\,CO_2} + \underset{\text{water}}{6\,H_2O} \xrightarrow{\text{chlorophyll}} \underset{\text{glucose}}{C_6H_{12}O_6} + \underset{\text{oxygen}}{6\,O_2}$$

✓ Respiration in which organic matter is oxidized in the presence of molecular O_2 (aerobic respiration) or anaerobic respiration, which uses oxidants other than O_2, such as NO_3^- or SO_4^{2-}

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

✓ Degradation of biomass by bacteria and fungi.

- Biodegradation of dead organic matter leads in the accumulation of excess waste residue and converts organic carbon, nitrogen, sulfur, and phosphorus to simple organic forms that can be utilized by plants.

Carbon Cycle

- ✓ Biodegradation of organic matter occurs in treatment of municipal wastewater by reactions represented in a general sense by,

$$\{CH_2O\} + O_2(g) \rightarrow CO_2 + H_2O + \text{biomass}$$

- ✓ Methane production by methane-forming bacteria, such as Methanobacterium, in anoxic (oxygen-less) sediments, plays a key role in local and global carbon cycles as the final step in the anaerobic decomposition of organic matter. It is the source of about 80% of the methane entering the atmosphere.

$$2\{CH_2O\} \rightarrow CH_4 + CO_2$$

- ✓ Microbial methane production is a fermentation reaction, defined as an oxidation-reduction process in which both the oxidizing agent and reducing agent are organic substances.

Carbon Cycle

- ✓ Bacterial utilization and degradation of hydrocarbons.
  - The oxidation of higher hydrocarbons under aerobic conditions by **Micrococcus, Pseudomonas, Mycobacterium**, and **Nocardia** is an important environmental process by which petroleum wastes are eliminated from water and soil.
- ✓ The initial step in the microbial oxidation of alkanes is conversion of a terminal $-CH_3$ group to a $-CO_2$ group followed by β–oxidation

$$CH_3(CH_2)_3CH_2O_2H + 3O_2 \rightarrow CH_3CH_2CH_2O_2H + 2CO_2 + 2H_2O$$

Carbon Cycle

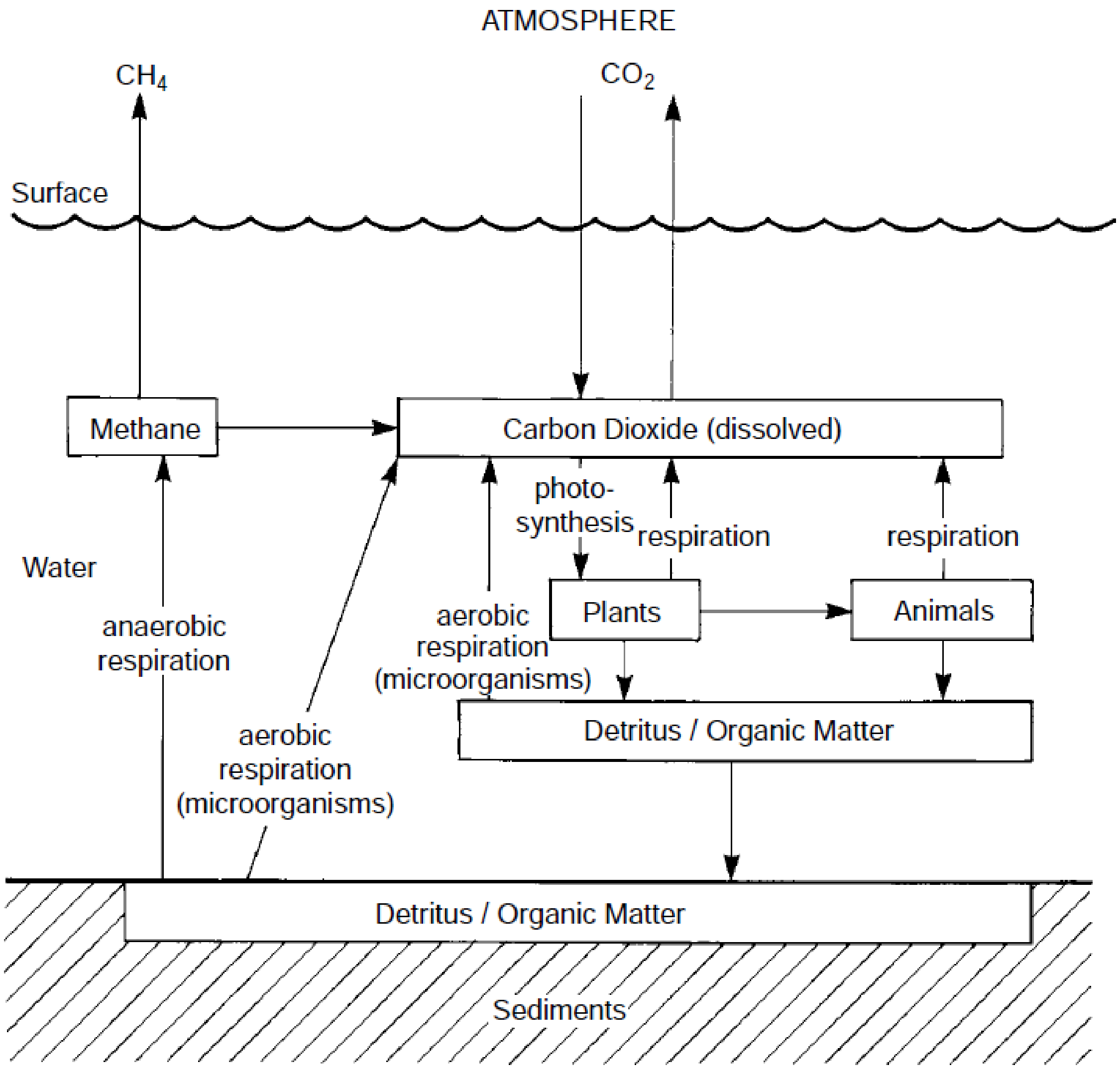


FIGURE 13.9 Transformations of carbon in aquatic systems.

Nitrogen Cycle

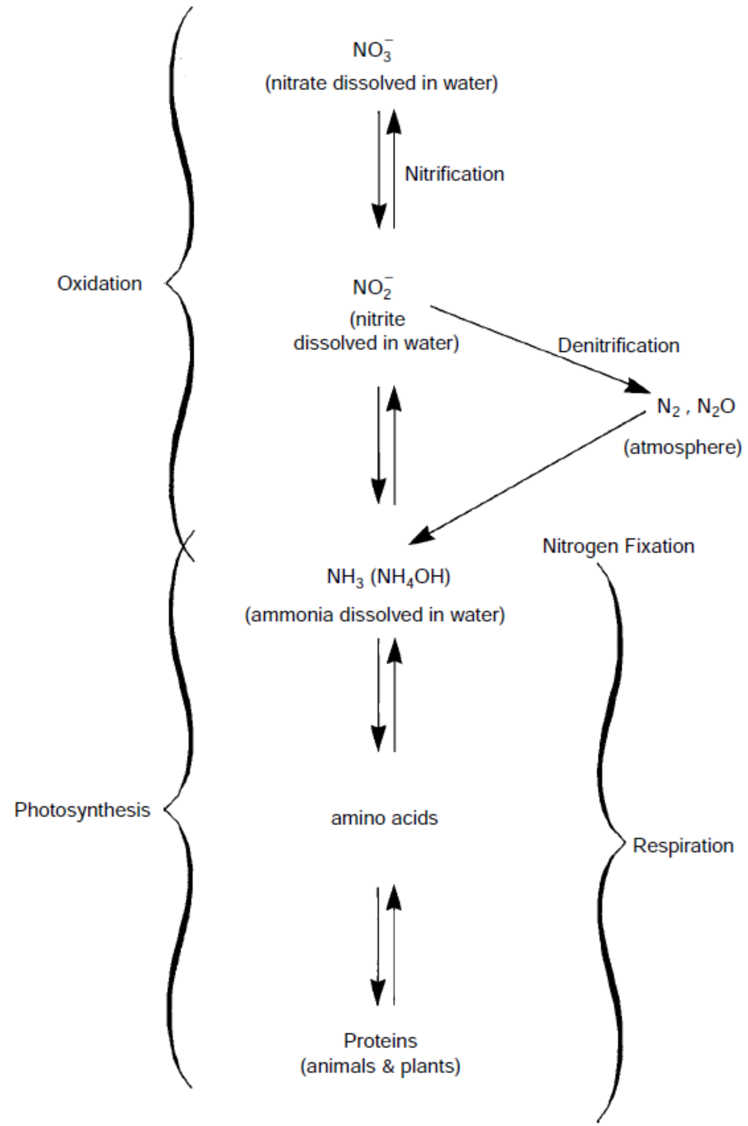


FIGURE 13.10 Transformation of nitrogen in an aquatic system.

- ✓ Carbon cycle
- ✓ Nitrogen cycle
- ✓ S and P-cycles – self-study

Sustainability

- ✓ The ability to be maintained at a certain rate or level.
  - avoidance of the depletion of natural resources in order to maintain an ecological balance.

- ✓ Richard Heinberg proposes that we become a more sustainable society by understanding the five axioms of **sustainability.**

- ✓ **Axiom 1**. Any Society that Continues to Use Critical Resources Unsustainably will Collapse
  - Who doesn’t limit the consumption of essential resources like Water, Essential plant nutrients and Energy will eventually collapse

https://www.google.co.in/search?client=opera&q=Sustainability&sourceid=opera&ie=UTF-8&oe=UTF-8

Sustainability

- ✓ **Axiom 2**. Population Growth and/or Growth in the Rates of Consumption of Resources Cannot Be Sustained

- ✓ **Axiom 3**. To Be Sustainable, the Use of Renewable Resources Must Proceed at a Rate that Is Less Than or Equal to the Rate of Natural Replenishment

- ✓ **Axiom 4**. To Be Sustainable, the Use of Nonrenewable Resources Must Proceed at a Rate that Is Declining, and the Rate of Decline Must Be Greater than or Equal to the Rate of Depletion

- ✓ **Axiom 5**. Sustainability Requires that Substances Introduced into the Environment from Human Activities Be Minimized and Rendered Harmless to Biosphere Functions

Sustainability

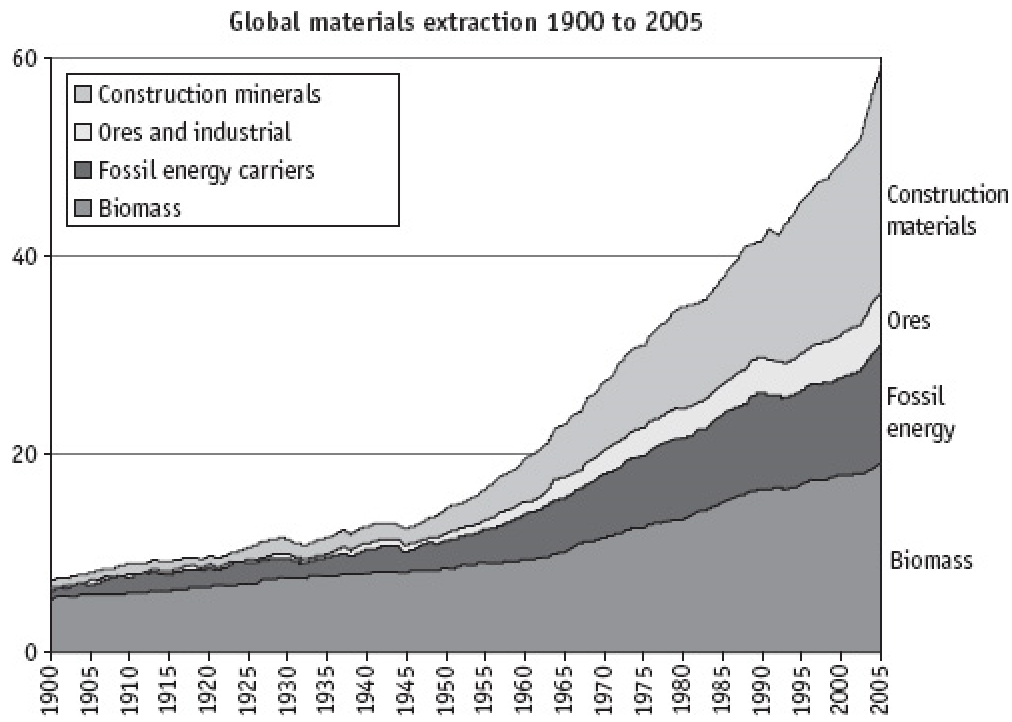


Figure 16.2 Global material extraction remained fairly constant from 1900 to 1950. Beginning in 1950, the rate of extraction increased. In 1990, the rate increased even more. Reproduced F. Krausman, et al., Growth in global materials use, DDP and polulation during the 20th century. Ecological Economics 2009: 68, 2696–2705.

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https://www.google.co.in/search?client=opera&q=Sustainability&sourceid=opera&ie=UTF-8&oe=UTF-8

Sustainability

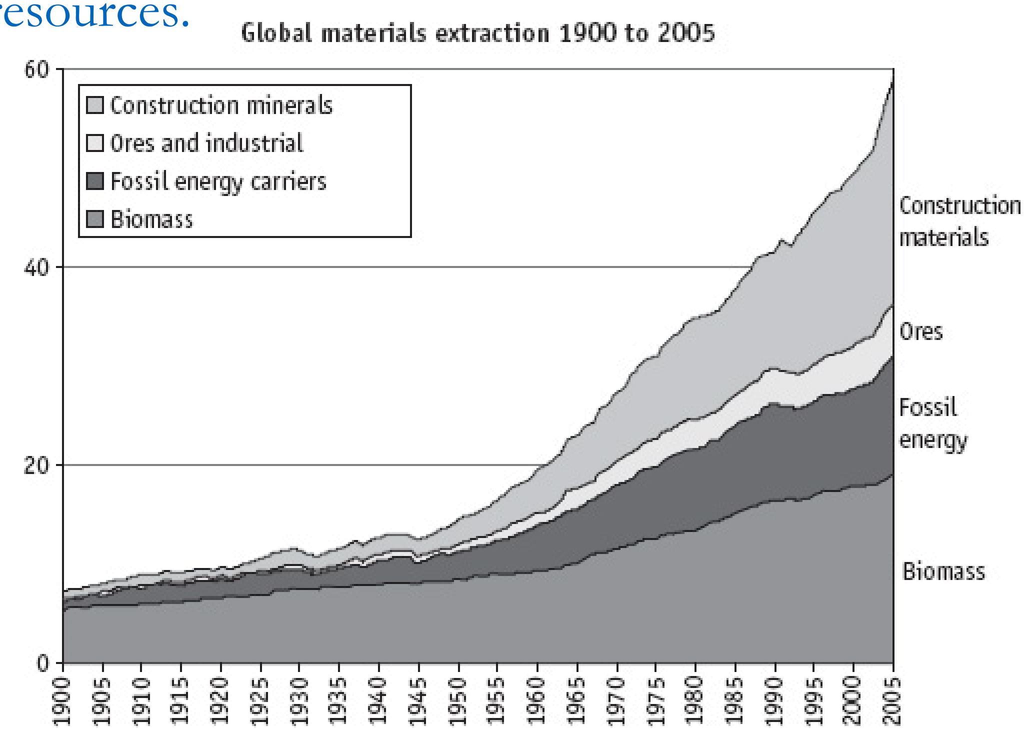
- ✓ **Axiom 2**. Population Growth and/or Growth in the Rates of Consumption of Resources Cannot Be Sustained
  - 1% rate of growth in the present human population would result in a doubling of the population every 70 years
  - Means, by 2080 earth would have 14 billion population
  - Amount of arable land, quantity of non-renewable resources and the quantity of water are fixed
- ✓ **Axiom 3**. To Be Sustainable, the Use of Renewable Resources Must Proceed at a Rate that Is Less Than or Equal to the Rate of Natural Replenishment
  - Each renewable resource has a “rate of natural replenishment”
  - Harvesting of a renewable resource at a rate greater than that of its natural replenishment will lead to the exhaustion of this resource
  - Goal: To ensure that the rate of harvest is below the rate of natural replenishment
  - Overcutting of forests produce barren areas, but leads to the shortage of wood and O_2
  - Overfishing serves the demand of food but causes extinction of some aquatic species.

Sustainability

- ✓ **Axiom 4**. To Be Sustainable, the Use of Nonrenewable Resources Must Proceed at a Rate that Is Declining, and the Rate of Decline Must Be Greater than or Equal to the Rate of Depletion
  - **Rate of depletion** is defined as the amount of being extracted and used during a specified time interval (usually a year) as % of the total known amount
  - Cu-water pipes were replaced with pipes made of something else, the need for Cu would be reduced
  - Cu is a non-renewable resource and a finite quantity exists, reducing the demand for Cu would therefore reduce the rate of depletion (rate of extracting Cu from the earth)

Sustainability

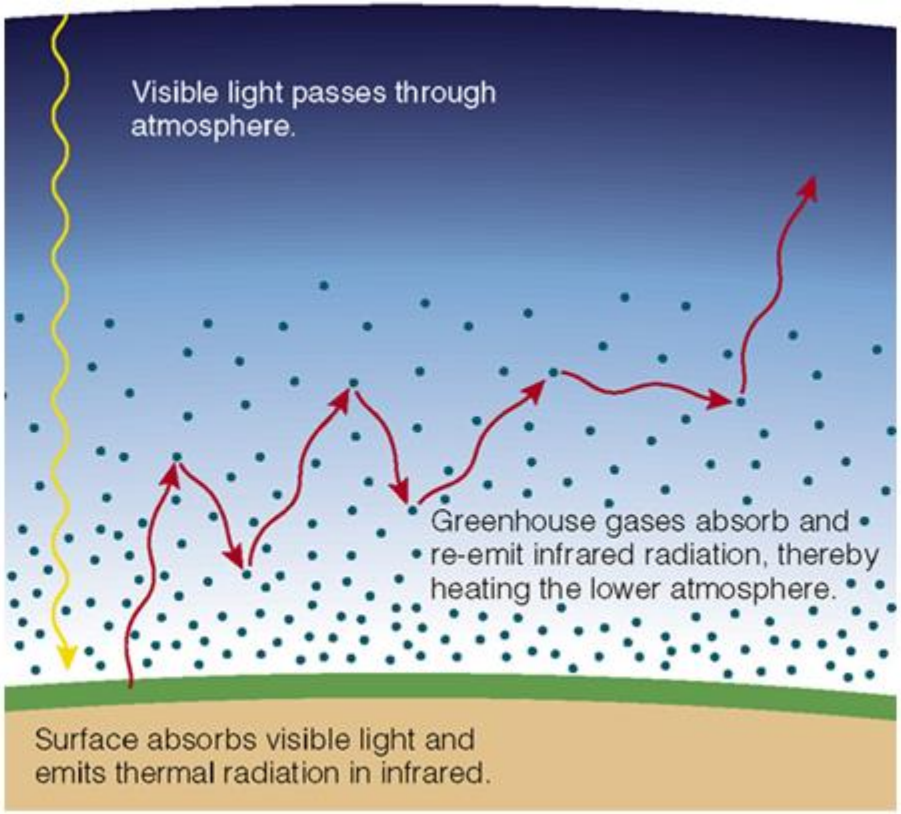
- ✓ **Axiom 5**. Sustainability Requires that Substances Introduced into the Environment from Human Activities Be Minimized and Rendered Harmless to Biosphere Functions
  - o Modern world rise from the extraction processing, & consumption of nonrenewable resources.



Global material extraction remained fairly constant from 1900 to 1950. Beginning in 1950, the rate of extraction increased. In 1990, the rate increased even more. Reproduced F. Krausman, et al., Growth in global materials use, DDP and polulation during the 20th century. Ecological Economics 2009: 68, 2696–2705.

Global warming

- ✓ Earth's atmosphere is slightly warmer than what it should be due to direct solar heating because of a mild case of greenhouse effect…
- ✓ The ground is heated by visible and (some) infrared light from the Sun.
- ✓ The heated surface emits infrared light.
- ✓ The small amount of greenhouse gases (H_2O, CO_2) traps (absorb and re-emit) the infrared radiation, increasing the temperature of the atmosphere…



Greenhouse Gases

- ✓ The primary components of Earth's atmosphere, N_2 and O_2 do not have absorption in the IR wavelength range, therefore, do not have a significant role in setting the surface temperature of the planet…

- ✓ Greenhouse gas are efficient in absorbing IR light … The most important greenhouse gases are:
  - H_2O – Water vapor.
  - CO_2 – Carbon dioxide
  - CH_4 – methane

- ✓ The most abundant greenhouse gas in Earth's atmosphere is water vapor.

- ✓ Most of the greenhouse heating of Earth's atmosphere is due to Water vapor absorption of IR radiation emitted by Earth, and then transferring the energy to the surrounding air molecule

The Atmosphere of Earth

- ✓ The atmosphere of Earth contains primarily N_2 (77%) and O_2 (21%).
- ✓ What happened to all the CO_2 ?
- ✓ Where did all the O_2 come from?

World	Composition	Surface Pressure*	Winds, Weather Patterns	Clouds, Haze
Mercury	helium, sodium, oxygen	10^{-14} bar	None: too little atmosphere	None
Venus	96% CO_2 3.5% N_2	90 bars	Slow winds, no violent storms, acid rain	Sulfuric acid clouds
Earth	77% N_2 21% O_2 1% argon H_2O (variable)	1 bar	Winds, hurricanes	H_2O clouds, pollution
Moon	helium, sodium, argon	10^{-14} bar	None: too little atmosphere	None
Mars	95% CO_2 2.7% N_2 1.6% argon	0.007 bar	Winds, dust storms	H_2O and CO_2 clouds, dust

* 1 bar ≈ the pressure at sea level on Earth.

CO_2

- ✓ CO_2 is a colourless gas…
- ✓ condenses into solid form (dry ice) at -78°C in atmospheric pressure.
- ✓ condenses into liquid at -57°C at pressure above 5.1 atmospheric pressure.
- ✓ Atmospheric CO_2 is derived from (The sources …)
  - Volcanic outgassing
  - burning of organic matter
  - Respiration of living organisms
  - …

- ✓ CO_2 can be stored in (The Sinks …)
  - Highly soluble in water: forms H_2CO_3
  - Dissolved CO_2 in water can interact with silicate minerals to form carbonated minerals…
  - …

Carbon Dioxide Cycle

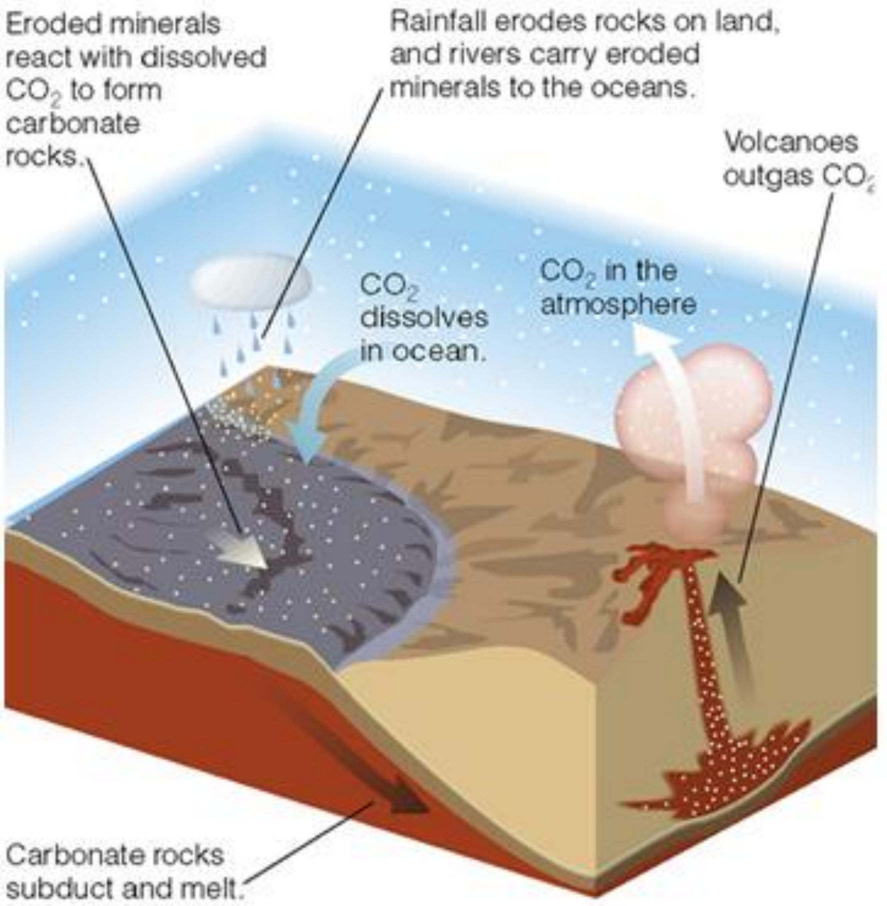
- ✓ The mechanism by which Earth self-regulates its temperature is called the **carbon dioxide cycle**.

- ✓ Starting with the carbon dioxide in the atmosphere:
  - Volcanoes outgas CO_2 into the atmosphere.
  - Atmospheric carbon dioxide dissolves in the oceans.
  - At the same time, rainfall erodes rocks on Earth's continents and rivers carry the eroded minerals to the oceans.
  - In the oceans, the eroded minerals combine with dissolved carbon dioxide and fall to the ocean floor, making carbonate rocks such as limestone.
  - Over millions of years, the conveyor belt of plate tectonics carries the carbonate rocks to subduction zones, and subduction carries them down into the mantle.
  - As they are pushed deeper into the mantle, some of the subducted carbonate rock melts and releases its carbon dioxide, which then outgasses back into the atmosphere through volcanoes.

The CO_2 Cycle

- ✓ The CO_2 cycle acts as a thermostat that regulates the temperature of the Earth…

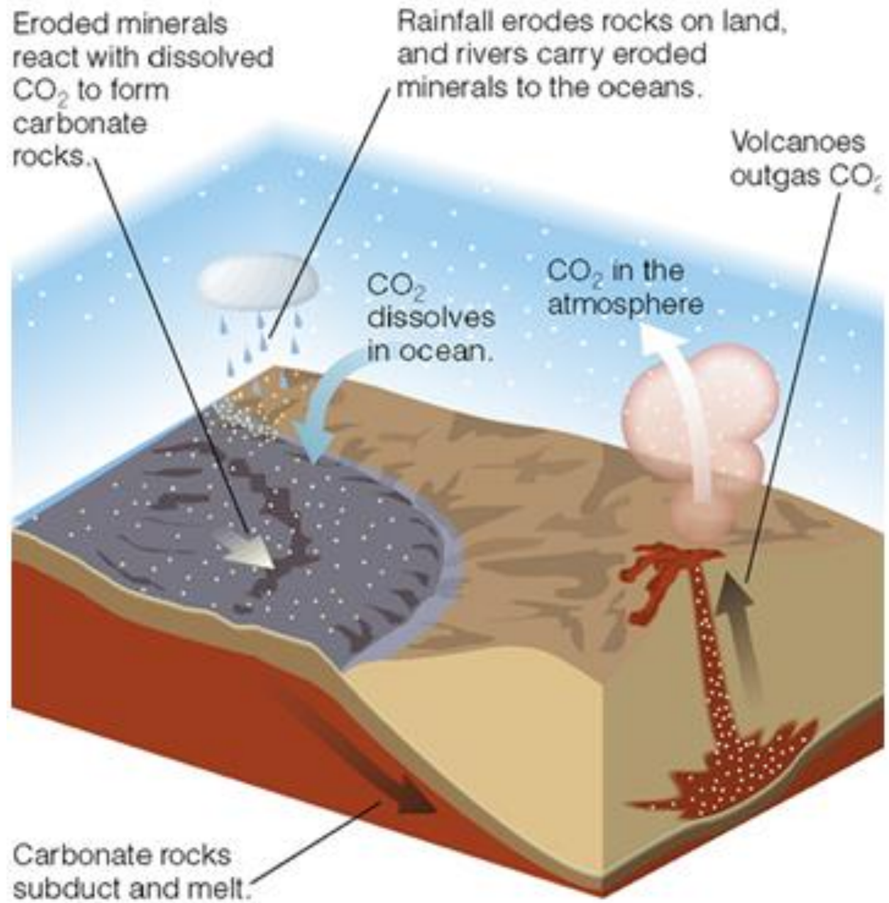
- ✓ If Earth warms up a bit, then
  - carbonate minerals form in the oceans at a higher rate.
  - The rate at which the oceans dissolve CO_2 gas increases, pulling CO_2 out of the atmosphere.
  - The reduced atmospheric CO_2 concentration leads to a weakened greenhouse effect that counteracts the initial warming and cools the planet back down.



The CO_2 Cycle

✓ If Earth cools a bit,

- carbonate minerals form more slowly in the oceans.
- The rate at which the oceans dissolve CO_2 gas decreases, allowing the CO_2 released by volcanism to build back up in the atmosphere.
- The increased CO_2 concentration strengthens the greenhouse effect and warms the planet back up



Feedback Loop

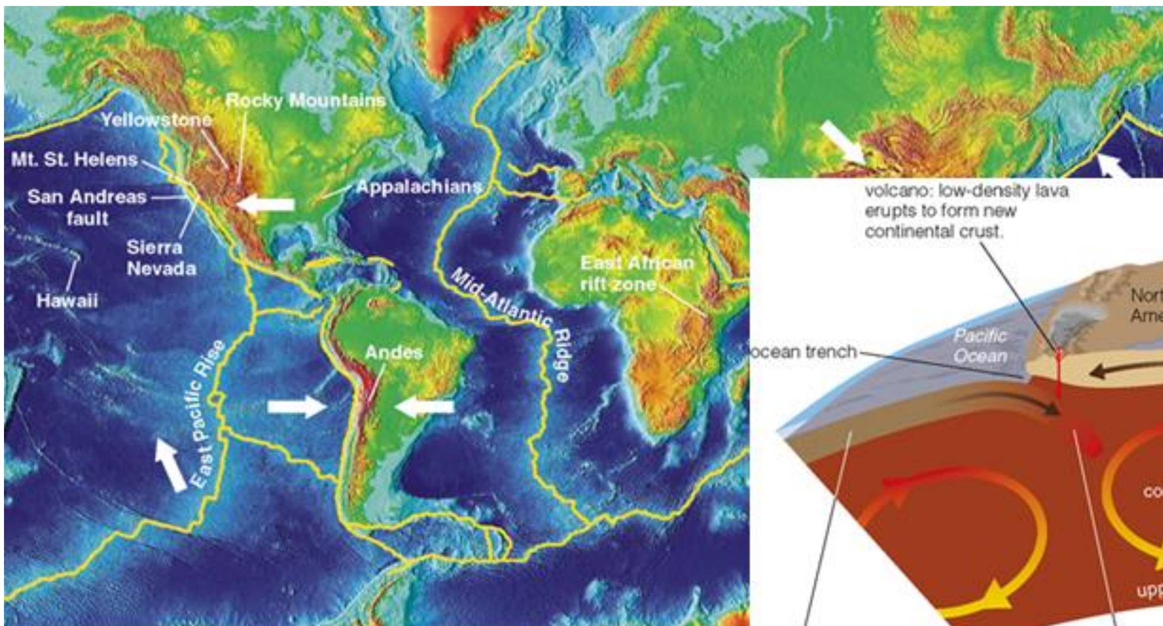
- ✓ Positive Feedback
  - Mechanisms that make things worse…
  - e.g., Increasing CO_2 in the atmosphere leads to the release of more CO_2

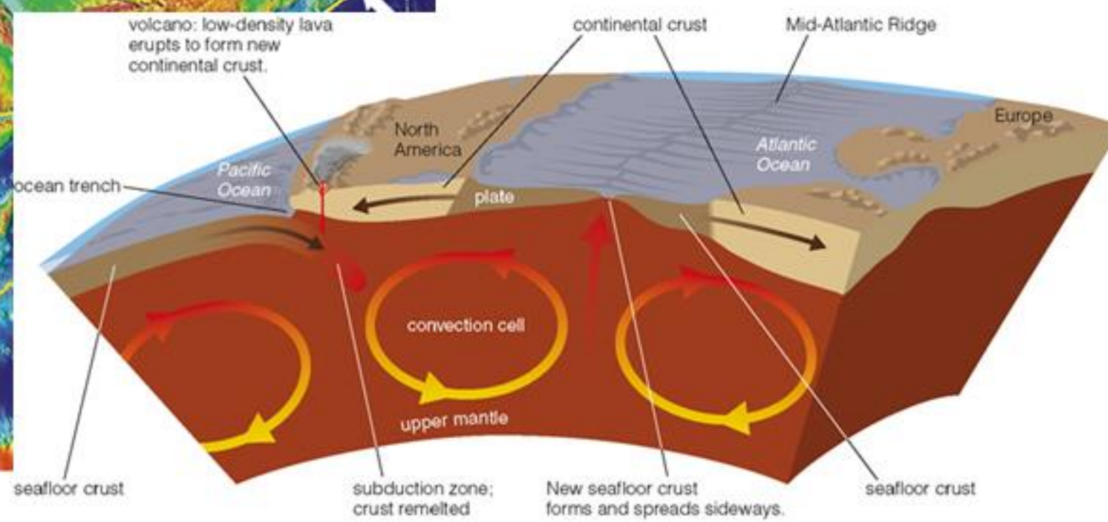
- ✓ Negative Feedback
  - Mechanisms that are self-correcting…
  - e.g., Increasing CO_2 in the atmosphere leads to higher rate of CO_2 removal, such as our CO_2 cycle.

Plate Tectonics

✓ Plate tectonics plays an important role in the CO_2 cycle in that it helps to carry the carbonate rocks into the mantle, which are then released again by volcanic activities.

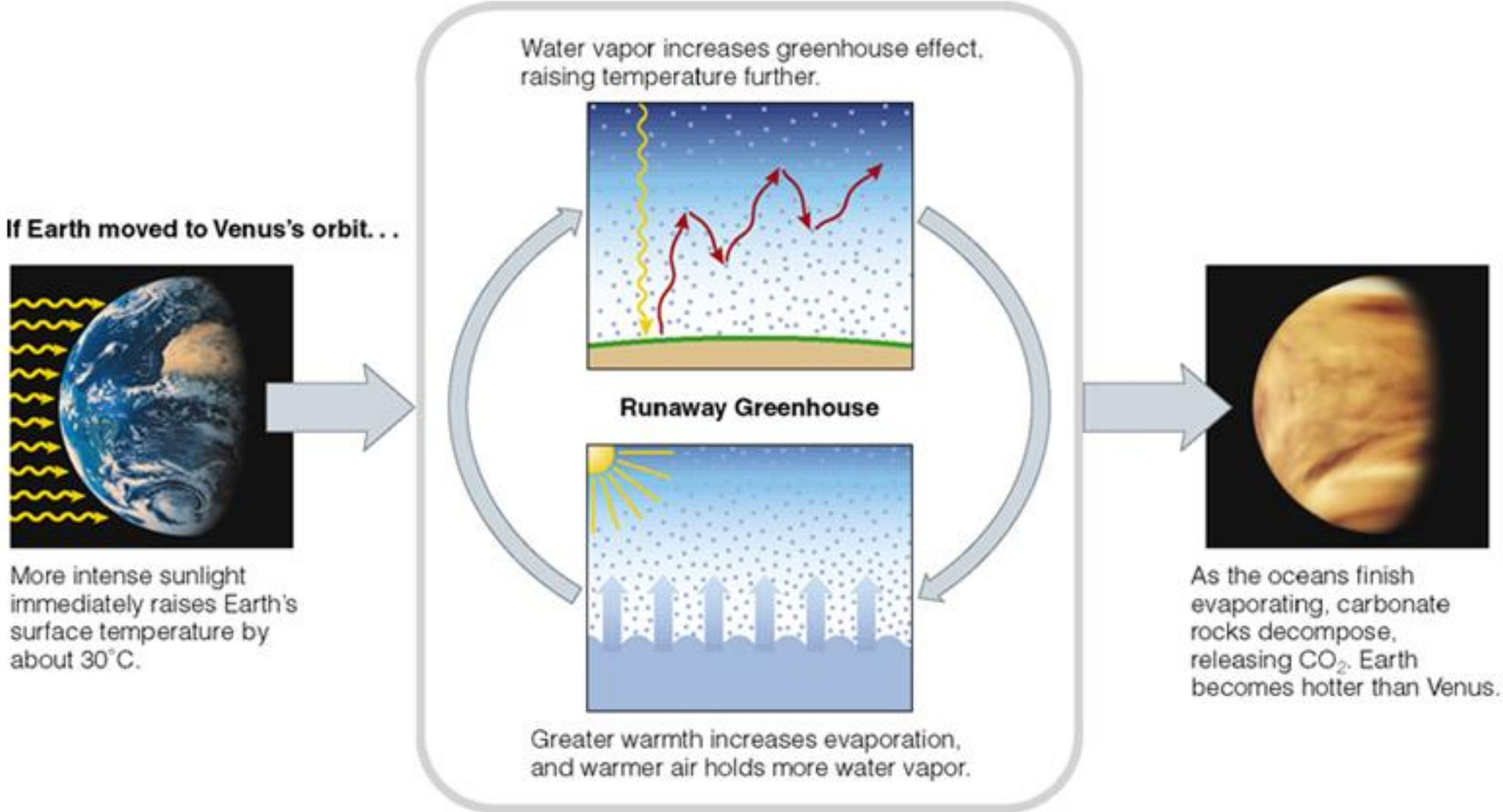
- Earth's lithosphere is broken into pieces (the plates).
- These plates float on top of the mantle, interacting with each other to produce the geological features we see and feel today.





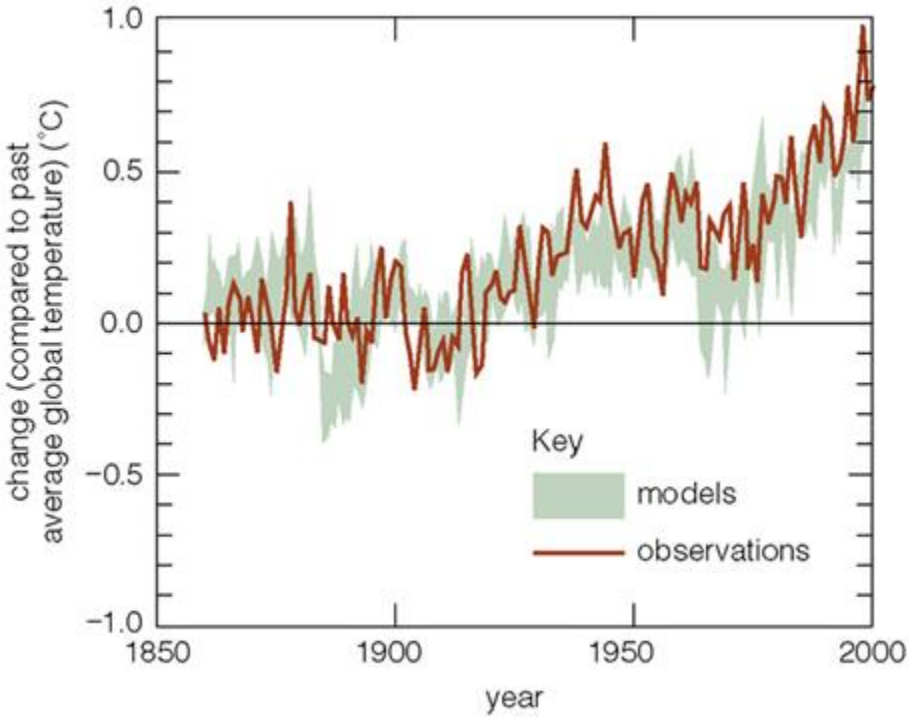
Runaway Greenhouse Effect

- ✓ If we were to move the Earth closer to the Sun, like where Venus is now, then we would suffer runaway greenhouse effect, lose all the water and will become hot like Venus.



Global Warming

- ✓ There is a gradual increase in the average temperature of the Earth's atmosphere in the last 100 years…It has risen about 1°C since 1900…
  - Are human activities causing global warming?
  - What other (non-human) factors can cause global warming?
  - How does global warming affect our life?

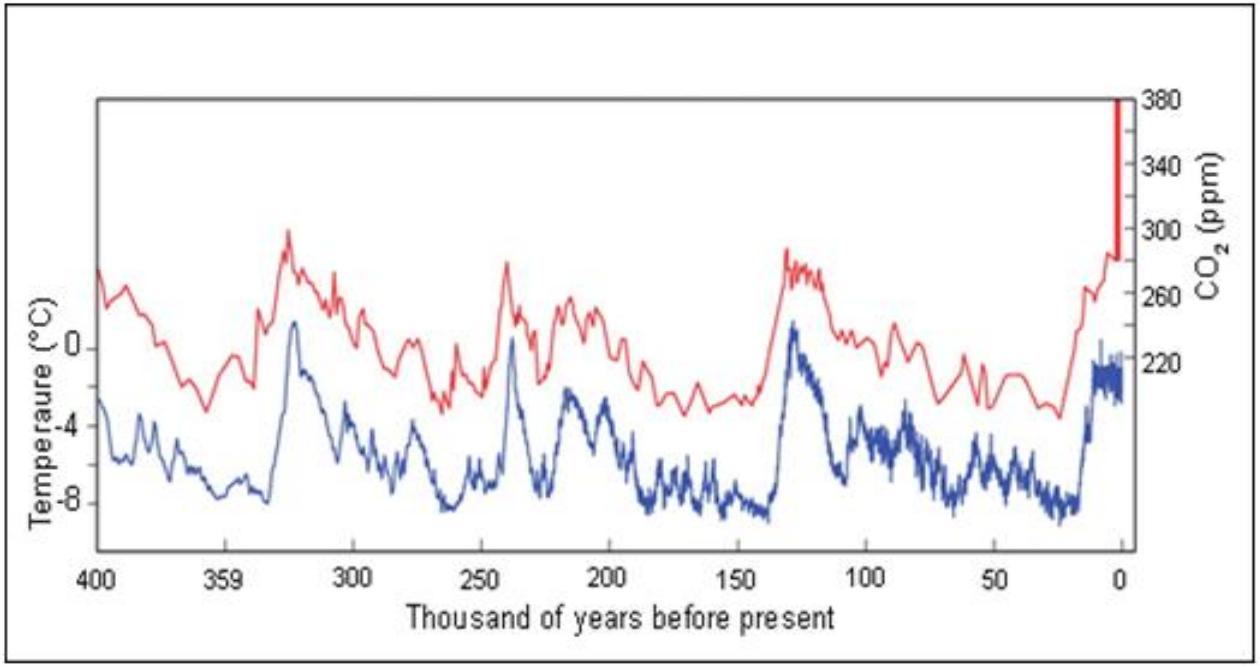


The Long-Term Stability of Earth's Climate – 400,000 years

- ✓ The atmospheric concentration of CO_2 measured from Antarctic ice core data implies that Earth's climate has been pretty stable over the past 400,000 years

- ✓ It also shows a rapid increase of about 30% in the past few centuries… – 270 ppm (parts per million) to 370 ppm

Changes in Carbon Dioxide and Temperature in the last 400,000 years



- ✓ Fluctuations in temperature (blue) and in the atmospheric concentration of carbon dioxide (red) over the past 400,000 years as inferred from Antarctic ice-core records .

- ✓ The vertical red bar is the increase in atmospheric carbon dioxide levels over the past two centuries and before 2006.

A. V. Fedorov et al. Science 312, 14s85 (2006) 17. 18.
Reproduced from EPA Climate Change Website.

How do we measure atmospheric CO_2 concentration in the past?

✓ Precise measurements of atmospheric CO_2 concentration is available only in the last few decades…

✓ Information about atmospheric CO_2 concentration and temperatures in the past can be inferred by several different methods, such as

- Tree-ring
- Deep ocean sediment
- Ice core records – Coral
- …

Where Did O_2 Come From?

- ✓ Life and Photosynthesis.
  - Photosynthesis converts CO_2 to O_2 , and incorporates carbon into amino acids, proteins, and other components of living organisms.
  - O_2 will be depleted from the atmosphere very rapidly without a source.
  - O_2 is a very reactive chemical that likes to be combined with other elements through oxidation. For example, CO_2 , H_2O, FeO (rust). That's how we make fire!
  - O_2 Absorbs UV, which also transform some of the O_2 into O_3, which absorbs even more UV

- ✓ ⇒ O_2 not only supports life, it also protect life!

- ✓ UV light can break the water molecules to release oxygen, but the contribution is small….