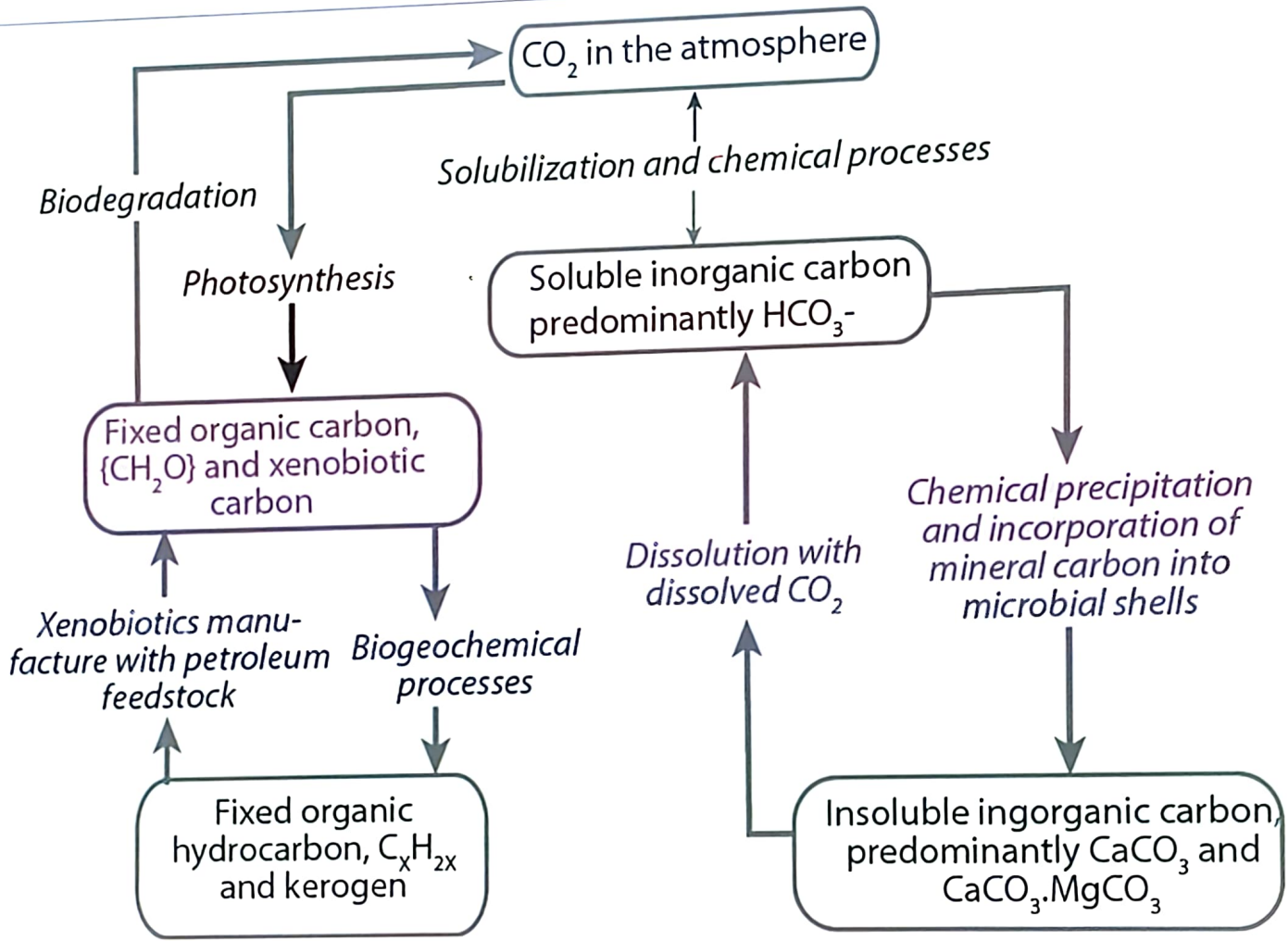
Carbon Cycle



Carbon Cycle

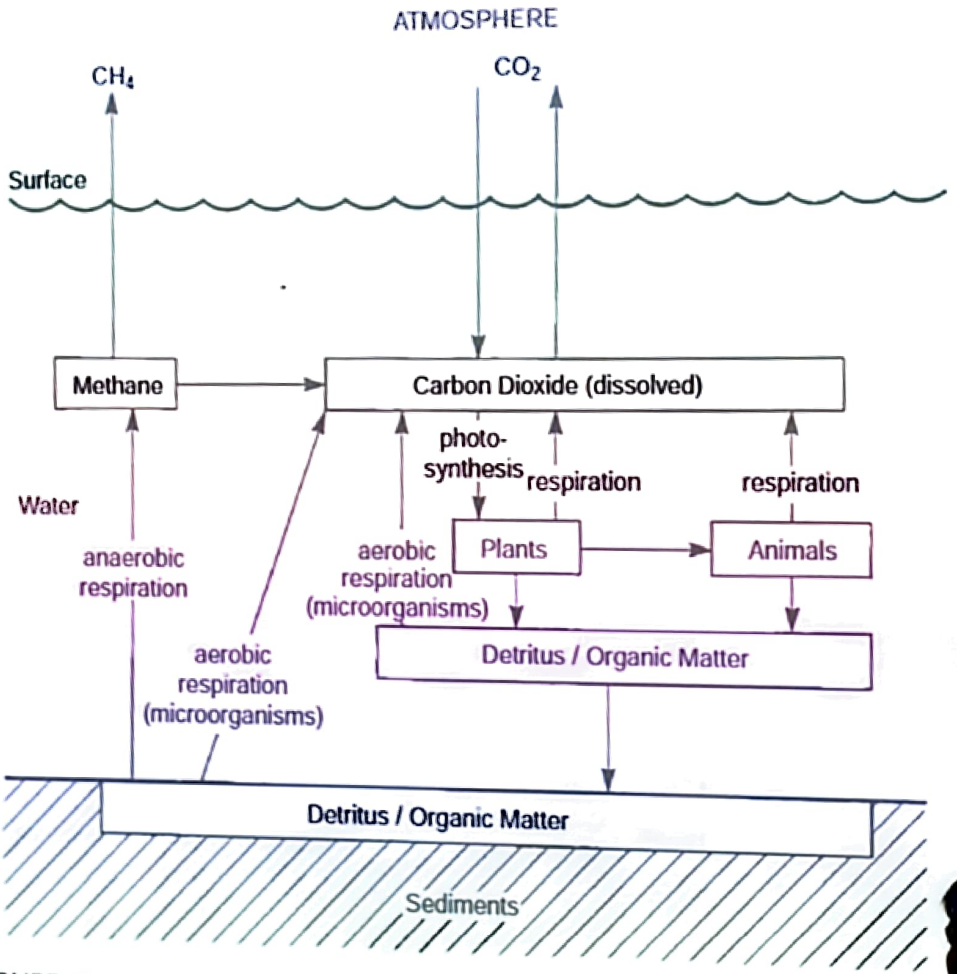
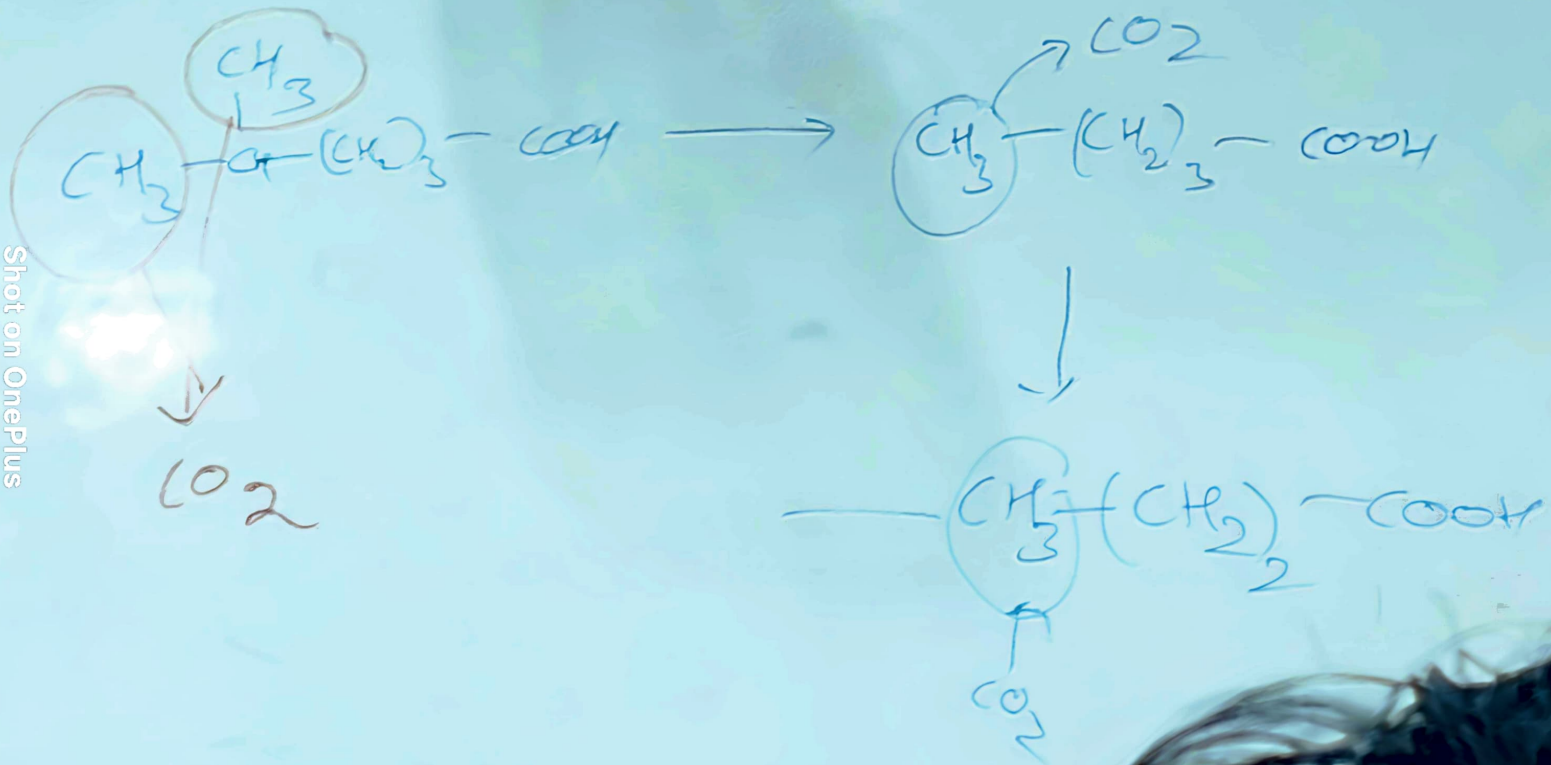


FIGURE 13.9 Transformations of carbon in aquatic systems.



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.
- ✓ 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

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

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

- ✓ 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.
  - o Biodegradation of dead organic matter leads in the accumulation of excess wa residue and converts organic carbon, nitrogen, sulfur, and phosphorus to sim organic forms that can be utilized by plants as fertilizer.

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…
  - …

The Atmosphere of Earth

✓ The atmosphere of Earth contains primarily N_2 (77%) and O_2 (21%).

✓ What happened to all the CO_2 ?

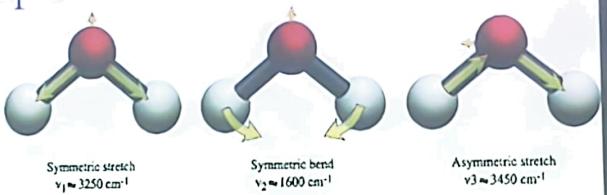
✓ Where did all the O_2 come from?

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

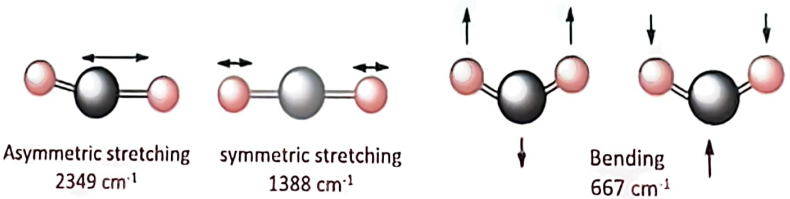
* 1 bar ≈ the pressure at sea level on Earth.

Greenhouse Gases

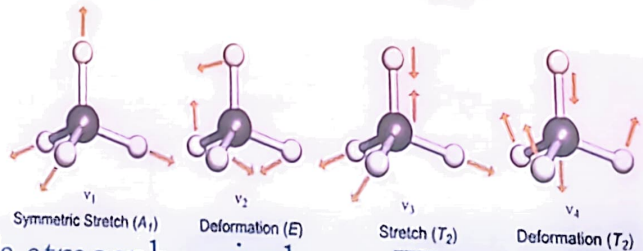
- ✓ The primary components of Earth's atmosphere, N_2 and O_2 do not have absorption in the IR wavelength range, therefore, do not have a significant role in setting the surface temperature of the planet…



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



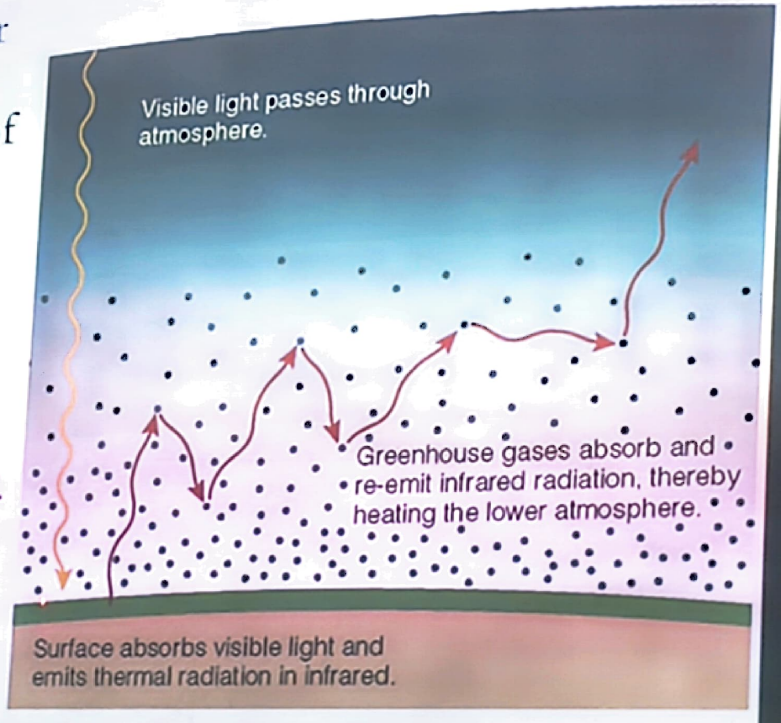
- ✓ The most abundant greenhouse gas in Earth's atmosphere is water vapor.



- ✓ 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

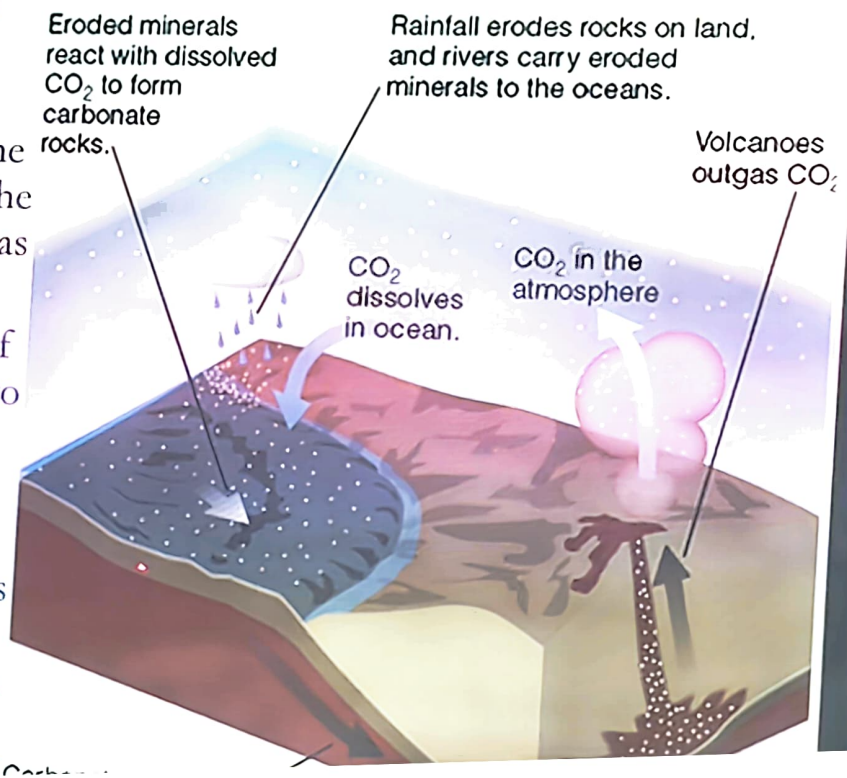
Global warming

- ✓ 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…



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:
  - 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.



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.

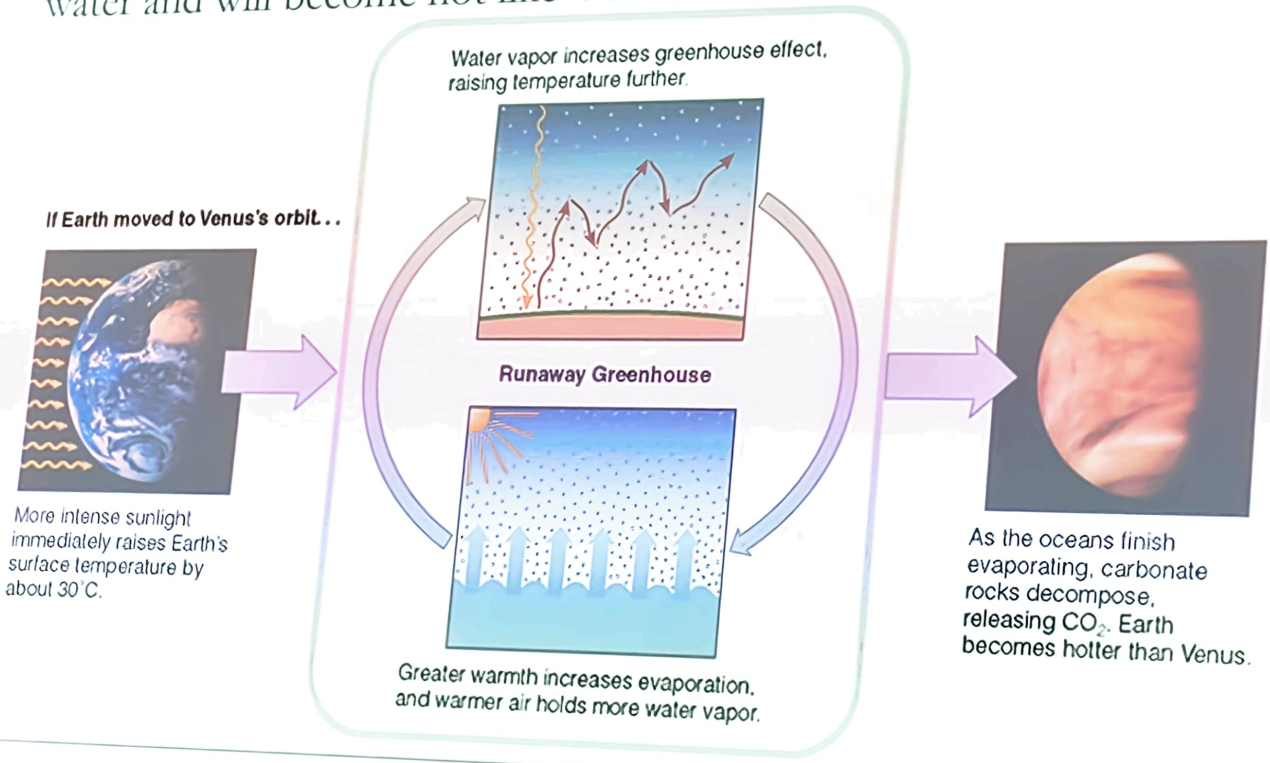
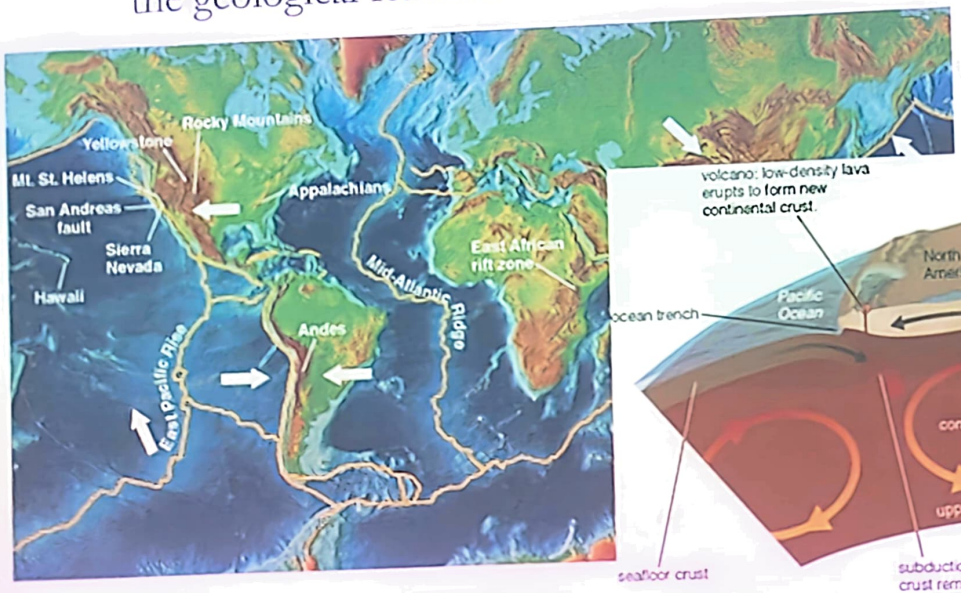
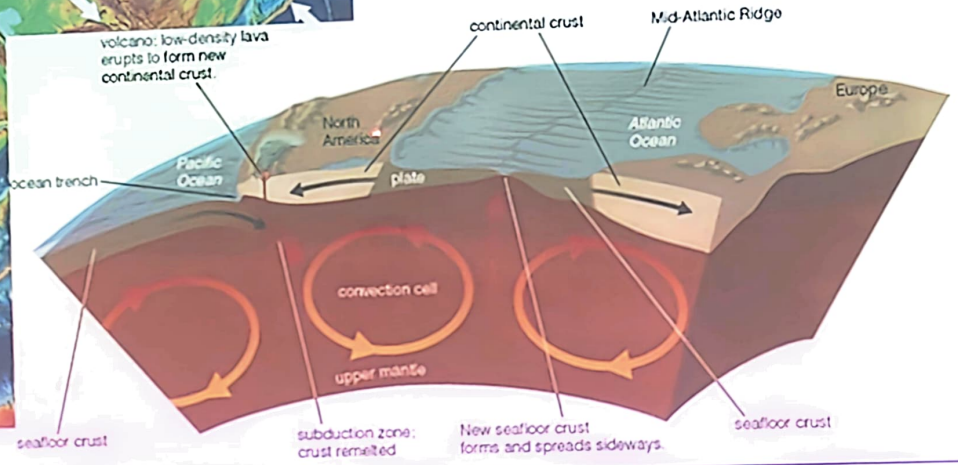


Plate Tectonics

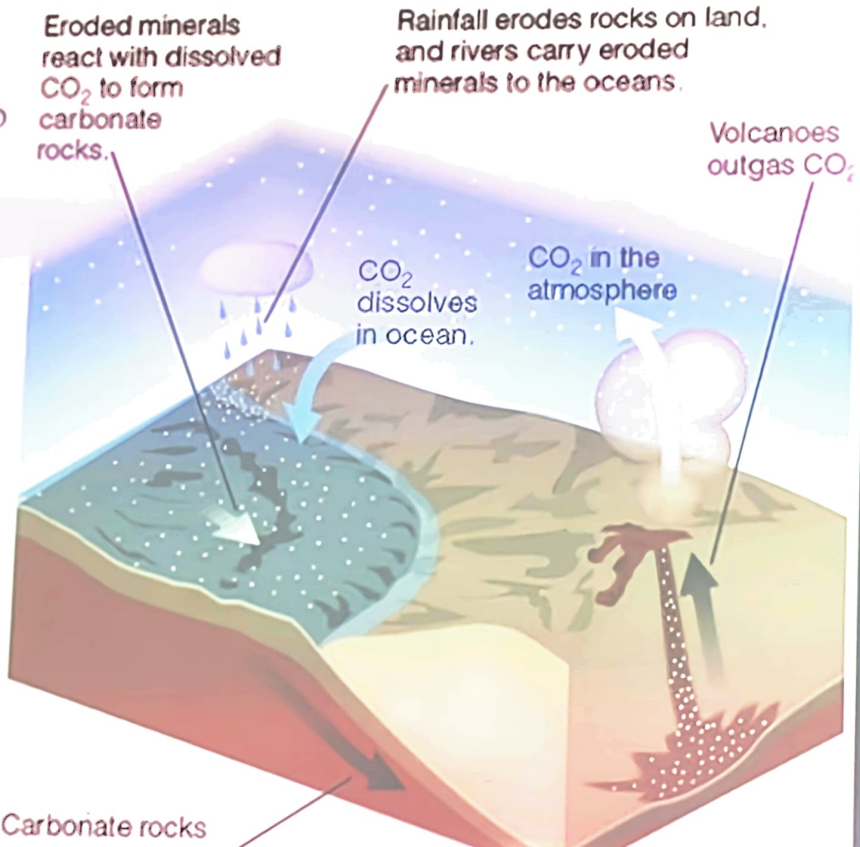
- ✓ Plate tectonics plays an important role in the CO_2 cycle in that it helps to carry the carbonate rocks into the mantle, which are then released again by volcanic activities.
  - Earth's lithosphere is broken into pieces (the plates).
  - These plates float on top of the mantle, interacting with each other to produce the geological features we see and feel today.





The CO_2 Cycle

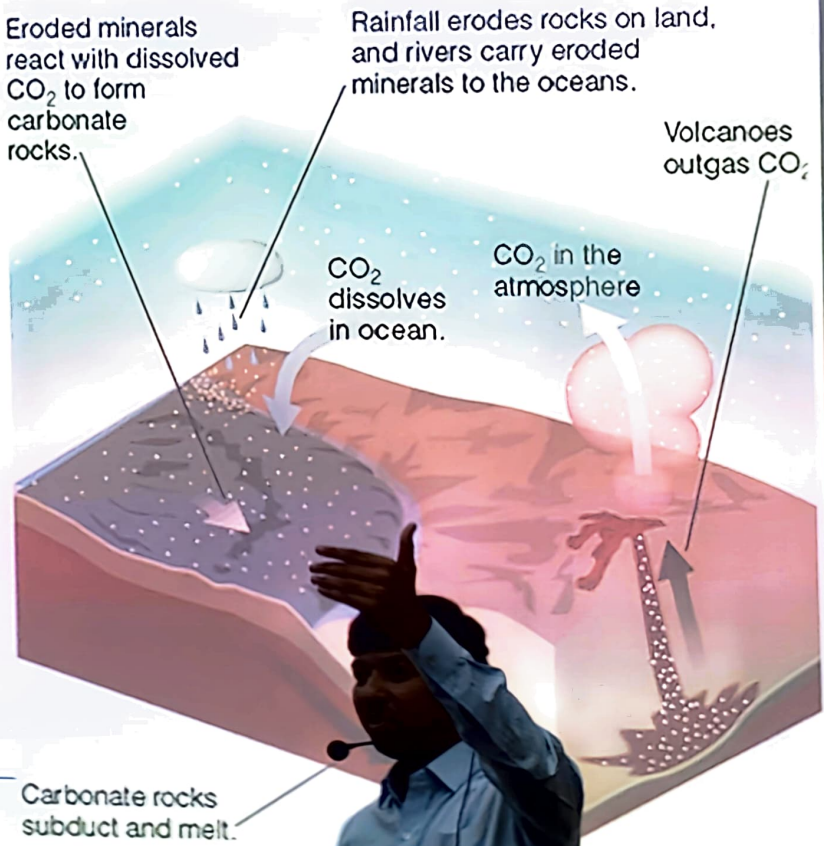
- ✓ If Earth cools a bit,
  - carbonate minerals form more slowly in the oceans.
  - The rate at which the oceans dissolve CO_2 gas decreases, allowing the CO_2 released by volcanism to build back up in the atmosphere.
- The increased CO_2 concentration strengthens the greenhouse effect and warms the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



The CO_2 Cycle

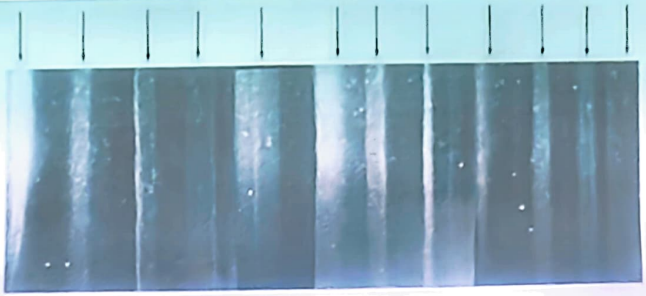
- ✓ The CO_2 cycle acts as a thermostat that regulates the temperature of the Earth…

- ✓ 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.



Antarctic Ice Core

- ✓ Located high in mountains and in polar ice caps, ice has accumulated from snowfall over many millenia.
- ✓ Scientists drill through the deep ice to collect ice cores. These cores contains dust, air bubbles, or isotopes of oxygen, that can be used to interpret the past climate of that area.



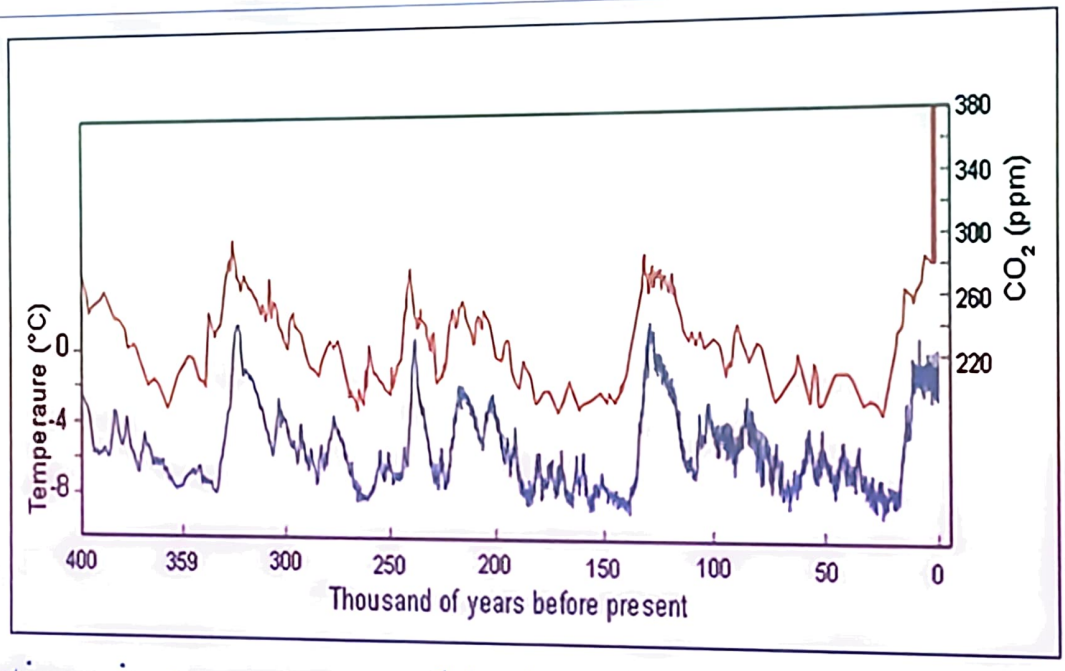
19 cm long section of GISP 2 ice core from 1855 m showing annual layer structure illuminated from below by a fiber optic source. Section contains 11 annual layers with summer layers (arrowed) sandwiched between darker winter layers.

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
  - …

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.

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?