Lecture 21

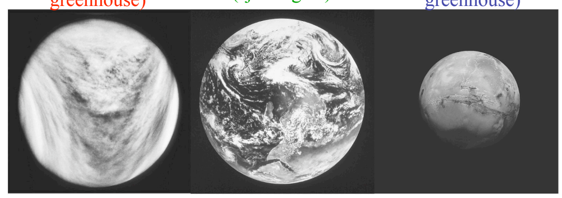
1. Briefly finish off last time: fates of Venus & Mars

2. The effect of life on the early atmosphere.

3. The rise of atmospheric oxygen (first half of Chap. 11 of textbook, p.207-220)

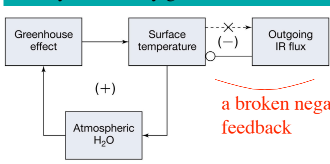
What makes a good planet go bad?

Venus (runaway greenhouse)	Earth ("just right")	Mars (virtually no greenhouse)



- Oceans boiled away - No more weathering - Carbon partitions to atmosphere - CO_2 is ~245,000 times that on Earth Ts = 460 C	- has oceans - hydrological cycle - weathering returns CO_2 to lithosphere - plate tectonics (volcanoes) return carbon to atmos. - negative feedback	- farther from Sun; too cold for liquid water - no water vapor greenhouse - too small for plate tectonics - no carbon cycle - CO_2 is ~16 times Earth T_s = -55C

Theory of runaway greenhouse on Venus



a broken negative feedback

- Atmosphere became so warm and full of water vapor that almost no infrared radiation could escape from the surface
- Only infrared from the cold upper stratosphere escaped, which was not coupled to the surface temperature
- Surface became warmer and warmer, oceans evaporated
- No carbonate-silicate cycle => CO_2 built up in atmosphere
- No rain => sulfur also built up (sulfuric acid clouds on Venus)

LIVING and DEAD PLANETS

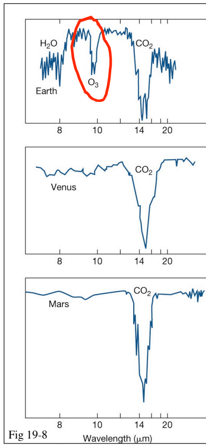


Fig 19-8

◀ Outgoing infrared spectra observed by satellites:

Which planet is the odd one out?

If photosynthesis ceased, O_2 would decrease exponentially to <2% of present levels in about 10 m.y.

NASA's *Terrestrial Planet Finder (TPF)* (2020 launch), will search the atmospheres of Earth-sized extrasolar planets for O_2 (via O_3) => life, possibility of complex life

What we mean by a reducing vs. oxidizing atmosphere

Certain planetary atmospheres are said to be “reducing” (e.g. Jupiter, Titan)
Other planetary atmospheres are “oxidizing” (e.g. Earth)

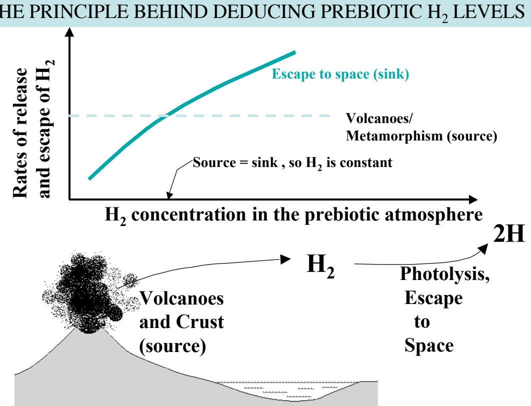
An oxidizing atmosphere is *hydrogen poor*.

A reducing atmosphere is *hydrogen rich*. Even a small excess of H_2 or hydrogen-bearing reducing gases (e.g. CH_4) tips the balance to an anoxic (i.e. virtually O_2-free) atmosphere.

What was the prebiotic atmospheric composition of our planet?

And then what happened after life appeared?

THE PRINCIPLE BEHIND DEDUCING PREBIOTIC H_2 LEVELS



Prebiotic atmosphere was weakly reducing with almost no O_2

For reasonable values of outgassing on the early Earth (a few times the present rate of H_2 outgassing due to more tectonic activity), the calculated prebiotic H_2 level is ~1000 ppmv.

Prebiotic O_2 produced by photolysis of water vapor (and escape of hydrogen so that the photolysis products cannot recombine) would be consumed by photochemical reaction with hydrogen. Resulting O_2 levels are ~10^{-12} bar,i.e.about 1 part per trillion.

Compare 0.55 ppmv H_2 in today’s troposphere. Why low today?
H_2 reacts with the abundant O_2 through photochemical reactions. (Think of the troposphere as analogous to a slow combustion engine, with sunlight as the spark-plug.)

Some likely effects of early microbial life

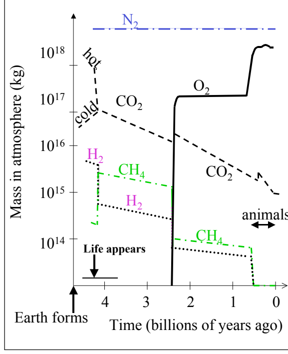
1. Making methane. Microbes eat H_2:
   $4H_2 + CO_2 = CH_4 + 2H_2O$

2. Microbes take C from CO_2 to make organic matter.

   1 & 2 => pCO_2 probably drops (CH_4 control of greenhouse)

3. Microbes extract N from the air (*nitrogen fixation*). N is is used in proteins. N would be returned to the air either as NH_3 which is decomposed by solar ultraviolet light to leave N_2, or released directly as N_2 after cycling by other microbes (*denitrification*).

History of Earth's atmospheric composition



This diagram is a composite from geochemical data and theoretical reasoning (Your instructor's best estimate)

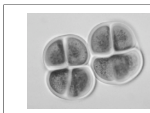
Rise of O_2

Broad reasons why important:

O_2 levels set the tempo for biological evolution.
O_2 allows complex life, here and on other Earth-like planets. Formation of O_3 layer screens out harmful UV for higher life.

Is the development of an O_2-rich atmosphere common on planets elsewhere in the galaxy / universe?

Are planets inhabited by complex life elsewhere in the Universe? Is the "Star Trek"/"Star Wars" picture wrong? (Read *Rare Earth* popular book by UW's Peter Ward & Don Brownlee)



Where Earth's O_2 came from: The cyanobacteria.

O_2-producing photosynthetic bacteria, called **cyanobacteria**, inhabit all places on Earth where there is water and sunlight. There are about 10^{27} cyanobacteria in the oceans.

One type of cyanobacterium, *Prochlorococcus,* is the most abundant organism on planet Earth. (Yet was only discovered in 1988!!)

When cyanobacteria die, their organic molecules are degraded but the basic structure of some of these molecules can be preserved.

Oils derived from cyanobacteria cell membranes are found in 2.7 Ga marine sedimentary rocks, i.e., cyanobacteria have been in the oceans since at least 2.7 Ga. Yet O_2 rose ~2.4-2.3 Ga. Why the delay?