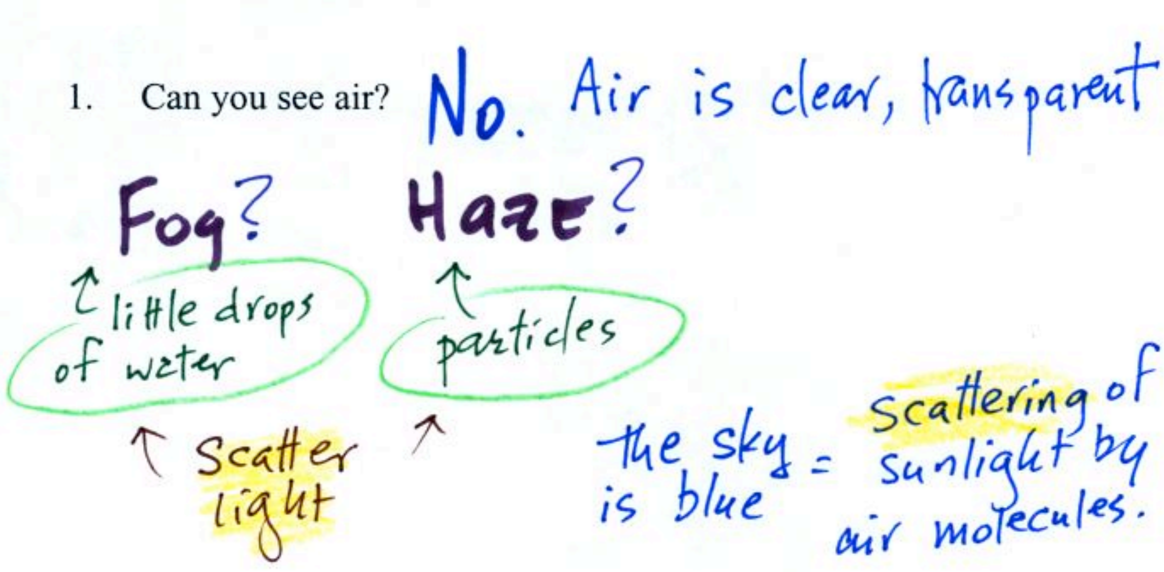
Goals for Module 1:

1. Describe the composition of Earth's Atmosphere
2. Introduce dew point temperature
3. Illustrate the evolution of Earth's Atmosphere
4. List a few of the main air pollutants, their characteristics and their effects on the environment and human health.
5. Understand the Environment Protection Agency (EPA) regulations on permissible ambient concentration levels.
6. Distinguish between the two different types of chemical fogs.

Module 1: Lecture 1

In this first lecture we will mostly be concerned with the composition of our atmosphere. Here are some questions to think about.

1. Can you see air?
2. Can you smell or taste air?
3. Can you feel or touch air?
4. What is air made of?



At first glance, these questions appear to be simple. Air is generally clear, transparent, and invisible. But sometimes the air looks foggy or hazy because you are seeing the effects of small water droplets (fog) or small particles of some material (aerosols) suspended in the air. The droplets and particles themselves may be too small to be seen with the naked eye but are visible because they scatter (redirect) light. We will soon learn more about the scattering of light. The sky itself is blue because air molecules also scatter sunlight.

2. Can you smell or taste air? Not usually

Trace gases & pollutants sometimes have a smell

You normally cannot smell or taste the main constituents of air. We can however smell certain air pollutants and trace gases even when their concentrations are very small.

3. Can you feel or touch air?

Complicated

It is harder to answer Question 3 because we are always in contact with air. At sea level we will learn that air pressure is pressing on every square inch of our bodies with almost 15 pounds of force. If that were to change suddenly we'd feel it; and it would probably be very painful. The air that surrounds us also affects the transport of energy into and out of our bodies. You can appreciate this by comparing the feeling you have standing in 70 ^{o}F air and in ^{o}70 F water.

Let us answer Question #4 by first listing the two most abundant gases in air. The most abundant gas is nitrogen (N_2). Liquid nitrogen is relatively inexpensive and is readily available at a research university like the University of Arizona. You can see **liquid** nitrogen if you were to pour it into a Styrofoam cup (liquid nitrogen is very cold and would probably cause a glass or plastic cup to crack or shatter). Liquid nitrogen is clear (not blue as shown in the figure below) and looks like water (though you certainly would not want to drink it). At room temperature the liquid nitrogen evaporates and turns into invisible nitrogen gas. The cloud that you see surrounding the cup is made up of water droplets and/or ice crystals. Nitrogen was discovered in 1772 by Daniel Rutherford (a Scottish botanist). Atmospheric nitrogen is relatively unreactive and is sometimes used to replace air in packaged foods to preserve freshness. We use liquid nitrogen in several of the class demonstration in this course.

Oxygen is the second most abundant gas in the atmosphere. Oxygen is the most abundant element (by mass) in the earth's crust, in ocean water, and in the human body. [Here is a photograph]() of liquid oxygen. It really does have a (very faint) blue color (I was disappointed when I saw the picture the first time because I had imagined the liquid oxygen might be a deep vivid blue). Here are the 5 most abundant gases in the earth's atmosphere (you can find a much longer, more complete list at a variety of online sources). The percentage concentrations will vary somewhat depending on how much water vapor is present.

Composition of the atmosphere

Nitrogen (N_2) 77%

Oxygen (O_2) 20%

can trade places

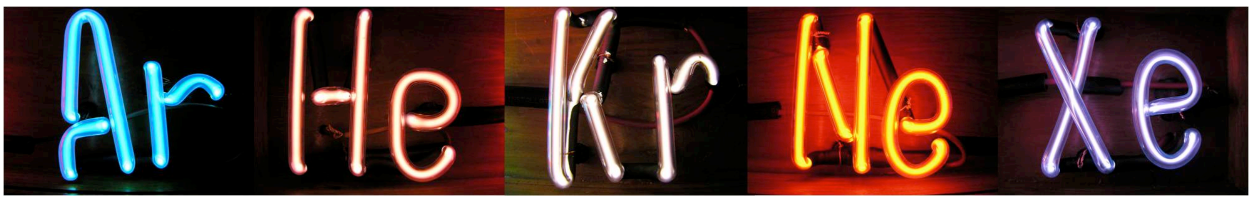
Water vapor (H_2O) 2% can vary from near 0% to 3 or 4%.

Argon (Ar) 1%

Carbon dioxide (CO_2) (0.038%)

Water vapor and argon are the 3rd and 4th most abundant gases in the atmosphere. The concentration of water vapor can vary from near 0% to as high as 3% or 4%. Water vapor is, in many locations, the 3rd most abundant gas in air. Most of the year in desert regions like Arizona, argon is in the third position and water vapor is fourth. Water vapor, a gas, is invisible. Clouds are visible because they are made up of small drops of liquid water or solid crystals of ice. **Water is the only compound that exists naturally in solid, liquid, and gaseous phases in the atmosphere.**

Argon is an unreactive noble gas (helium, neon, krypton, xenon, and radon are also noble gases). Noble gases are often used in neon signs. Each of the noble gases has a distinctive color (from left to right: argon, helium, krypton, neon, and xenon).



Here is a little more explanation (from Wikipedia) of why noble gases are so unreactive. Do not worry about all these additional details. The noble gases have full valence electron shells. Valence electrons are the outermost electrons of an atom and are normally the only electrons that participate in chemical bonding. Atoms with full valence electron shells are extremely stable, have less of a tendency to gain or lose electrons, and therefore do not readily form chemical bonds.

Water plays an important role in the formation of clouds, storms, and weather. Meteorologists are very interested in knowing and keeping track of how much water vapor is in the air at a particular place and time. One of the variables they use is the dew point temperature. The value of the dew point gives you an idea of how much water vapor is actually contained in the air. The higher the dew point value, the higher the water vapor concentration in ambient air.

The dew point ← job #1.
temperature tells you
something about the amount
of water vapor in the air.

The chart below gives a rough equivalence between dew point temperature and percentage concentration of water vapor in the air.

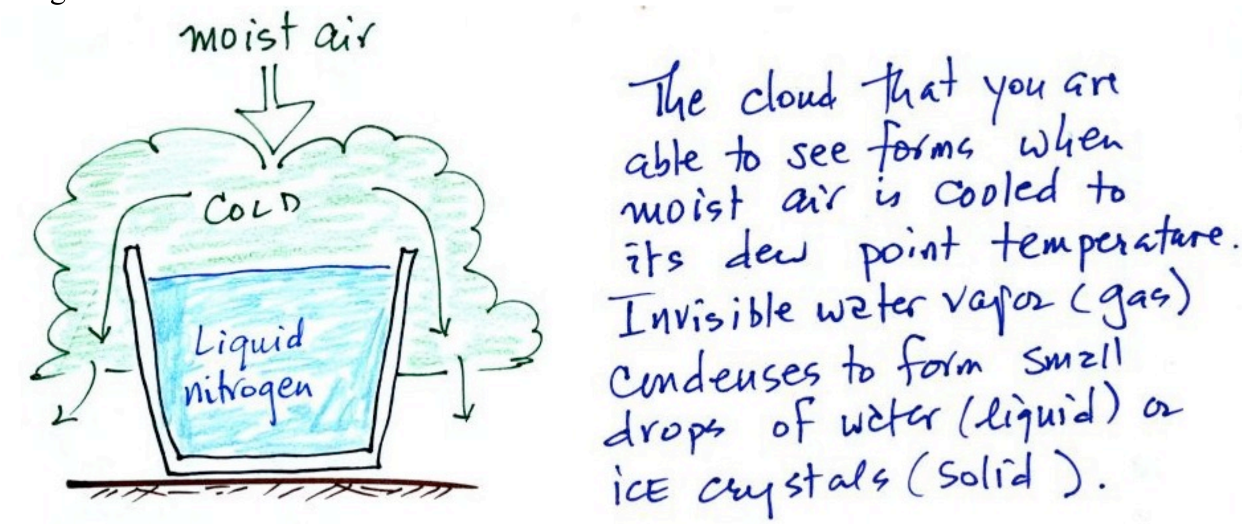
dew point temperature	approximate water vapor concentration	
25°F	0.5%	most of the year in SE Arizona
45 °F	1%	
		Summer thunder-storm Season in Az.
65° F	2%	Common in many parts of the US in Summer
75 °F	3%	
85 °F	4%	rare, potentially deadly Conditions.
low 90s	world record	

The air temperature will always be equal to or warmer than the dew point temperature. Experiencing 80^o dew points would be very unpleasant (and possibly life threatening because your body might not be able to cool itself). Click here to see current dew point temperatures across the U.S.

The dew point has another "job."

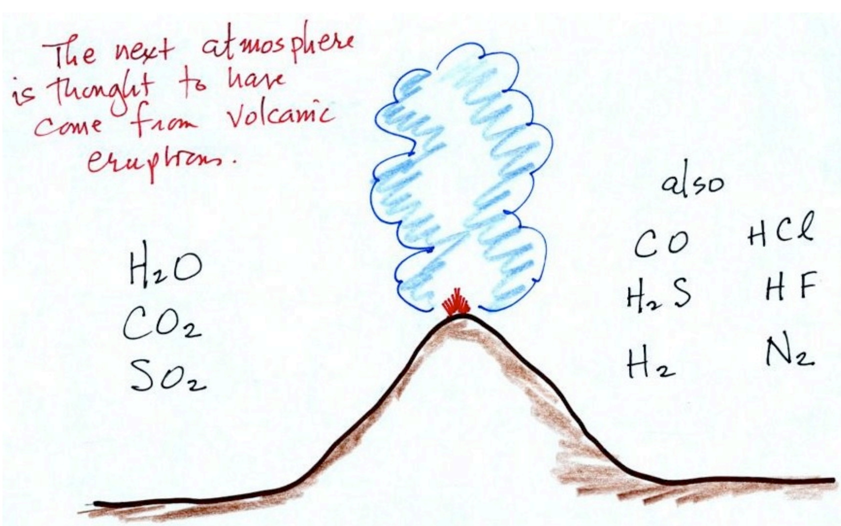
When you cool moist air
to its dew point temp., ← job#2
RH (relative humidity) reaches 100%,
a cloud forms (water
vapor condenses & forms
small drops of water).

We could use the cup of liquid nitrogen to show this. The cloud came from moisture in the air. The cloud is not made of nitrogen gas (which is invisible). Note again that a certain amount of "artistic" license was used in the figure above; liquid nitrogen is not blue and water clouds are not green.

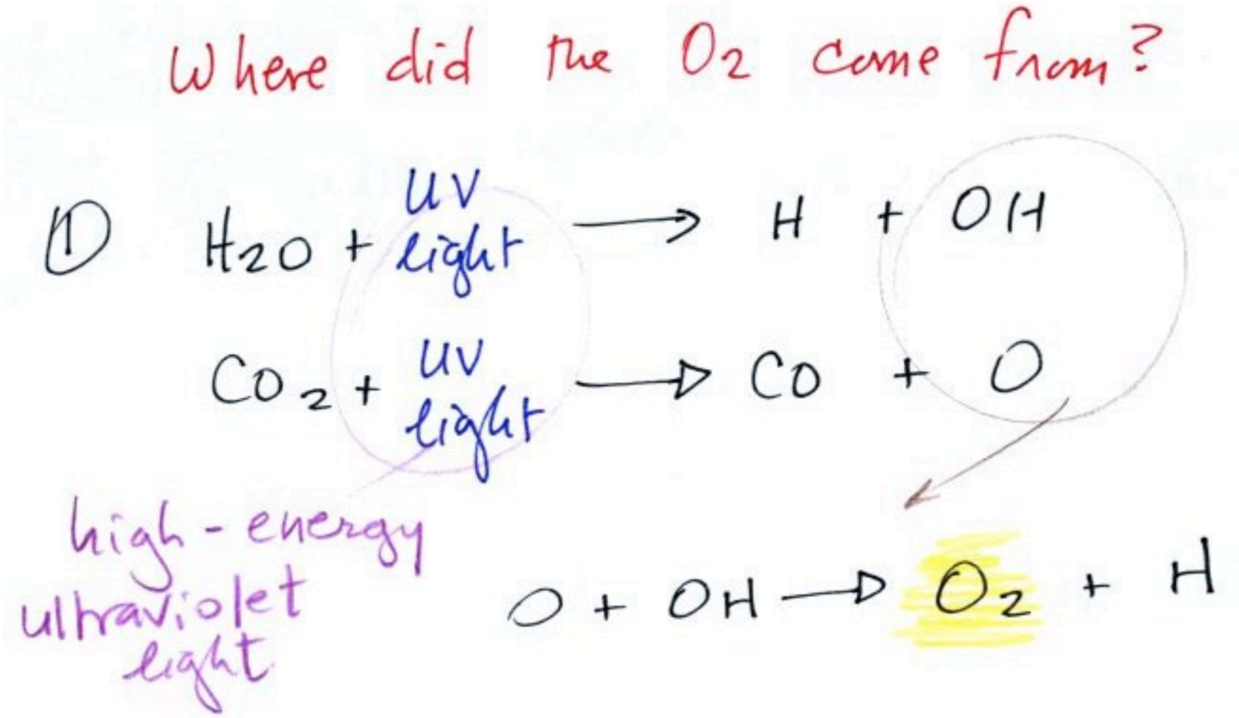


The earth's original atmosphere, which was composed mostly of hydrogen (H) and helium (He), was very different from the atmosphere that we have today. This original atmosphere either escaped into space (the earth was hot and the gases were moving around with enough speed that they could overcome the pull of the earth's gravity) or was swept into space by the solar wind.

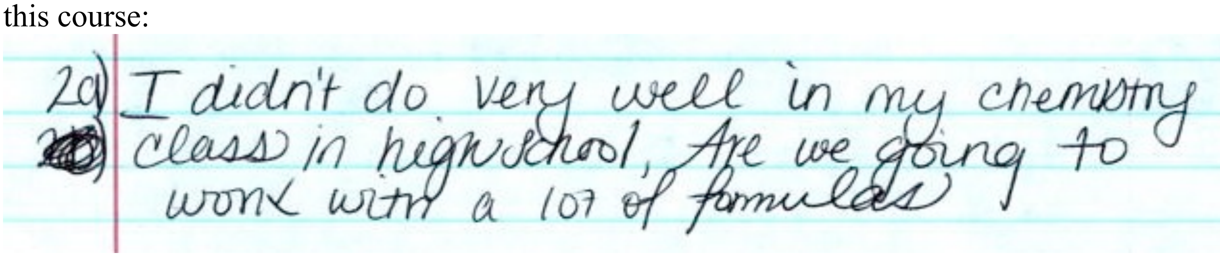
Our present atmosphere is thought to have come from volcanic eruptions. Volcanoes emit a lot of water vapor and carbon dioxide. As the earth began to cool the water vapor condensed and began to create oceans. Carbon dioxide dissolved in the oceans and slowly turned into rock. Smaller amounts of nitrogen (N_2) are emitted by volcanoes. Nitrogen is relatively inert and remained in the air. Nitrogen concentration built up over time.



Volcanoes did not add any of the oxygen that is the atmosphere. Where did that come from? The oxygen is thought to have first come from **photo dissociation** of water vapor and carbon dioxide by the ultraviolet light in sunlight. The O and OH react to form O_2 and H.



Here is a comment from the anonymous survey conducted in one of the classroom versions of this course:


20) I didn't do very well in my chemistry class in highschool, Are we going to work with a lot of formulas

It is sometimes easier and clearer to show or explain a reaction in formulas instead of words. I will not expect you to remember the chemical formulas in the example above (though you should be able to interpret the equations if they are written down). You will not have to balance chemical equations in this course either. You might just remember that the earth's original oxygen came from oxygen in water and carbon dioxide.

It is probably also good to remember that ultraviolet light is capable of breaking molecules apart. Once molecular oxygen (O_2) started to accumulate in the air, it began to react with atomic oxygen (O) to form ozone (O_3).

Once you have O_2 you can make O_3 (ozone).

$$O_2 + \text{UV light} \longrightarrow O + O$$

$$O + O_2 \longrightarrow O_3$$

Once formed, ozone began to absorb ultraviolet light. Life forms were able to safely move from the oceans (which would absorb UV light in the absence of ozone) onto land. Eventually plants and photosynthesis would become the main source of atmospheric oxygen. Note that combustion (and respiration) is really just the opposite of photosynthesis. We burn fossil fuels to generate energy. Water vapor and carbon dioxide are by products.

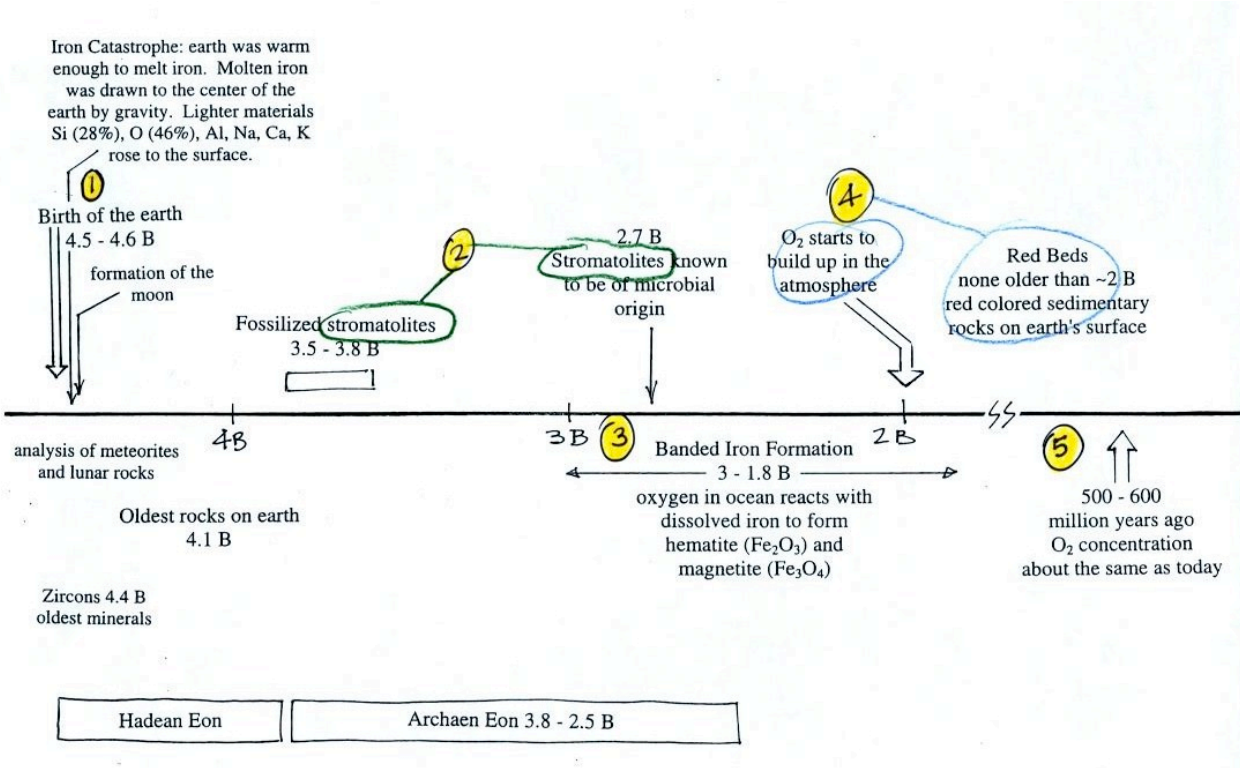
photosynthesis

$$H_2O + CO_2 + \text{Sunlight} \longrightarrow O_2 + \text{plant tissue}$$

combustion

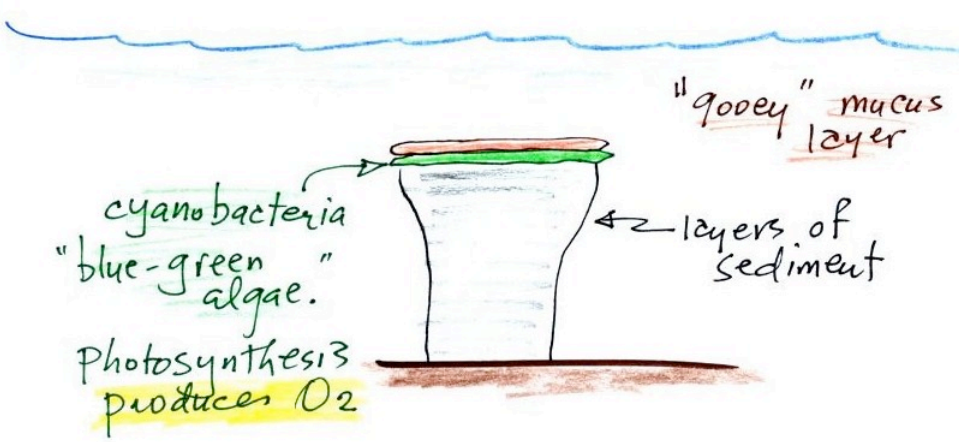
$$\text{Fossil fuel} + O_2 \longrightarrow H_2O + CO_2 + \text{energy}$$

Here is a slightly different look at the origin and buildup of oxygen in the earth's atmosphere. This figure shows some of the important events in the history of the earth and evolution of the atmosphere. The numbered points are emphasized.



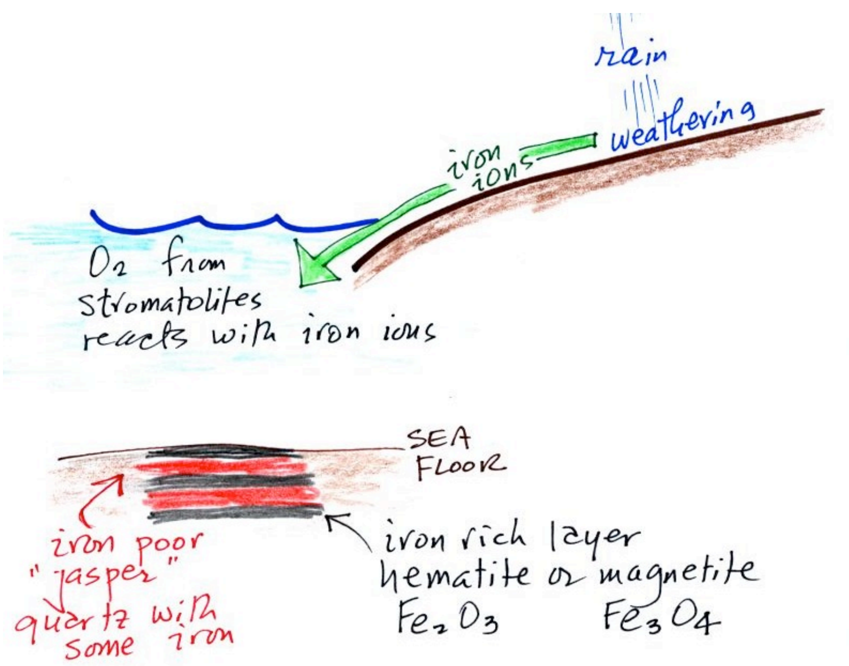
At **Point 1** in the timeline above, the earth is thought to be between 4.5 and 4.6 billion years old. The iron catastrophe was an important event in the earth's history. The accumulation and circulation of liquid metal in the earth's core gave the earth a magnetic field. The magnetic field then began to deflect and thereby protect the earth from the solar wind. Remember that the solar wind may have swept away the earth's original atmosphere.

Stromatolites (**Point 2** in the timeline above) are column-shaped structures made up of layers of sedimentary rock and are created by microorganisms (cyanobacteria = blue green algae) living at the top of the stromatolite. Fossils of the microbes, which may be 2.7 billion years old, have been found in stromatolites and are some of the earliest records of life on earth. Much older stromatolites (3.5 to 3.8 billion years old) are also presumably produced by microbes, but so far no fossils, have been found. We are learning about stromatolites because the cyanobacteria were able to produce oxygen using photosynthesis.



Living stromatolites are found in a few locations today. The picture below is from Coral Bay Australia, located on the western tip of the continent. The picture was probably taken at low tide because normally stromatolites are covered with ocean water.

Once cyanobacteria began to produce oxygen in ocean water, the oxygen reacted with dissolved iron (iron ions in the figure below) to form hematite or magnetite. These two minerals precipitated out of the water to form a layer on the sea bed. Periodically the oxygen production would decrease or stop. (Rising oxygen levels could have killed the cyanobacteria or seasonal changes could have slowed the photosynthesis). During these times of low dissolved oxygen concentrations, layers of jasper would form on the ocean bottom instead of hermatite or magnetite. Eventually the cyanobacteria would recover and begin producing oxygen again, resulting in a new layer of hematite or magnetite. The rocks that resulted, containing alternating layers of black hematite or magnetite and red layers of jasper are known as the banded iron formation (**Point 3** in the timeline above). See a Wikipedia reference and images for rather spectacular images of this kind of rock.



Eventually the dissolved iron in the ocean was used up (**Point 4** in the time line figure above). Oxygen produced by cyanobacteria no longer reacted with iron and was free to diffuse from the ocean into the atmosphere. Once in the air, the oxygen could react with iron in sediments on the earth's surface. This produced red colored sedimentary rock. None of these so-called red beds are older than about 2 billion years old. Thus it appears that a real buildup up oxygen began around 2 billion years ago. Oxygen concentrations reached levels that are about the same as today around 500 to 600 years ago (**Point 5** in the timeline above).