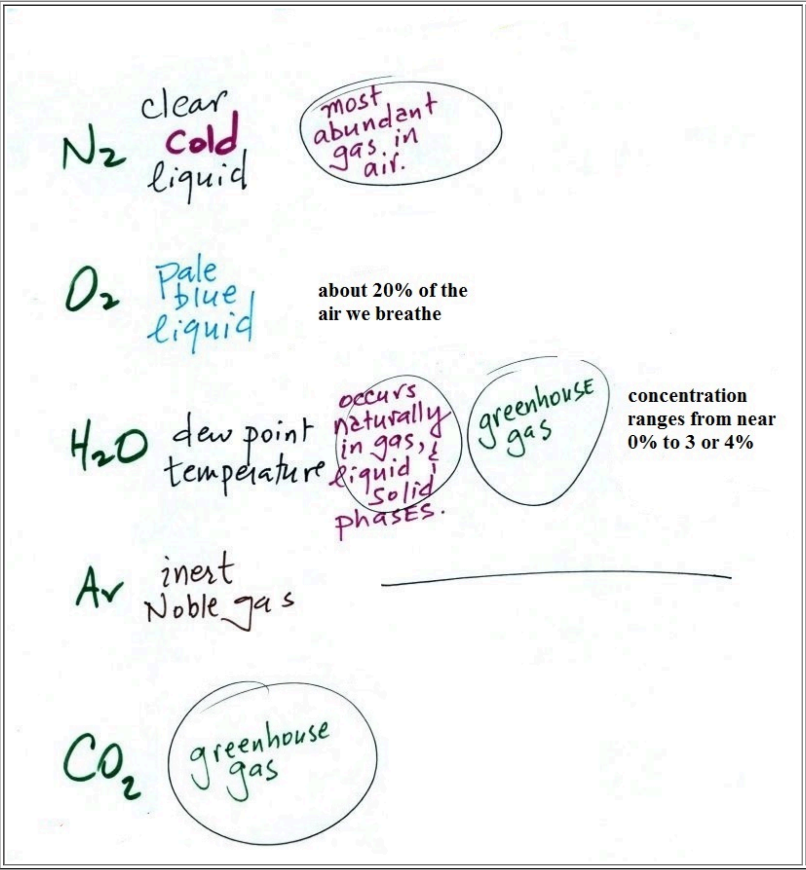
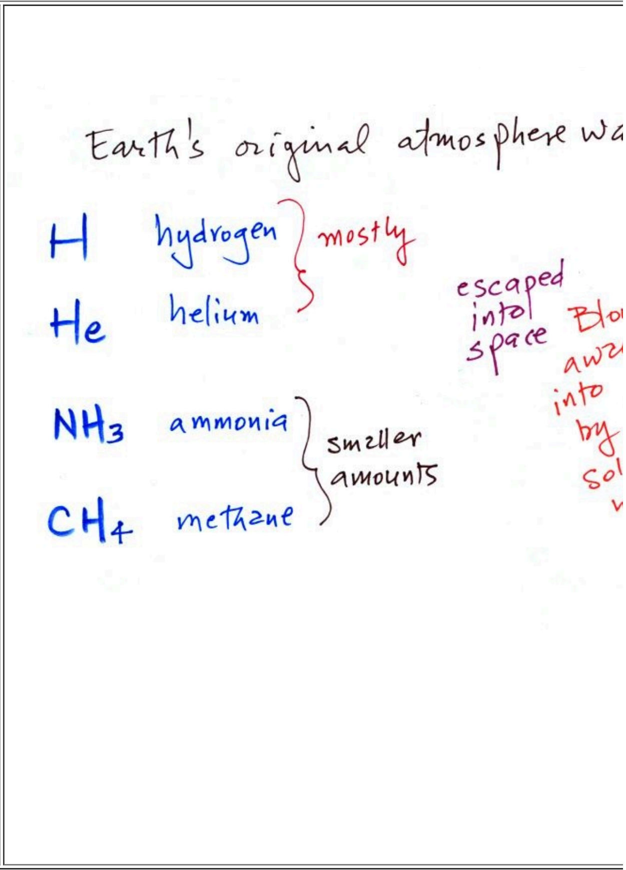
The earth's original atmosphere and the origin(s) of our present atmosphere

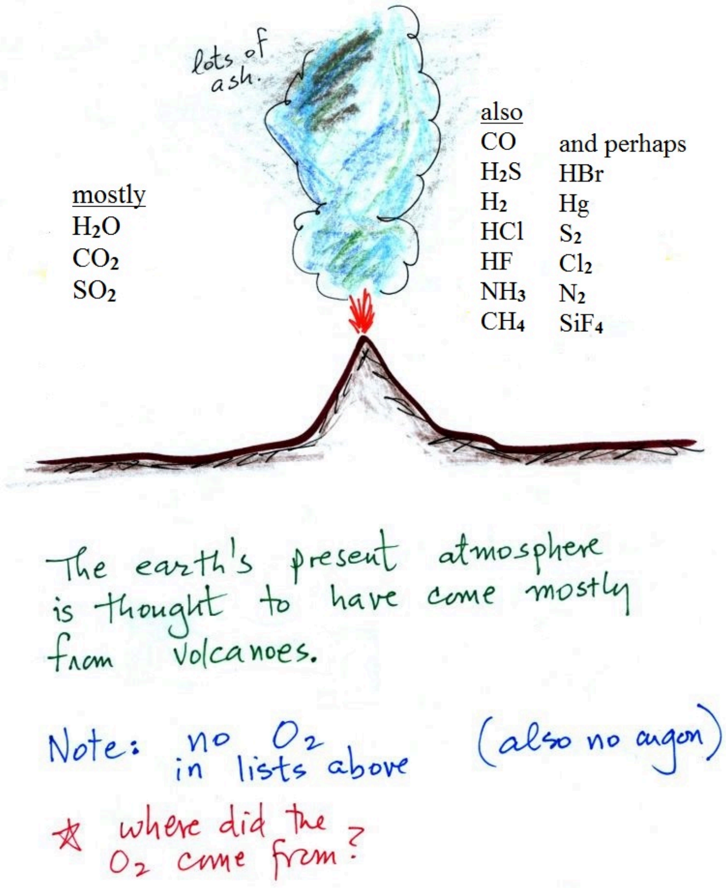
Our present day atmosphere (shown below at left) is very different from the earth's original atmosphere (at right below) which was mostly hydrogen and helium with lesser amounts of ammonia and methane.





The early atmosphere either escaped into space (the earth was hot and light weight gases like hydrogen and helium 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 (click on the link if you are interested in learning more about the solar wind, otherwise don't worry about it).

With the important exception of oxygen (and argon perhaps), most of our present atmosphere is though to have come from volcanic eruptions. In addition to ash, volcanoes send a lot of water vapor, carbon dioxide, and sulfur dioxide into the atmosphere. Carbon dioxide and water vapor are two of the 5 main gases in our present atmosphere.



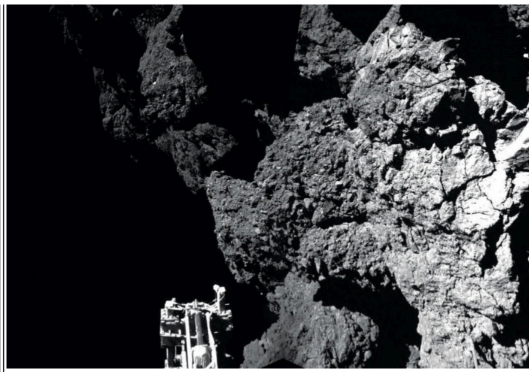
Volcanoes also emit lots of other gases, many of them are very poisonous. Some of them are shown on the right side of the figure. The gases in the "also" list were mentioned in a lot of online sources, the gases in the "perhaps" list were mentioned less frequently. The relative amounts of these "also" and "perhaps" gases seems to depend a lot on volcano type.

As the earth began to cool the water vapor condensed and began to create and fill the earth's oceans. Carbon dioxide dissolved in the oceans and was slowly turned into rock. Nitrogen containing compounds like ammonia (NH_3) and molecular nitrogen (N_2) are also emitted by volcanoes. I'm guessing that the nitrogen in NH_3 reacted with other gases to produce N_2. Molecular nitrogen is pretty nonreactive so once in the air its concentration was able to built up over time.

The photo above shows the Eyjafjallajokull volcano in Iceland photographed on Apr. 17, 2010 (image source)

Here are some additional pictures of the Eyjafjallajökull volcano which you should really have a look at. Eyjafjallajökull caused severe disruption of airline travel between the US and Europe. Here's another set of photos also from the Boston Globe.

This photograph is a mosaic of 4 images taken over a roughly 20 minute period from an altitude of 28.6 km (17.8 miles). Photo credit: "Comet 67P on 19 September 2014 NavCam mosaic" by ESA/Rosetta/NAVCAM found a Wikipedia article on the Rosetta mission.



A mosaic of the first two images showing the Philae lander o surface. photo credit: ESA/Rosetta/Philae/CIVA photo sour

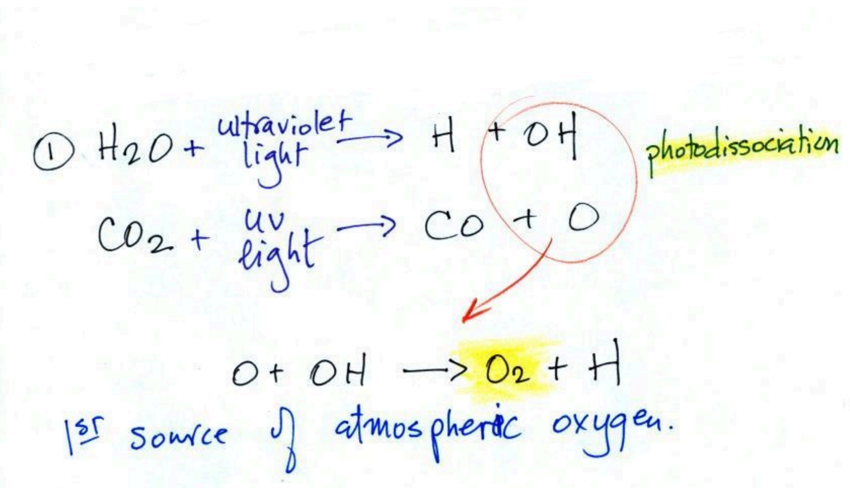
Even more amazing than the photographs of the Icelandic volcano are these photographs of Comet 67P/Churyumov-Gerasimenko taken by the European Space Agency Rosetta spacecraft. The spacecraft was launched on March 2, 2004 and went into orbit around the comet on August 6, 2014. On November 12, the Rosetta spacecraft deployed the Philae lander which successfully landed on the surface of the comet and operated for a brief time. The lander was not able to fully deploy its solar panels and used up its battery power and went into "sleep" mode after about 60 hours of operation. In June this year the comet had moved into a sunnier part of its orbit and the lander began sending data again. The comet has just reached perihelion (shortest distance between the comet and the sun). The Rosetta spacecraft has photographed material being ejected from the comet (you'll find a nice animation here).

I've included this photograph of a comet because some researchers don't believe that volcanic activity alone would have been able to account for all the water that is on the earth (oceans cover about 2/3rds of the earth's surface). They believe that comets and asteroids colliding with the earth may have brought significant amounts of water. The Rosetta spacecraft has determined that the water on this particular comet differs from the composition of the water in the earth's oceans (this reference reports "The ratio of deuterium to hydrogen in the water from the comet was determined to be three times that found for terrestrial water.") This suggests that comets like 67P were probably not an important source of the earth's water.

Where did the oxygen in our atmosphere come from?

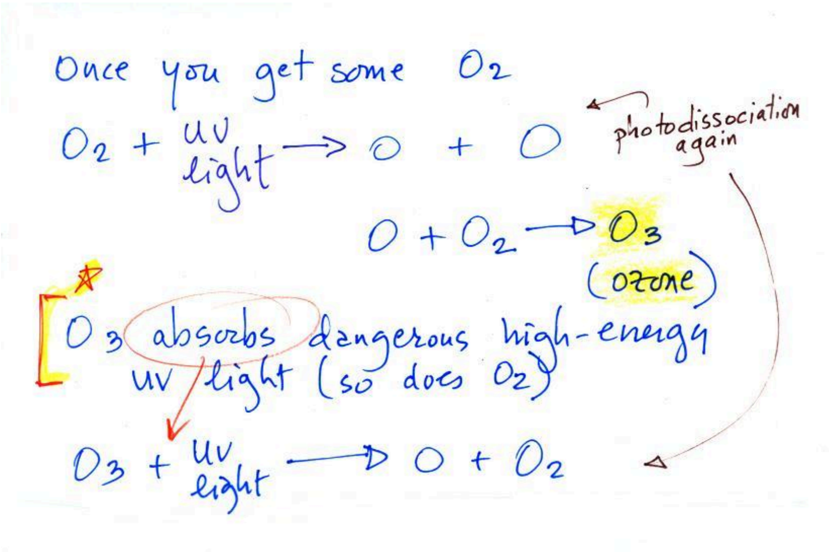
Oxygen is in H_2O, CO_2, and SO_2 (and many of the other gases emitted by volcanoes) but volcanoes aren't a direct source of the molecular oxygen (O_2) that is present in air. Where did the O_2 come from? There are a couple of answers to that question.

1st source of atmospheric oxygen



Oxygen is thought to have come from photo-dissociation of water vapor and carbon dioxide by ultraviolet (UV) light (the high energy UV light is able to split the H_20 and CO_2 molecules into pieces). Two of the pieces, O and OH, then react to form O_2 and H.

By the way I don't expect you to remember the chemical formulas in the example above. It's often easier and clearer to show what is happening in a chemical formula than to write it out in words. If I were to write the equations down, however, you should be able to interpret them. Ultraviolet is a dangerous, high energy, potentially deadly form of light and it's probably also good to remember that ultraviolet light is capable of breaking molecules apart.



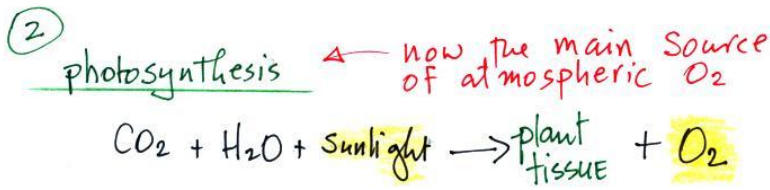
Once molecular oxygen (O_2) begins to accumulate in the air UV light can split the O_2 apart to make atomic oxygen (O). The atoms of oxygen can react with molecular oxygen to form ozone (O_3).

Ozone in the atmosphere began to absorb the dangerous and deadly forms ultraviolet light and life forms could then begin to safely move from the oceans onto land (prior to the buildup of ozone, the ocean water offered protection from UV light. A molecule of O_3 absorbs some UV preventing it from reaching the ground.

$$O_3 + \text{UV light} \text{ ---> } O_2 + O$$

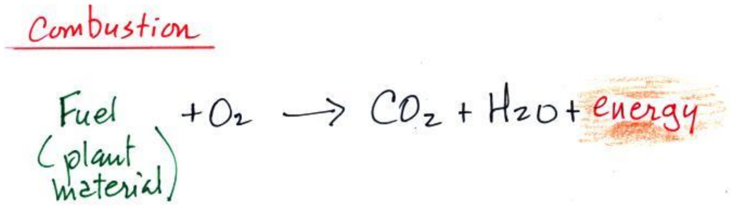
You might think the O_2 and O would recombine. But if you picture hitting something with a hammer and breaking it, the pieces usually fly off in different directions. That's essentially what happens with the O and O_2 .

<u>2nd and more important source of atmospheric oxygen.</u>
Once plant life had developed sufficiently and once plants moved from the oceans onto land, photosynthesis became the main source of atmospheric oxygen.



Photosynthesis in its most basic form is shown in the chemical equation above. Plants need water, carbon dioxide, and sunlight in order to grow. They can turn can turn $H_2 0$ and CO_2 into plant material. Photosynthesis releases oxygen as a by product.

Combustion is really just the opposite of photosynthesis and is shown below.

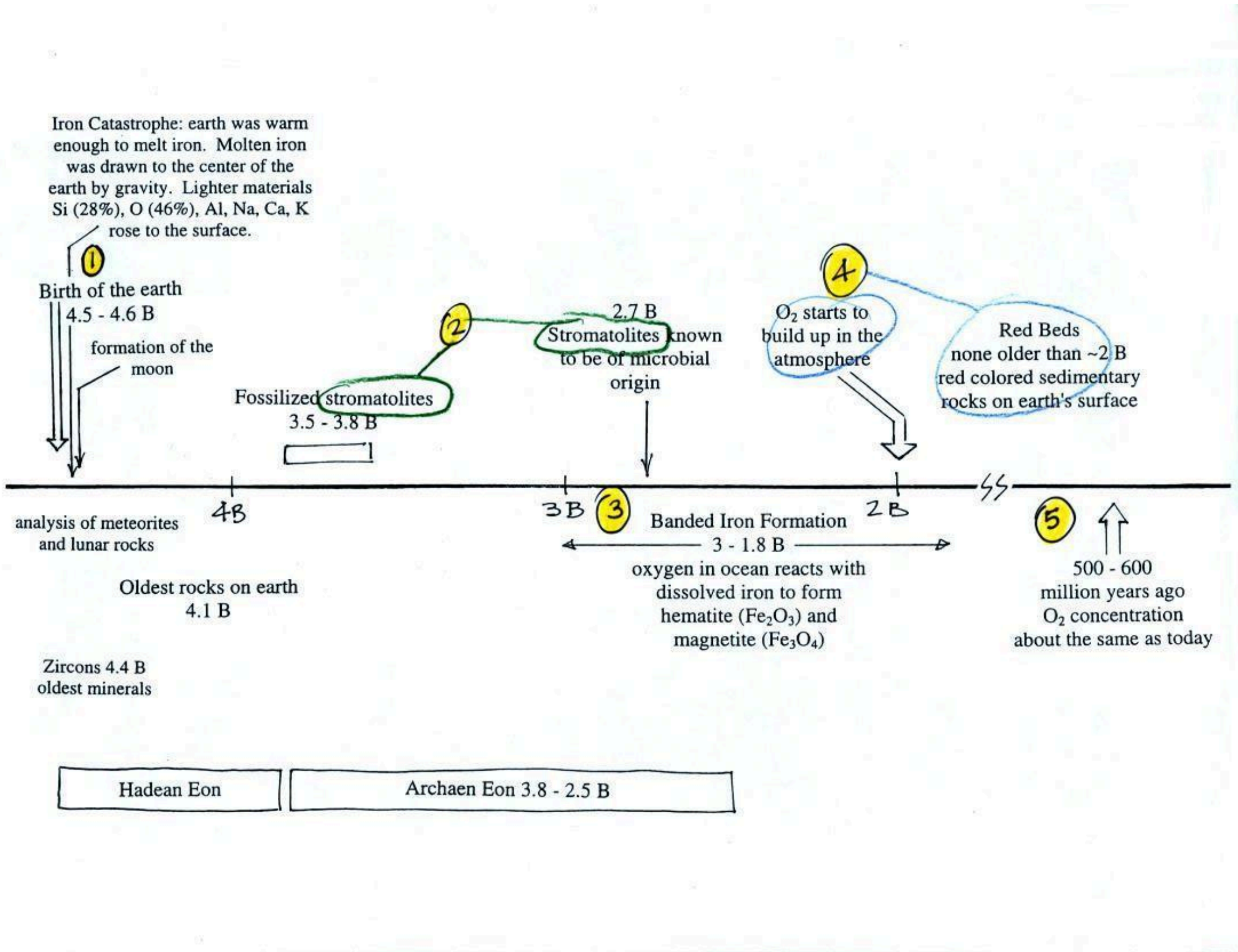


We burn fossil fuels (dead but undecayed plant material) to generate energy. Water vapor and carbon dioxide are by products. Combustion is a source of CO_2 (photosynthesis is a "sink" for atmospheric CO_2 , it removes CO_2 from the air). Carbon dioxide is the subject of an upcoming 1S1P assignment and we'll see these two equations again there and when we study the greenhouse effect and global warming.

Here's a detail that I often forget to mention when this material is covered in class (and something you probably don't need to remember). The argon we have in the atmosphere apparently comes from the radioactive decay of potassium in the ground. Three isotopes of potassium occur naturally: potassium-39 and potassium-41 are stable, potassium-40 is radioactive and is the source of the argon in the atmosphere.

Stromatolites, banded iron, red beds - geological evidence of oxygen on earth

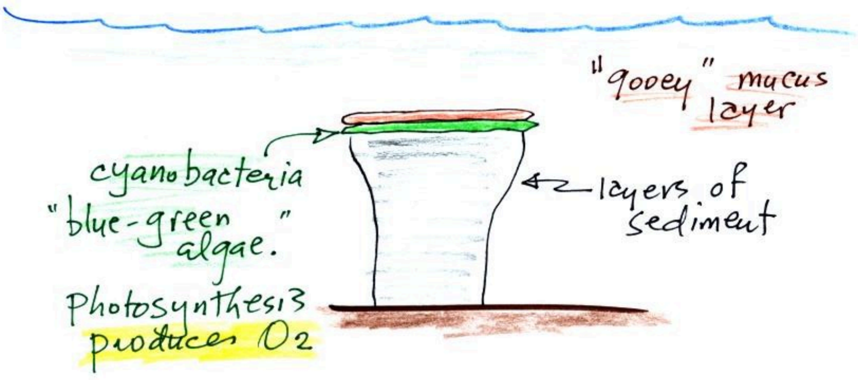
The following figure is the first page in the packet of photocopied ClassNotes.



This somewhat confusing figure shows some of the important events in the history of the earth and evolution of the atmosphere. There were 5 main points I wanted you to take from this figure, and really 1-3 are the most important.

First, **Point 1**: the earth is thought to be between 4.5 and 4.6 billion years old. If you want to remember the earth is a few billion years old that is probably close enough. A relatively minor point shown in the figure: the formation of the earth's molten iron core was important because it gave the earth a magnetic field. The magnetic field deflects the solar wind and prevents the solar wind from blowing away our present day atmosphere.

Stromatolites (**Point 2**) are geological features, column-shaped structures made up of layers of sedimentary rock, that are created by microorganisms living at the top of the stromatolite (I'm not a geologist and I've never actually seen a stromatolite, so this is all based on photographs and written descriptions). Fossils of the very small microbes (cyanobacteria = blue green algae) have been found in stromatolites as old as 2.7 B years and are some of the earliest records of life on earth. Much older (3.5 to 3.8 B year old) stromatolites presumably also produced by microbes, but without microbe fossils, have also been found.

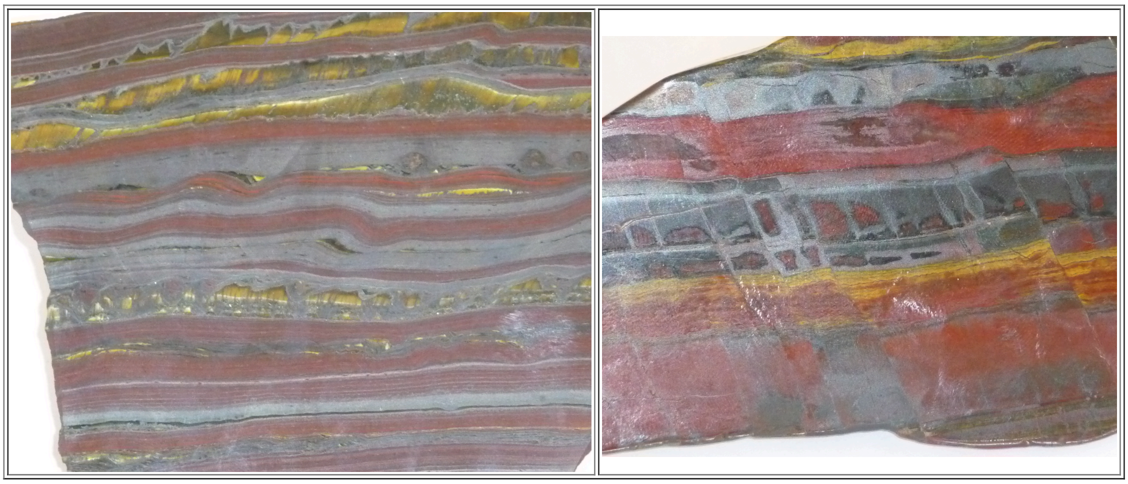


Blue green algae grows at the top of the column, under water but near the ocean surface where it can absorb sunlight. As sediments begin to settle and accumulate on top of the algae they start to block the sunlight. The cyanobacteria would then move to the top of this sediment layer and the process would repeat itself. In this way the stromatolite column would grow layer by layer over time. You might be wondering why we are learning about stromatolites. It's because the cyanobacteria on them were able to produce oxygen using photosynthesis.

Living stromatolites are found in a few locations today.The two pictures above are from Lake Thetis (left) and Shark Bay (right) in Western Australia (the two photos above and the photograph below come from this source). The picture was probably taken at low tide, the stromatolites would normally be covered with ocean water. It doesn't look like a good place to go swimming, I would expect the top surfaces of these stromatolites to be slimy. Hamelin Pool in Western Australia is a World Heritage Area, the stromatolites there are the oldest and largest living fossils on earth (see this source for more information)

Living stromatolites at Highborne Cay in the Bahamas.

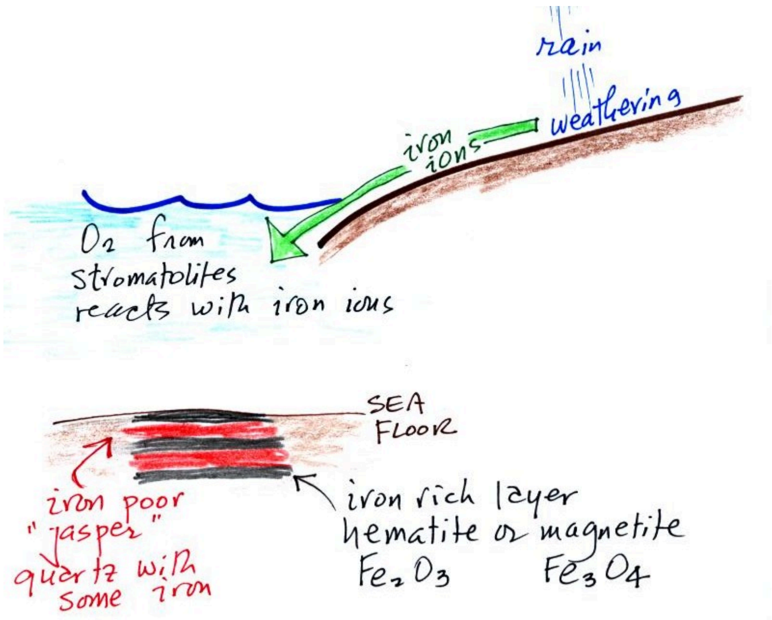
Point 3 refers to the banded iron formation, a type of rock formation. These rocks are 2 - 3 billion years old (maybe older) and are evidence of oxygen being produced in the earth's oceans. Here are a couple of pictures of samples of banded iron formation rock that I passed around in class.



The main thing to notice are the alternating bands of red and black. The rocks are also relatively heavy because they contain a lot of iron. The next paragraph and figure explain how these rocks formed.

Banded iron formation

Rain would first of all wash iron ions from the earth's land surface into the ocean (this was at a time before there was any oxygen in the atmosphere). Once in the ocean, the iron ions reacted with oxygen from the cyanobacteria living in the ocean water to form hematite or magnetite. These two minerals precipitated out of the water to form a layer on the sea bed. This is what produced the black layers.



Periodically the oxygen production would decrease or stop (rising oxygen levels might have killed the cyanobacteria or seasonal changes in incoming sunlight might have slowed the photosynthesis). During these times of low oxygen concentration, red layers of jasper would form on the ocean bottom. The jasper doesn't contain as much iron.

Eventually the cyanobacteria would recover, would begin producing oxygen again, and a new layer of hematite or magnetite would form. The rocks that resulted, containing alternating layers of black hematite or magnetite and red layers of jasper are known as the banded iron formation. In addition to the red and black layers, you see yellow layers made of fibers of quartz in the samples passed around class.

Eventually the oxygen in the oceans reacted with all of the iron ions in the water. Oxygen was then 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 (rust colored) sedimentary rock. These are called "Red Beds" (**Point 4**). None of these so-called red beds are older than about 2 B years old. Thus it appears that a real buildup up of oxygen in the atmosphere began around 2 B years ago.

Red State Park near Sedona Arizona. An example of "red beds" that formed during the Permian period 250-300 million years ago.

Oxygen concentrations reached levels that are about the same as today around 500 to 600 million years ago (**Point 5** in the figure).