Earth History & Geobiology

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Intro: Earth differs from other rocky planets by the presence of the hydrosphere, free oxygen and the presence of complex life. It is a major scientific challenge (the million dollar question if you like) to understand how water, oxygen and live came to the earth, I present just an outline of the "main-stream" of scientific opinions. This is an area of intense ongoing research.

First lets have a look at the chronology of the Early Earth (PPT)

- Formation of solar system
- Core segregation
- Accretion near completion
- Formation of Atmosphere
- Oldest evidence for silica diff
- Oldest preserved minerals
- Oldest preserved rocks.

I. Formation of the Hydrosphere

Why do we have so much water on Earth (PPT)?

The fact the water is present on the earth is not easy to explain. If reduced iron is present H_2O reacts to FeO and H_2 likely an important process during early earth history. At the elevated temperature conditions that prevailed during that time hydrogen escaped to the universe. Likely during the giant moon forming impact event volatile elements were lost (the earth is considerably depleted in e.g. K_2O compared to C1). So if we lost all volatile elements why do we have water on Earth ?

- It is thought that the presence of water is related to the so-called "late heavy bombardment either due to comets (Dirty Snowballs) or through Asteroids (bounded in minerals, Clays, Serpentine).
- Comets do not have same D/H isotopic composition as the earth, therefore many people think that water was delivered by Meteorites.
- Late heavy bombardment possibly related to a resonant instability in the Kuiper belt, Main evidence for it is found on Moon, (spike of ages of impact related melts). Its existence is debated…
- Earliest clear evidence for water is as old as 3.8 Ma (Isua rocks)

II. Conditions on the early earth pretty cold ? (ppt)

Sun's luminosity increases by 5% each 1 Ga, because of the change in particles due to fusion processes. Yet paleo estimates on earth surface (isotopes of C and O) indicate a rater “constant” temperature regime and based on the above mentioned excample we know that liquid water was present on the Earth at 3.8 Ga.

This problem is the so-called “faint young sun paradox”.

Possible solution is an extreme greenhouse gas condition due to the decrease in silicate weathering and lower CO2 sequestration with decreasing surface temp and run off (PPT), resulting in an overall buffered surface temp.

The CO_2 problem will bring us to the next big unsolved question in geosciences the rise of oxygen.

III. Early atmosphere

What do we know about earth earliest atmosphere?

Detrital minerals and certain rock association give us an indication of the surface conditions, we know based on the rock types (e.g. Cgl with rounded pebbles) the surface water was present in the early earth. Additionally, we can use the mineralogical composition of detrital minerals to make inferences on the atmospheric conditions. In Archean sediments we find detrital Uraninite, Siderite and Pyrite. These minerals are not stable under oxic conditions and so indicate the the earliest atmosphere was reducing. These observations are in accordance with the presence of BIF in Archean terranes. As Taylor told you before these rocks are formed as chemical sediment precipitated out of the ocean water under anoxic/oxic conditions. Fe2+ introduced e.g., from black smokers into the ocean, is soluble in water contrary Fe3+ is insoluble. Accordingly, under anoxic conditions we have a lot of Fe 2+ dissolved in the oceans that precipitate out when we (locally) increase the oxygen concentration. It is thought that the layering of Magnetite and silica is du to the fact that locally bacteria increase the oxygen content resulting in precipitation of magnetite layers. Increased oxygen content however, was poisonous for early life forms and so they died of resulting in the formation of chert (generally considered the results of “background” sedimentation; only important if nothing else accumulates). With time the bacteria grew back resulting in the alternating layers of magnetite and chert. However, this mechanism can not account necessarily for all observation in BIF (presence of reduced Fe...), alternative models involve anoxygenic photosynthesis processes such as:

$$4Fe^{2+} + CO_2 + H_2O \rightarrow CH_2O + 2\ Fe_2O_3 + 2\ H^+$$

in this model the oxidized iron scavenges Si from seawater. Reaction between CH_2O and Fe_2O_3 could produce the reduced Fe in that model.

So when did the earth evolve from anoxic to oxic conditions?

Once again we can use an isotopic system to answer that question. Sulfur has three different stable isotopes. Those isotopes fractionate according to their mass (mass dependent fractionation) Only under the absence of free oxygen there is a complicated mechanism in the upper atmosphere that results in mass independent sulfur fractionation. This plot show the presence of sulfur MIF fractionation with time and you can see that there is a sharp decrease in MIF at ~ 2.4 Ga, the rise of oxygen… It is generally thought that oxygen is produced by biological processes algae) so the increase of oxygen should correlate with the appearance of life. Even so in detailed discussed, there is evidence that life existed on earth billions of years before the rise of oxygen.

So what triggered the rise of oxygen??

Wo do not have a definite answer to the question. What most people agree on is that you have to loose a reduced reservoir in order to balance the free oxygen. Two important redox reaction are frequently considered and based on those we will look at two models but multiple more exist:

One model involves the formation of organic carbon

$CO_2 + H_2O \rightarrow CH_2O + O_2$

In this model to oxidize the atmosphere we have to "loose" the reduces organic carbon. As geological reworking is quite profound over geological timescales, a popular model is to subducted the reduced carbon in for of e.g. black shales etc.

An alternative model is the so-called hydrogen escape model:

In that model oxygen is formed by

$$CO_2 + H_2O \rightarrow CH_4 + 2O_2 \rightarrow CO_2 + O_2 + 2H_2$$

The hydrogen as mention before has the potential to escape to space both models have problems and are discussed. It is relatively easy to come up with a possible model that explain the rise of oxygen the difficult part is to get the right answer from the rocks.

In order to explain the Cambrian explosion and the overall C isotopic composition, it is currently popular to assume that rise of oxygen occurred in two steps, whereas it is very difficult to quantify the absolute values of each stage.

The whole process seems to temporally correlate with the postulated global glaciation event and if true have to be additionally incooporated in those models.

Lets assume we have oxygen and we developed organism that can cope with free oxygen. Another poorly understood phenomenon in earth history is mass extinctions.

We know from paleontological studies that species die out over short time scale in what appear to be catastrophic events. (PPT)

The big question circles around the trigger of these mass extinction and two popular endmember models are discussed gigantic volcanic eruptions

Outlook: What will happen to earth through time? (ppt)

Luminocity The Sun's luminosity is increasing about 5% every billion years. We can show this by considering the Sun as an ideal gas and calculating how its density and temperature change as the number of particles change due to fusion burning.
Recall that the primary fusion pathway in the Sun is 4 H → 1 He, that the primordial ratio of H/He is about 9/1,
and that the Sun converts about 10% of its H in its lifetime of 10 billion years.
Consider 110 particles in the Sun at present. How many will there be in 10 billion years?
Now 10 billion years later
100 H → 90 H
10 He → 10 + 10/4 = 12.5 He
$n_1 = 110 \rightarrow n_2 = 102.5$ particles
The fractional change in number of particles is n_2-n_1/n_1 = $\Delta n/n$ = -7.5/110 per 10 billion years.
Now apply this to the ideal gas law, PV = nRT, where P = pressure, V = volume, n = number of particles, R = gas constant, and T = temperature.
If we assume PV/R = constant, then nT = constant: if the number of particles in the Sun decreases, its temperature will increase:
If the temperature of the Sun increases, its Luminosity (or power emitted) will also increase. The Stefan-Boltzmann relation tells us that the radiant flux = power/area of any blackbody depends on its temperature T and size: Flux = σT^4 = L/area. If we again neglect any changes in the Sun's size, this means that $L \sim T^4$
We find an increase of about 30% in ten billion years. If the process is linear, this would yield an increase of 3% in one billion years – close to the actual 5%.
(The process is not quite linear, and we have neglected changes in size and pressure.)