Earth History & Geobiology
Chronology of the early Earth

4567 Ma: Formation of Solar system (Pb-Pb)  0
4530±10: Core segregation (Hf-W-U-Pb)  30-50
4480±20: Moon forming event (Rb-Sr)  70-110
4450±50: Accretion of Earth nearly complete  120±50
<4450±50: formation of the Atmosphere (I-Xe)  >120±50
4420±80: Formation of the oldest Crust (Sm-Nd)  140±80
4417 Ma: oldest minerals on Moon (Zircon)  150
4404 Ma: oldest minerals on Earth (Zircons from Aus)  163
4000 Ma: oldest preserved continental crust  570

Photograph courtesy of NASA. Image in the public domain.
Why does the Earth have so much water?
Hydrogen loss

- accretion of the early earth due to impact of numerous planetesimals
- Thereby native iron was added to the >1000 °C hot surface.
- On the surface iron reacts with H\textsubscript{2}O: Fe\textsuperscript{0} + H\textsubscript{2}O = FeO + H\textsubscript{2}
- Even today on Earth (final size) H and He can escape,
- Only the two lightest elements can reach the escape velocity of ~ 40,300 km/h (11 km/s)
- The early earth had no magnetic field so solar wind reached earth surface enhancing the loss of the atmosphere

<table>
<thead>
<tr>
<th>gas</th>
<th>mass</th>
</tr>
</thead>
<tbody>
<tr>
<td>H\textsubscript{2}</td>
<td>2</td>
</tr>
<tr>
<td>He</td>
<td>4</td>
</tr>
<tr>
<td>CH\textsubscript{4}</td>
<td>16</td>
</tr>
<tr>
<td>CO\textsubscript{2}</td>
<td>44</td>
</tr>
<tr>
<td>N\textsubscript{2}</td>
<td>28</td>
</tr>
<tr>
<td>O\textsubscript{2}</td>
<td>32</td>
</tr>
<tr>
<td>Ar</td>
<td>40</td>
</tr>
</tbody>
</table>
During gravitational differentiation, iron sank to the center and lighter material floated upward...

...to give us Earth as a layered planet.
Why does the Earth have so much water?

Likely added by a later event...

Evidence for surface water

© source unknown. All rights reserved. This content is excluded from our Creative Commons license. For more information, see http://ocw.mit.edu/help/faq-fair-use/.

Photograph courtesy of NASA. Image in the public domain.

Likely added by a later event...
Likely most of the volatiles elements originate from meteorites.

The D/H of comets is distinctive different from Earth.
Comets are “dirty snowballs”, composed of dust and ice.

Photograph courtesy of NASA. Image in the public domain.
We think the water was added by the late heavy bombardment event.
Impact rate on the Earth

Earth is too small during the main accretion event to retain hydrogen. \( \text{H}_2\text{O} \) react with Fe to FeO and \( \text{H}_2 \)
→ depletion of H, noble gases etc.

Giant impact add additionally energy –
Volatile elements get “lost in space”

Later addition of volatiles by a “late heavy bombardment”
Evidence for it are observed on the moon
(ages spectra of impact melts), indirect evidences on Earth.

“late heavy bombardment” might not happen
in all planetary systems

© source unknown. All rights reserved. This content is excluded From our Creative Commons license. For more information, see http://ocw.mit.edu/help/faq-fair-use/.
Analyses of oxygen isotopes in Zircons possible indicate presence of water at > 4 Ga
We formed a early earth but what were the condition on It?

Courtesy of Brian Smallwood. Used with permission.
Huronian, Canada ~2.45 Ga

Detrital siderite, FeCO₃
Detrital minerals that are unstable in the presence of "free" oxygen.

Detrital uraninite, \(\text{UO}_2\)

Detrital pyrite, \(\text{FeS}_2\)
Pilbara, Australia \(~3.25\) Ga

Detrital siderite, \(\text{FeCO}_3\)
Pilbara, Australia \(~2.75\) Ga

Huronian, Canada \(~2.45\) Ga

\(\text{FeS}_2\)
\(\text{UO}_2\)
\(\text{FeCO}_3\)
BIF:
Banded Iron Formations

Chert (=SiO$_2$) coated with Fe-Oxide

Magnetite-layers(Fe$^{II}$Fe$^{III}_{2}$O$_4$)

© sources unknown. All rights reserved. This content is excluded from our Creative Commons license. For more information, see http://ocw.mit.edu/help/faq-fair-use/.
Presence of free water is puzzling given the low luminosity of the young sun.
Modern oxic soil profile, southeastern Brazil
Feedback between silicate weathering and CO$_2$ sequestering.
Timeline of earth history removed due to copyright restrictions.
Some people, like Fred Hoyle, proposed that life came from another planets with the help of meteorites.
Stanley Miller and Harold Urey showed, that aminoacids can easily be produced on earth surface
They simulated lightning in a oxygen free atmosphere
Alternatively life might have originated at the bottom of the ocean (distinct advances: strong geochemical gradients, protected from UV, Heat, reducing conditions, not too much convection)
**Prokaryote:**

Cellular life forms without nucleus

Extremophiles:

$T > 100 \, ^\circ\text{C}$, $\text{pH}$ down to 1, $P$ bis 1000 bar

---

**Eukaryote:**

Cellular life forms with nucleus

---

© sources unknown. All rights reserved. This content is excluded from our Creative Commons license. For more information, see http://ocw.mit.edu/help/faq-fair-use/.
Isotopic fingerprint of life

© sources unknown. All rights reserved. This content is excluded from our Creative Commons license. For more information, see http://ocw.mit.edu/help/faq-fair-use/.
Archean S-33 anomaly and atmospheric $O_2$

$$\Delta^{33}S = \delta^{33}S - 0.515 \delta^{34}S$$

Data source: Farquhar, Ono, Johnston etc.
Rise of oxygen how does it work?

© Heinrich D. Holland. Some rights reserved. License: CC-BY-SA. This content is excluded from our Creative Commons license. For more information, see http://ocw.mit.edu/help/faq-fair-use/.
Evidence for the earliest evolution of the Earth are largely missing.

Oldest rocks

Possible earliest life forms (Discussed)

Prokaryote

Rise of Oxygen

Proven existents of Prokaryote and Eukaryote

Proven existents of Prokaryote and Eukaryote

Proven existents of Prokaryote and Eukaryote

Complex life forms: Cambrian explosion

Humans
The mass extinctions of the last 350 Ma correlate (?) with flood basalts.
(nearly) perfect Correlation between major flood basalts and mass extinction

© source unknown. All rights reserved. This content is excluded from our Creative Commons license. For more information, see http://ocw.mit.edu/help/faq-fair-use/.
Meteorite impact at the (K-T)?

Yes – but maybe slightly before mass Extinction (ca. 0.2-0.4 Ma),
So only one factor.
Outlook: What will happen to the earth in the next few Ga?

Sun today:
6% more intensive as before 560 Ma,
25% more intensive as before 4.5 Ga,
40% less intensive as in 6.4 Ga...
The End of time...

In 6 Ga sun might become a red giant

Courtesy of NASA. Images in the public domain.
Early Earth
\( T = 0.1 \text{ Ga} \)
\[
\begin{align*}
R &= 0.9 \, R_{\text{sun}} \\
L &= 0.7 \, L_{\text{sun}}
\end{align*}
\]

in 1 Ga: +10%
\( T = 5.6 \text{ Ga} \)
\[
\begin{align*}
R &= 1.0 \, R_{\text{sun}} \\
L &= 1.1 \, L_{\text{sun}}
\end{align*}
\]
→ its gone get pretty warm...

Double the age: +40%
\( T = 9.0 \text{ Ga} \)
\[
\begin{align*}
R &= 1.1 \, R_{\text{sun}} \\
L &= 1.4 \, L_{\text{sun}}
\end{align*}
\]
Now its hot...