Outline 9: Origin of the Earth: solids, liquids, and gases

The Early Archean Earth

Origin of Earth’s Matter

- The earth is made of recycled elements formed in stars that existed prior to our Sun.
- Supernova explosions produced nebular dust clouds of various elements.
- Our solar system formed from a nebular dust cloud.

The Crab Nebula, remnant of a supernova explosion in 1054 AD
Formation of Earth

- Our planet formed along with all the other planets when our solar system formed 4.6 BY ago.
- The planets formed by planetary accretion.
- Gravity slowly brought solids and gases together.
Formation of Earth

- All the planets had rocky cores and gaseous outer layers, just like modern Jupiter or Saturn.
- Earth was 1200 times more massive.
- Ignition of the sun stripped the inner planets of their gaseous outer layers.

Size comparison between the inner, rocky planets and the outer gas giant planets

Formation of Earth

- The early earth formed from meteorites, asteroids, comets, and planetesimals. It was cold and lumpy.
- It heated up and completely melted.
The earth formed by planetesimal accretion and meteorite impact

The Early Molten Earth

Heat sources:
1. Gravitational compaction
2. Impact energy converted to heat
3. Heat from radioactive decay - most important source

Heat generated by impact and radioactive decay began to melt the early earth.
Eventually the earth became completely molten and separated into layers by density.

A view of earth from the moon about 4.5 BY ago.

The Early Molten Earth

Earth became layered according to density.

- Core, 14% of volume; iron
- Mantle, 84% of volume; ultramafic material
- Crust, 2% of volume; mafic material or rocks
Origin of Oceans and Atmosphere

- Formed by degassing of the mantle.
- Modern oceanic (mafic) volcanic gases:
  - H₂O, 79%, as steam
  - CO₂, 12%
  - SO₂, 7%
  - N₂, 1%
  - Cl, <1%

Water from Rocks?

- Meteorites are 0.5% water.
- An equivalent amount of water in the mantle would fill the ocean basins 20 times!
- Volcanoes today release enough water to have filled the ocean basins 100 times during earth history!
A. Stony meteorite – ultramafic in composition, olivine-rich like the mantle.

B. Stony-iron meteorite – olivine and iron that were the source of the earth’s mantle and core.

Solid crust and liquid water, 4.4 BY ago?

The First Atmosphere

• Order of abundance after water vapor, \( H_2O \):
  Carbon dioxide, \( CO_2 \)
  Sulfuric acid, \( H_2SO_4 \)
  Ammonia, \( NH_3 \)
  Methane, \( CH_4 \)
The First Atmosphere

- Poisonous to modern life.
- No free oxygen.
- Contained the basic elements of life: carbon, oxygen, nitrogen, sulfur, and hydrogen.

The Modern Atmosphere

- 78% nitrogen
- 21% oxygen
- 1% argon
- 0.03% carbon dioxide
- What happened to all the CO₂?

Photosynthesis

The Modern Atmosphere

- Created by biological processes. The only planet with free oxygen.
- Photosynthetic bacteria used water and carbon dioxide to make sugar and the by-product oxygen.
  \[6\text{H}_2\text{O} + 6\text{CO}_2 \rightarrow C_6\text{H}_{12}\text{O}_6(\text{sugar}) + 6\text{O}_2\]
How do Venus and Mars help us understand Earth’s origins?
Venus: too hot
Mars: no liquid water

Venus, shrouded in clouds of sulfuric acid

Venus beneath the clouds. False colors show topography.
Radar image of the surface of Venus

Computer image of rift valley on the surface of Venus

View from Russian Venus lander that lasted a few minutes in 1982. Temperature was 500 degrees C (900 degrees F).

Temperature was 500 degrees C (900 degrees F).
Mars viewed by the Hubble space telescope. 50% farther from the sun than Earth.

The north pole of Mars: seasonal changes of the water-CO$_2$ ice cap.

Mars viewed by a fly-by space probe
Shaded relief image from MOLA produced for *Sky and Telescope* magazine. Shown are the Tharsis province including the major volcanoes, the Valles Marineris, and the Chryse outflow regions. The Argyre impact basin can be seen at the lower right.

Ancient magnetic reversal patterns (>3 BY) on Mars suggest plate tectonic processes early in the history of Mars.

Magnetic Stripes from Sea Floor Spreading
Another view of the magnetic stripes on Mars.

Cyclone on Mars near the North Pole
April 27, 1999

Civilization on Mars?
Mars lander and Sojourner, 1997. The -100°C temps at night wore down the batteries.

Sojourner getting up close and personal with the rock Yogi for a chemical analysis.

Sojourner did find life on Mars, or at least that’s what some folks say on the internet!
Sand dunes in valley on Mars

Layered Sedimentary Rocks on Mars indicate once Flowing Water

River Delta Deposits on Mars indicate once Flowing Water
On earth, this texture occurs when crystals of salt minerals form within rocks sitting in briny water. At El Capitan, small cavities called “VUGS” may be voids left when the crystals disappeared. Water may have dissolved them over time.

Meanwhile, Opportunity continued to study the mysterious “blueberries” at Shoemaker’s Patio in Eagle Crater.

During the week, data from Opportunity revealed that the “blueberries” contain hematite, an iron-bearing mineral often formed in water.
Water ice on Mars, 2008


Buried glaciers on Mars still have lots of water

Mars has lost an Arctic Ocean's worth of water (March 2015)

NASA scientists have determined that a primitive ocean on Mars held more water than Earth's Arctic Ocean and that the Red Planet has lost 87 percent of that water to space.


Mars on the left, Earth on the right. How did these conglomerates form?


2012: Curiosity Rover: Conglomerate outcrop on Mars: an ancient stream bed