Lecture 9. Evolution of Earth.

Objectives:

1. Major phases in the evolution of the Earth.
2. Coevolution of the environment and life.

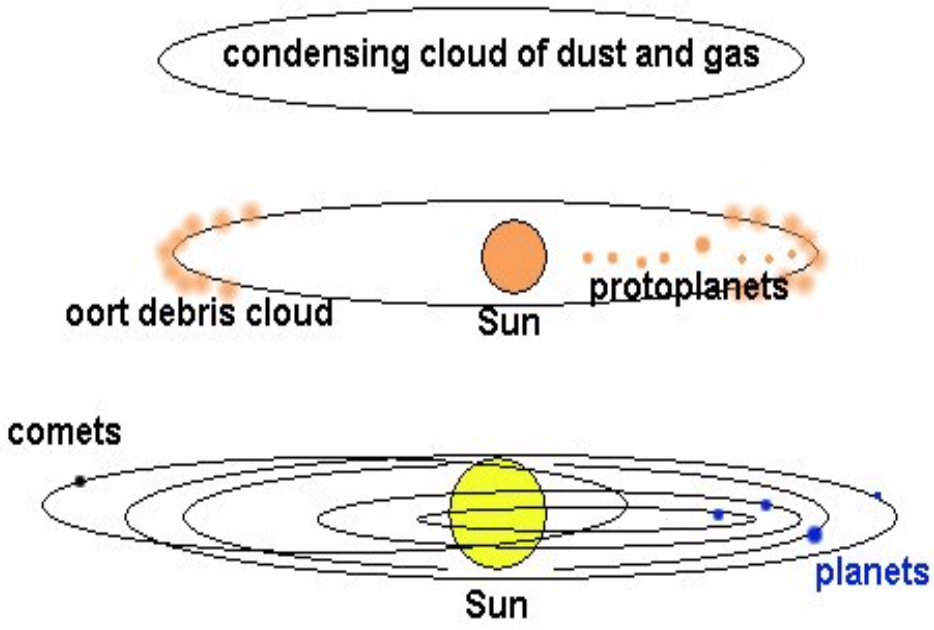
Readings: Turco: p. 84-87; 91-107

1. Major phases in the evolution of the Earth:

- The **accretion of the Earth** and its primitive atmosphere from the primordial solar nebula.
- The differentiation of the interior of the planet and the associated **outgassing** of volatile materials.
- The **chemical era** of abiotic photochemical transformation of the primordial atmosphere to form the organic molecules from which life could spring.
- The **microbial era** during which the first simple life-forms evolved, proliferated, and forever modified the atmosphere and environment.
- The **geological era** in which the physical reconfiguration of oceans and continents caused major deviations in the evolution of life and the atmosphere.
- The **recent age**, when humans appeared with the intelligence to exploit fully all of the capability to alter significantly the global atmosphere and environment.

Origin of the Earth (about 15 to 20 billion years ago):

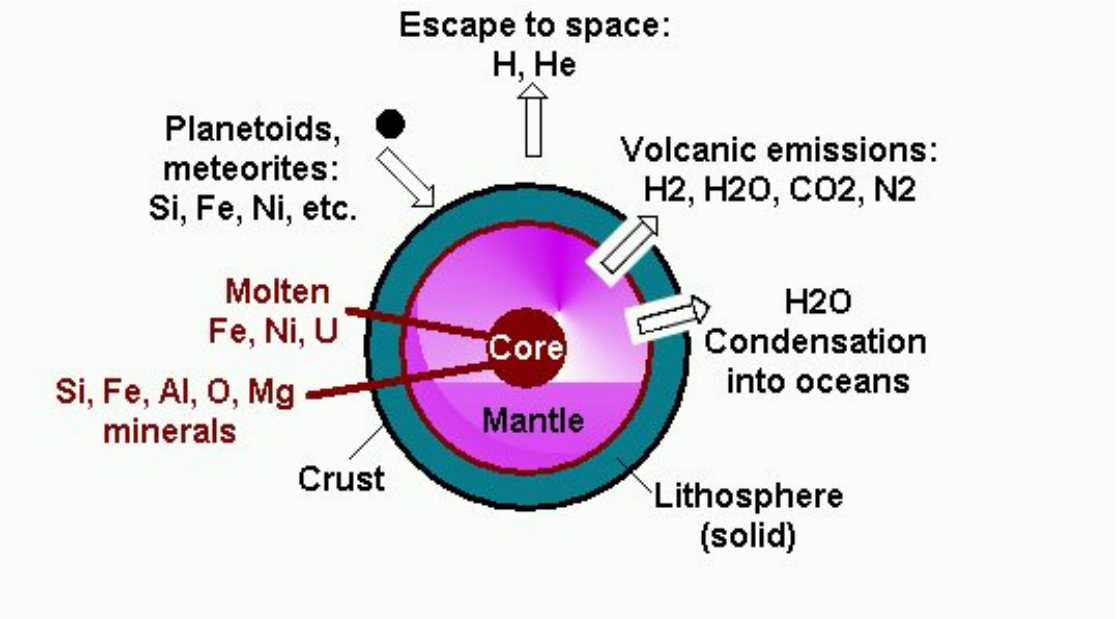
Figure 9.1 The formation of the solar system: a) in the earliest stage, a dense cloud of dust and gas coalesced as the primordial Solar nebula; b) later, the sun and planets condensed as clearly defined objects; c) finally, most of the residual dust and gas was swept up, with only the asteroids and comets remaining.



- The Earth condensed from the solar nebula about 4.5 billion years ago under the influence of gravity.
- The infant atmosphere on Earth consisted of light volatile gases, mainly hydrogen (H_2) and helium (He).

Planetary differentiation and outgassing:

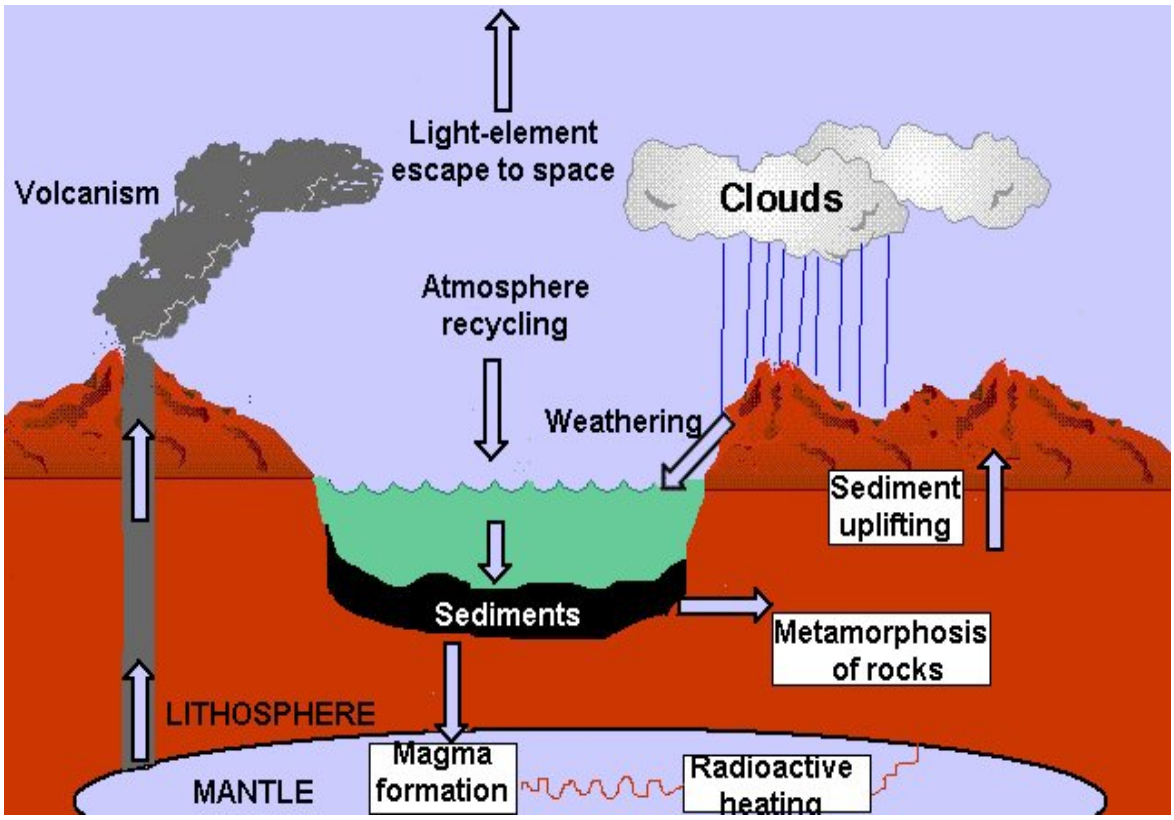
Figure 9.2 The differentiated structure of the early Earth and the principal geophysical and geochemical processes contributed to the evolution of the atmosphere (Turco 1997).



- Molecular oxygen (O_2) was not present in the early atmosphere because all of the elemental oxygen in the solar nebula originally chemically bound in compounds such as CO_2 and H_2O.
- Three dominant volatiles in the earlier atmosphere: H_2O, CO_2, N_2

- The cycling of volatiles controls most of the environmental conditions (the global cycles of important volatiles are discussed in Lectures 9-13).

Figure 9.3 The main processes that recycle material through the Earth's reservoirs.



Chemical era :

atmosphere is controlled by chemical and physical processes (no life exists)

- Because of atmospheric composition (no O_3), high UV radiation initiated various photochemical processes involving gases such as water vapor (H_2O), carbon monoxide (CO_2), methane (CH_4), ammonia(NH_3), and hydrogen (H_2).

For instance:

$2\ NH_3 + h\nu \rightarrow ... \rightarrow N_2 + 3\ H_2$

- Quantity of some gases in the atmosphere was changed during the Earth evolution (e.g., O_2), but other gases remained about constant (e.g., N_2).

Importance of ocean formation on Earth:

⇒ establish a hydrological cycle (discussed in Lecture 13)

⇒ ocean is a key reservoir of volatiles and is a critical factor in climate in several ways- by generating water clouds; by limiting CO_2 in the atmosphere through carbon monoxide conversion to limestone sediments; and by acting as a reservoir for heat storage

⇒ ocean provided the first living organisms

Conversion of carbon monoxide to carbonate sediments in the ocean:

CO_2 (gas) + H_2O ←→ H_2CO_3 (aqueous)

H_2CO_3 (aqueous) ←→ $H^+ + HCO_3^-$

HCO_3^- ←→ $H^+ + CO_3^{2-}$

NOTE: Aqueous phase chemistry will be discussed in Lecture 13.

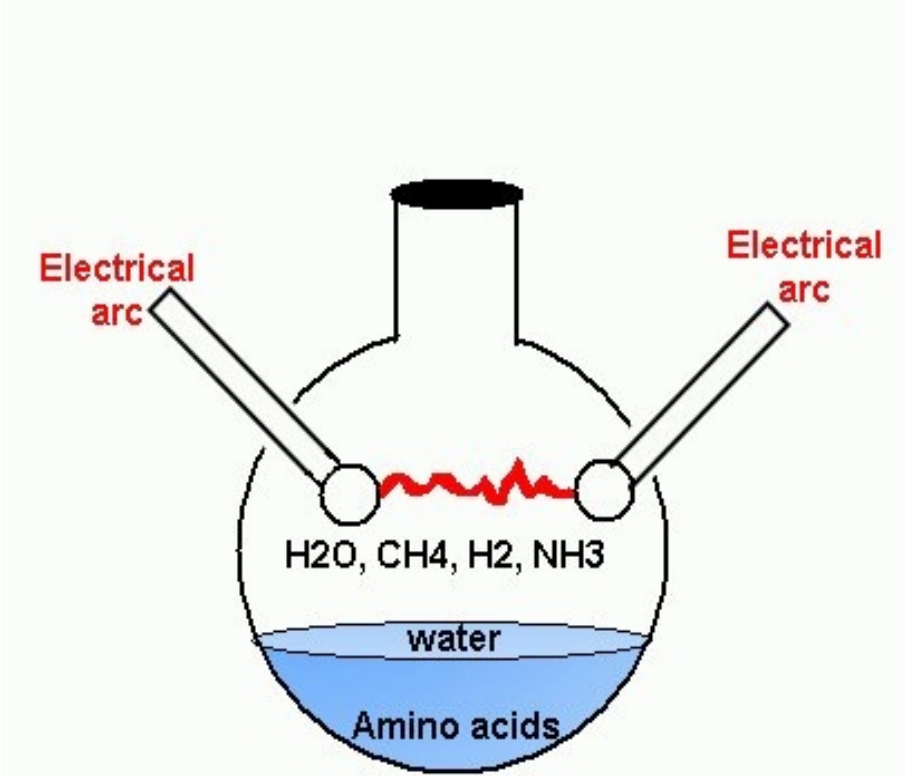
$Ca^{2+} + CO_3^{2-}$ →$CaCO_3$ (precipitate)

Microbial era :

life was formed in the form of microscopic organisms

- Mixture of gases (such as H2, N2, CH4, H2O, NH3) exposed to high-energy (lightning, UV radiation, etc.) can form organic molecules of life.

Figure 9.4 The Miller-Urey experiment to create the building blocks of life.



NOTE: The moment in time and the chemical means of formation of the first living organism remain unknown.

2. Coevolution of the environment and life.

Major steps:

- Abiotic chemical evolution on a lifeless Earth;
- Bacterial evolution;
- Photosynthesis: green plants utilize light, water, and carbon dioxide;
- Atmospheric oxygen accumulation;
- Aerobic respiration: evolution of oxygen-using life-forms;
- Ozone layer formation: allows life to move out of the oceans into land;
- Complex terrestrial life.

- The microbes have had the greatest influence on the atmosphere in terms of basic metabolic chemical transformation. However, *Homo sapiens* (meaning ‘wise man’) can cause worldwide changes due to our unprecedented intelligence (despite that the total human ‘biomass’ is less that 0.1% of all biomass on Earth.