

Chapter 7. Home: The Double World

The Double Planet

- The Earth and the Moon can be considered a double planet, each orbiting around the *center of mass*. The mass of the Moon is roughly 0.012 times the Earth's mass. The mean density of the Moon is 3.3 g/cm^3 . The gravity on the Moon's surface is 1/6 that on the Earth's surface.
- *Tides* are caused by the differential gravitational pull exerted by the Moon. The strongest tides occur at new Moon at perigee when the Earth is at perihelion.
- The Moon's gravitational pull on the Earth's bulge slows down the Earth's spin by 0.0015 second per century. The Earth's gravitational pulls on the Moon's bulge slowed down the Moon's spin, too, until the Moon has been tidally locked onto the Earth. This is called *synchronous rotation*.
- Radioactive dating. Radioactive isotopes may decay into lighter, more stable elements. ^{238}U (uranium) decays into ^{206}Pb (lead) with a half life of 4.5×10^9 yrs. We may derive the age of a radioactive rock from its current content of ^{238}U and ^{206}Pb .
- The rocks of the Earth show ages up to 4.2×10^9 yr. The oldest Moon rocks are $4.3\text{--}4.5 \times 10^9$ yr old. The ages of meteorites are $4.5\text{--}4.6 \times 10^9$ yr. The Earth was formed together with the rest of the planetary system around the Sun, so the Earth must be at least about 4.6×10^9 yr old.

The Earth's Surface

- The surface coverage of the Earth: 30% dry lands (continents) and 70% water (oceans). Mountains exist on continents as well as under the oceans. Mountains are organized into groups and long chains.
- The Earth's dry lands are covered by rocks and soil. Most rocks are silicates made of silicon, oxygen, and other metals. The most common surface rocks are granites. Basalts are heavier rocks and dominate the ocean beds. Soil consists of crushed rocks and compost.
- The continents contain the oldest rocks, $\sim 4.2 \times 10^9$ yr. The seabed is $< 2 \times 10^8$ yr, indicating that it is constantly destroyed and renewed.
- The Earth's surface is active with earthquakes and volcanoes. *Cinder-cone volcanoes* erupt explosively, throwing ashes and rocks for large distances. *Shield volcanoes* are mild and produce runny lava outflows.

The Contrasting Lunar Surface

- The surface of the Moon has no water and no atmosphere. The surface gravity is too low to retain an atmosphere.
- The lunar surface shows bright and dark areas.

	Bright Areas	Dark Areas
Name	lunar highlands	maria
Percentage reflectivity	higher (15%)	lower (8%)
Craters	many	few

- The impact of a meteoric body creates shock waves that blast and melt rocks and expel the debris to large distances. Upon impact, kinetic energy is converted to heat energy, and its amount is comparable to that released by a small nuclear bomb. A powerful impact creates a complex crater with crater walls, central peaks (the floor rebounds), secondary craters, rays, ejecta blankets, etc. Some rocks, blasted off the moon, have even made their way to Earth.
- *Maria* is the plural of *Mare*, Latin for “Sea”. Most maria have circular outlines indicating that they are contained by enormous impact craters, called *impact basins*. The impact was so powerful that the crust was ruptured to allow outflows of magma. The solidified magma gives maria the dark appearance.
- The farside of the Moon has fewer mare formation because of a thicker crust.
- A period of “heavy bombardment” occurred at 3.8 to 4 billion years ago. Most of the craters we see were formed toward the tail, at late heavy bombardment. The mare formation took place after the heavy bombardment.

Impacts and the Earth

- Impact craters exist on Earth as well, although many have been erased by surface activities and erosion. The meteorites that hit water will not produce craters. 150 craters on Earth have been confirmed.
- The meteorite impact that formed the crater at Mexico’s Yucatan peninsula may be responsible for the extinction of dinosaurs.

Interiors

- The first clue to the structure of the Earth is its average density, 5.5 g/cm^3 , which is much higher than the average density of surface rocks, implying that the Earth’s center must have much higher densities.
- When the interior of a planet is still in a liquid form, the heavy metals sink to the center under the force of gravity and the lighter material floats to the top (surface). This process is called *differentiation*. Iron, the most common metal, sinks to the center of the Earth and forms the core.
- Earthquake waves, or seismic waves, are used to probe the internal structure of the Earth. Two types of seismic waves are useful: the *primary wave* (P wave) and the *secondary wave* (S wave).

The P wave vibrates the rock back and forth along the direction of the wave, while the S wave vibrates the rock perpendicular to the wave's direction. S waves and P waves have different speeds. Their speeds depend on the material, density, and temperatures encountered along the paths. The arrival times of the original, reflected, and refracted seismic waves at many different stations around the Earth can be used to analyze the interior structure of the Earth.

- S waves cannot pass through liquid. Since no S waves can propagate to the opposite side of the Earth, the Earth must have a liquid core. The center of the liquid core has such a high pressure that a solid core is formed.
- The liquid core has a higher temperature at the bottom. The hot liquid has lower density and can rise to the top at lower temperature. As it cools, it falls back down again. This circulation is called convection.
- Iron is a good electric conductor, in which electrons can move freely among atoms. The circulation of iron, or the convection in the liquid core, generates a magnetic field.
- The Earth's structure consists of, from the center outwards: the iron solid core (thickness $\sim 1,200$ km), the iron liquid core ($\sim 2,200$ km), a narrow transition zone, the mantle ($\sim 2,700$ km), and the lithosphere (~ 100 km). The mantle is the source of the volcanic lavas. The upper part of the lithosphere is the crust.
- The Earth's core slowly solidify to give off heat, and it is also heated by radioactive elements. The crust is a pretty good insulator, so the interior of the Earth is still hot.
- The Moon has a small average density, 3.3 g/cm^3 , indicating a very small iron core, if it exists at all. The Moon does not have a magnetic field, so the iron core must be solid. The iron core is surrounded by a mantle which is the source of lava.

Continental Drift, Plate Tectonics, and Surface Features

- Some 200 million years ago, the great continents were part of a single land mass called *Pangaea*. These continents have been drifting apart. The distance between America and Europe increases at a rate of about 5 cm per year.
- The Earth's lithosphere is divided into 16 separate plates. The movements of the plates lead to the global continental drift. This movement is caused by convection within the upper part of the mantle.
- A plate holding a seabed can dive beneath a plate holding a continent. This process, called subduction, is responsible for the chains of tall mountain ranges and volcanic activities around the Pacific. Plates can also meet at a *fault*.
- Mantle material may come up in *plumes* that probably begin at the core-mantle boundary. As the magma emerges from the crust at the top of the plume, it may create a lava plateau or an isolated shield volcano. The plume is fixed, but the top structure moves with the plate and make a *plume track* in the crust.
- The Moon has only a single plate; it has no continents, no continental drift, no volcanoes, and

no mountains.

Atmospheres

- The Earth's atmosphere consists of 77% N₂, 21% O₂, ~1% H₂O, and 0.033% CO₂.
- The content of H₂O and CO₂, though small in amounts, causes the *greenhouse effect*. The surface of Earth absorbs the sunlight, heats up, and emits like a blackbody. The blackbody radiation of the Earth (at ~300 K) peaks at infrared wavelengths. The H₂O and CO₂ in the atmosphere absorb the infrared radiation and retain the heat in the atmosphere. This is called the greenhouse effect.
- The atmosphere has several distinct layers. The lowest one, called troposphere, contains 90% of the air. The weather changes occur in the troposphere. Commercial airplanes fly near the upper part of the troposphere to avoid turbulences.
- A Moon day is 29.5 Earth days. During the daytime, the Moon's surface can be heated by the sunlight to 110°C (383 K). Lacking an atmosphere, the lunar surface at night can cool down to -170°C (103 K).

Why a Double Planet

- The Moon was probably formed 4.6 billion yr ago. A Mars-sized intruder collided with the Earth. The intruder and the early Earth fused together, and the tidal debris formed the Moon.