Chapter 7
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7.1 Overall Structure of Planet Earth

- Mantle
- Two-part core
- Thin crust
- Hydrosphere (oceans)
- Atmosphere
- Magnetosphere

Figure 7-1. The Main Regions of Planet Earth At the center lies our planet’s solid inner core, about 2600 km in diameter, and surrounding this is a liquid outer core, some 7000 km across. Most of the rest of Earth’s 13,000-km interior is taken up by the mantle, which is topped by a thin crust only a few tens of kilometers thick. The liquid portions of Earth’s surface make up the hydrosphere. Above the hydrosphere and solid crust lies the atmosphere, most of it within 50 km of the surface. Earth’s outermost region is the magnetosphere, extending thousands of kilometers into space.
7.2 Earth’s Atmosphere

- The blue curve shows the temperature at each altitude.
- Troposphere is where convection takes place—responsible for weather.

Figure 7-2. Earth’s Atmosphere Diagram of Earth’s atmosphere showing the changes in temperature (blue curve, bottom axis) and pressure (right-hand axis) from the planet’s surface to the bottom of the ionosphere. Pressure decreases steadily with increasing altitude, but the temperature may fall or rise, depending on height above the ground.
Convection depends on warming of ground by the Sun

Figure 7-3. Convection Convection occurs whenever cool matter overlies warm matter. The resulting circulation currents are familiar to us as the winds in Earth’s atmosphere, caused by the solar-heated ground. Hot air rises, cools, and falls repeatedly back to Earth. Eventually, steady circulation patterns are established and maintained, provided that the source of heat (the Sun, in the case of Earth) remains intact.
7.2 Earth’s Atmosphere

**Ionosphere** is ionized by solar radiation and is good conductor

Reflects radio waves in the AM range, but transparent to FM and TV

**Ozone layer** is between ionosphere and mesosphere; absorbs ultraviolet radiation
Chlorofluorocarbons (CFCs) have been damaging the ozone layer, resulting in ozone hole.

FIGURE 7.4. Antarctic Ozone Hole This composite image constructed from satellite observations shows (in pink) a huge “hole” in the ozone layer over the Antarctic continent. The hole is a region where climatic conditions and human-made chemicals combine to rob our atmosphere of its protective ozone blanket. The depth and area of the hole have grown significantly since the hole was discovered in the 1980s. Its maximum size is now larger than North America.
Surface heating:

• Sunlight that is not reflected is absorbed by Earth’s surface, warming it

• Surface re-radiates as infrared thermal radiation

• Atmosphere absorbs some infrared, causing further heating
7.2 Earth’s Atmosphere

This is known as the greenhouse effect

Figure 7-5. **Greenhouse Effect** Sunlight that is not reflected by clouds reaches Earth’s surface, warming it up. Infrared radiation reradiated from the surface is partially absorbed by the carbon dioxide (and also water vapor, not shown here) in the atmosphere, causing the overall surface temperature to rise.
Scattering of light by air depends on the wavelength of the light—the wavelength of blue light is closer to the size of air molecules, so it is scattered most strongly. The amount of molecular scattering is proportional to the inverse fourth power of the wavelength of the light.
When the Sun is close to the horizon, light is scattered by dust in the air. The more dust, the more scattering; if there is enough dust, the blue light is greatly diminished, leaving a red glow in the sky.
7.2 Earth’s Atmosphere

History of Earth’s atmosphere:

• Primary atmosphere was hydrogen, helium; this escaped Earth’s gravity

• Secondary atmosphere, from volcanic activity, mostly nitrogen

• Life appeared, creating atmospheric oxygen
One result of modern society has been to increase CO$_2$ levels in the atmosphere. A corresponding increase in global average temperature has been seen as well. Exactly how much the temperature will continue to increase is not known.
Discovery 7-1: The Greenhouse Effect and Global Warming

Some possible consequences of global warming:

• Rise in sea level
• More severe weather
• Crop failures (as climate zones change)
• Expansion of deserts
• Spread of tropical diseases away from the tropics
Seismic waves: Earthquakes produce both pressure and shear waves. Pressure waves are longitudinal and will travel through both liquids and solids. Shear waves are transverse and will not travel through liquid, as liquids do not resist shear forces. Wave speed depends on the density of the material.

Figure 7-6. P and S waves (a) A pressure (P) wave traveling through Earth’s interior causes material to vibrate in a direction parallel to the direction of motion of the wave. Material is alternately compressed and expanded. (b) A shear (S) wave produces motion perpendicular to the direction in which the wave travels, pushing material from side to side. Also shown is the motion of one typical particle: In case (a), the particle oscillates forward and backward about its initial position. In (b), the particle moves up and down.
7.3 Earth’s Interior

We can use the pattern of reflections during earthquakes to deduce the interior structure of Earth.

Figure 7-7. **Seismic Waves** Earthquakes generate pressure (P, or primary) and shear (S, or secondary) waves that can be detected at seismographic stations around the world. The waves bend while moving through Earth’s interior because of the variation in density and temperature within our planet. S-waves (colored red) are not detected by stations “shadowed” by the liquid core of Earth. P-waves (colored green) do reach the side of Earth opposite the earthquake, but their interaction with Earth’s core produces another shadow zone, where almost no P-waves are seen.
Currently accepted model

Figure 7-8. Earth’s Interior Computer models of Earth’s interior imply that the density and temperature vary considerably through the mantle and the core. Note the sharp density change between Earth’s core and mantle.
Mantle is much less dense than core
Mantle is rocky; core is metallic—iron and nickel
Outer core is liquid; inner core is solid, due to pressure
Volcanic lava comes from mantle, allows analysis of composition
History: Earth was probably molten when formed and remelted due to bombardment by space debris. Heavier materials sank to the center. Radioactivity provides a continuing source of heat.

Figure 7-9. Earth’s Differentiation Earth’s interior changed considerably throughout its early history. (a) At its origin, 4.6 billion years ago, the Earth was probably already partly molten owing to debris bombardment and continued gravitational infall in its formative stage. (b) A second period of heavy bombardment, at about 4 billion years ago, likely caused its cooling surface layers to again become completely molten to a depth of tens of kilometers. (c) Early on especially, yet continuing to lesser extent to the present, radioactive heating from within has caused much of Earth’s interior to liquefy, allowing its heavy metals to sink to the core while its lighter-weight rocks floated to the surface.
More Precisely 7-2: Radioactive Dating

The number of protons in an atom’s nucleus determines which element it is. However, there may be different isotopes of the same element, with the same number of protons but different numbers of neutrons. Many of these isotopes are unstable and undergo radioactive decay. This decay is characterized by a half-life $T$: 

Fraction of material remaining = $(1/2)^{t/T}$
More Precisely 7-2: Radioactive Dating

This plot shows the fraction of the original sample remaining as a function of time.
Half-lives have been measured in the laboratory for almost all known isotopes. Knowing these, we can use them for determining the age of samples by looking at isotope ratios.

The most useful isotope for dating rock samples is uranium-238, which has a half-life of 4.5 billion years, comparable to the age of the Earth.
The dating process involves measuring the ratio between the parent nucleus and the daughter nucleus (lead-206 in the case of uranium-238).
Continental drift: Entire Earth’s surface is covered with crustal plates, which can move independently.

Figure 7-11. Global Plates Red dots represent active sites where major volcanoes or earthquakes have occurred in the 20th century. Taken together, the sites outline vast “plates,” indicated in dark blue, that drift around on the surface of our planet. The white arrows show the general directions and speeds of the plate motions.
7.4 Surface Activity

At plate boundaries, earthquakes and volcanoes occur.

Figure 7-10. Geological Activity (a) An active volcano on Kilauea in Hawaii. Kilauea seems to be a virtually ongoing eruption. (b) Other, more sudden eruptions, such as that of Mount St. Helens in Washington State on May 18, 1980, are rare catastrophic events that can release more energy than the detonation of a thousand nuclear bombs. (c) The aftermath of an earthquake that claimed more than 5000 lives and caused billions of dollars’ worth of damage in Kobe, Japan, in January 1995. (P. Chesley/Getty Images, Inc.; USGS; H. Yamaguchi/Sygma)
7.4 Surface Activity

Earth’s upper mantle, near a plate boundary; this is a subduction zone, where one plate slides below another.

Figure 7-12. Earth’s Upper Mantle The outer layers of Earth’s interior. The rocky lithosphere comprises both the crust and part of Earth’s upper mantle. It is typically between 50 and 100 km thick. Below it lies the asthenosphere, a relatively soft part of the mantle over which the lithosphere slips.
7.4 Surface Activity

A plate colliding with another can also raise it, resulting in very high mountains.

Figure 7-13. Himalayas Mountain building results mostly from plate collisions. (a) The subcontinent of India, imaged here by sensing infrared radiation from orbit, lies at the northernmost tip of the Indian plate. As this plate drifts northward, the Indian landmass collides with Asia, on the Eurasian plate. The impact causes Earth’s crust to buckle and fold, thrusting up the Himalayan mountain range (covered with snow at the upper right). (b) The results of the ongoing process depicted in (a) can be seen in this view of the area near Mount Everest. The folding of rock is especially evident in the foreground. (© Michael Klesius/National Geographic Image Collection)
Plates can also slide along each other, creating faults where many earthquakes occur.

Figure 7-14. Californian Fault A small portion of the San Andreas fault in California. The fault is the result of the North American and Pacific plates sliding past one another. The Pacific plate, which includes a large slice of the California coast, is drifting to the northwest relative to the North American plate. The motions of the two plates are indicated by arrows whose lengths are proportional to the plate speeds. *(U.S. Department of the Interior)*
Finally, plates can move away from each other, creating rifts.

Figure 7-15. **Seafloor Spreading** Samples of ocean floor retrieved by oceanographic vessels are youngest close to the Mid-Atlantic Ridge and progressively older farther away.
The new crust created at rift zones preserves the magnetic field present at the time it solidified. From this, we can tell that field reversals occur about every 500,000 years.
Plate motion is driven by convection

Figure 7-16. **Plate Drift** The motion of Earth’s tectonic plates is probably caused by convection—in this case, giant circulation patterns in the upper mantle that drag the plates across the surface.
7.4 Surface Activity

If we follow the continental drift backward, the continents merge into one, called Pangaea.

Figure 7-17. Pangaea Given the current estimated drift rates and directions of the plates, we can trace their movements back into the past. About 200 million years ago, they would have been at the approximate positions shown in (a). The continents’ current positions are shown in (d).
The magnetosphere is the region around the Earth where charged particles from the solar wind are trapped.
These charged particles are trapped in areas called the Van Allen belts, where they spiral around the magnetic field lines.
Near the poles, the Van Allen belts intersect the atmosphere. The charged particles can escape; when they do, they create glowing light called aurorae.

Figure 7-20. **Aurorae** (a) A colorful aurora flashes rapidly across the sky, resembling huge windblown curtains glowing in the dark. Aurorae result from the emission of light radiation after magnetospheric particles collide with atmospheric molecules. The colors are produced as excited ions, atoms, and molecules recombine and cascade back to their ground states. (b) An aurora high above Earth, as photographed from a space shuttle (visible at left). *(NCAR; NASA)*
Tides are due to the gravitational force on Earth from Moon—force on the near side of Earth is greater than force on the far side. Water can flow freely in response.

Figure 7-21. **Lunar Tides** This exaggerated illustration shows how the Moon induces tides on both the near and far sides of Earth. The lengths of the arrows indicate the relative strengths of the Moon’s gravitational pull on various parts of Earth. (a) The lunar gravitational forces acting on several locations on and inside Earth. The force is greatest on the side nearest the Moon and smallest on the opposite side. (b) The differences between the lunar forces experienced at the locations shown in part (a) and the force exerted by the Moon on Earth’s center. Closest to the Moon, the relative force is toward the Moon because the Moon’s gravitational pull is stronger at the surface than it is at the center. However, on the opposite side of Earth, the force at the surface is weaker than at the center, so the relative force is away from the Moon. The arrows thus represent the force with which the Moon tends to either pull matter away from or squeeze it toward Earth’s center. Closest to the Moon, the oceans tend to be pulled away from Earth; on the far side, Earth tends to be pulled away from the oceans. The result is a tidal bulge.
7.6 The Tides

The Sun has less effect because it is farther away, but it does modify the lunar tides

Figure 7-22. Solar and Lunar Tides The combined effects of the Sun and the Moon produce variations in the high and low tides. (a) When the Moon is either full or new, Earth, Moon, and Sun are approximately aligned, and the tidal bulges raised in Earth’s oceans by the Moon and the Sun reinforce one another. (b) At first- or third-quarter Moon, the tidal effects of the Moon and the Sun partially cancel each other, and the tides are smallest. Because the Moon’s tidal effect is greater than that of the Sun (since the Moon is much closer to us), the net bulge points toward the Moon.
7.6 The Tides

Tides tend to exert a “drag” force on the Earth, slowing its rotation.

This will continue until the Earth rotates synchronously with the Moon, so that the same side of the Earth always points toward the Moon.

Figure 7-23. Tidal Bulge The tidal bulge raised in Earth by the Moon does not point directly at the Moon. Instead, because of the effects of friction, the bulge points slightly ahead of the Moon, in the direction of Earth’s rotation. (The magnitude of the effect is greatly exaggerated in this diagram.) Because the Moon’s gravitational pull on the near-side part of the bulge is greater than the pull on the far side, the overall effect is to decrease Earth’s rotation rate.
Summary of Chapter 7

• Earth’s structure, from inside out: core, mantle, crust, hydrosphere, atmosphere, magnetosphere

• Atmosphere is mostly nitrogen and oxygen; thins rapidly with increasing altitude

• Greenhouse effect keeps Earth warmer than it would otherwise be

• Study interior by studying seismic waves

• Crust is made of plates that move independently
Summary of Chapter 7 (cont.)

• Movement at plate boundaries can cause earthquakes, volcanic activity, mountain ranges, and rifts

• New crust formed at rifts shows evidence of magnetic field reversals

• Earth’s magnetic field traps charged particles from solar wind

• Tides are caused by gravitational effects of Moon and Sun