INSTRUCTOR'S MANUAL

ESSENTIALS OF GEOLOGY

FIFTH EDITION

Stephen Marshak

Instructor's Manual by

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INSTRUCTOR'S MANUAL CONTENTS

CHAPTER 1

The Earth in Context

Learning Objectives

1. Students should be aware of the Big Bang theory. Distant galaxies are all moving away from us. The farthest galaxies are receding from us the fastest. All matter in the Universe was contained in a single point, approximately 13.8 billion years ago. At that time, the Universe explosively came into existence.
2. Stars, including our Sun, are nuclear-fusion reactors. For most of their life histories (on the order of billions of years), hydrogen atoms are fused together to form helium. Later stages in stellar evolution include fusion of helium atoms and other, heavier elements; ultimately, iron is the heaviest element that can be produced through fusion reactions within stars.
3. After their cycles of fusion are complete, large stars violently explode (forming supernovas), producing elements heavier than iron and leaving behind a residue of diffuse nebulae, which may be recycled to form a new star at some future point.
4. Our Solar System is approximately 4.57 Ga (billion years old). All eight planets revolve around the Sun in coplanar, elliptical orbits. All planets orbit in the same direction (counterclockwise, as viewed from above Earth's North Pole). These facts imply simultaneous planetary formation from a swirling nebula surrounding the Sun (the similarities in orbits would then be a natural result of conservation of angular momentum). The planets accreted from this nebula through gravitational attraction and haphazard collisions. Pluto, long considered the "ninth planet," has seen its status demoted; astronomers now recognize eight major planets.
5. The terrestrial planets (Mercury, Venus, Earth, and Mars) are relatively small, dense, and rocky worlds. The giant planets are predominantly composed of the light gases hydrogen and helium (Jupiter and Saturn) or ices (Uranus and Neptune); they are

much larger and much less dense than the terrestrial planets.

6. Our Moon is thought to have originated from debris accumulated when a protoplanet collided with Earth approximately 4.53 Ga.
7. The Earth System is subdivided into the atmosphere (gases and aerosols that envelop the planet), hydrosphere (Earth's water), geosphere (solid Earth), and biosphere (living things).
8. Earth is chemically divided into a thin, rocky crust dominated by silicate minerals, a thick mantle composed mostly of iron- and magnesium-rich silicates (subject locally to partial melting), and a thick, metallic core made primarily of iron (the outer portion of which is liquid). Students should know how seismic waves tell us that the outer core must be liquid.
9. Physically, the uppermost layers of Earth are the rigid lithosphere (crust and uppermost mantle) and the asthenosphere, which is weaker and flows plastically. The "plates" of plate tectonics theory are discrete slabs of lithosphere, which move with respect to one another atop the asthenosphere.

Summary from the Text

The geocentric model placed Earth at the center of the Universe. The heliocentric model placed the Sun at the center.

The Earth is one of eight planets orbiting the Sun. The Solar System lies on the outer edge of the Milky Way galaxy. The Universe contains hundreds of billions of galaxies.

Most astronomers agree that this expansion began after the Big Bang, a cataclysmic explosion that occurred about 13.7 billion years ago.

The first atoms (hydrogen and helium) of the Universe developed within minutes of the Big Bang. These atoms formed vast gas clouds, called nebulae.

Only very small atoms formed during Big Bang nucleosynthesis. The Earth, and the life forms on it, contain elements that could have been produced only during the life cycle of stars—intermediate-sized atoms formed by fusion during supernovae explosions. Thus, we are all made of stardust.

Gravity caused clumps of gas in the nebulae to coalesce into flattened disks with bulbous centers. As the central ball of this accretionary disk collapsed inward, it became a warm protostar. Eventually, the ball became so hot and dense that fusion reactions began, and it became a true star.

Planets developed from nebulae, the rings of gas and dust surrounding newborn stars. Matter in these nebulae condensed into planetesimals, which then clumped together to form protoplanets, and finally, true planets. Inner rings became the terrestrial planets; outer rings grew into giant planets, which consist mostly of gas and/or ice.

The Moon formed from debris ejected when a protoplanet collided with Earth in the young Solar System.

When a protoplanet grows large enough, it eventually becomes warm enough inside to differentiate into a core and mantle, and then to assume a near-spherical shape when it becomes so soft that gravity can smooth out irregularities.

The Earth has a magnetic that shields it from solar wind and cosmic rays.

A layer of gas surrounds the Earth. This atmosphere, which consists of 78% N_2, 21% O_2, and 1% other gases, can be subdivided into layers. Air pressure decreases with increasing elevation.

The surface of Earth can be divided into land (30%) and ocean (70%). Most of the land surface lies within 1 km of sea level. Earth's land surface has a great variety of landscapes due to variations in elevation and climate.

Earth materials include organic chemicals, minerals, glasses, rocks, melts, and volatiles. Most rocks on Earth contain silica (SiO_2). We distinguish among various basic rock types based on the proportion of silica.

The Earth's interior can be divided into three distinct layers: the very thin crust, the rocky mantle, and the metallic core.

Pressure and temperature both increase with depth in the Earth. The rate at which temperature increases as depth increases is the geothermal gradient.

The crust is a thin skin that varies in thickness from 7–10 km (beneath oceans) to 25–70 km (beneath the continents). Oceanic crust is mafic in composition, whereas average upper-continental crust is felsic to intermediate. The mantle is composed of ultramafic rock. The core is made of iron alloy.

Studies of seismic waves reveal that the mantle can be subdivided into an upper mantle and a lower mantle. The core can be subdivided into the liquid outer core and a solid inner core. Circulation of the outer core produces the Earth's magnetic field.

The crust plus the upper part of the mantle constitute the lithosphere, a rigid shell. The lithosphere lies over the asthenosphere, mantle that can flow.

Video and Animation Files

FORMATION OF THE SOLAR SYSTEM

Number: 1.1

Length: 3 minutes, 17 seconds

Summary: This video provides an overview of the Nebular Theory of Solar System origins. Emphasis is on the action of gravity condensing diffuse material and solar wind ejecting volatiles to leave refractory materials enriched in inner protoplanetary rings.

Classroom Use: This video could be shown on the first day of class to put the Earth in context within the Universe and to explain our understanding of Solar System formation.

Review and Discussion Questions:

1. What is the difference between volatile and refractory materials?
2. Why would we find more of the latter in planets such as Earth that formed near the Sun?

FORMATION OF THE EARTH

Number: 1.2

Length: 2 minutes, 29 seconds

Summary: This video examines the accretionary process that transformed Earth from planetesimal to protoplanet to full planet. It emphasizes the formation of the Earth's metallic core and Moon.

Classroom Use: This video makes a natural follow-up to 1.1, further illustrating how our planet came about.

Review and Discussion Questions:

1. Why is so much of the Earth's iron found in the core?

2. For a short time after the formation of the Moon, the Earth is thought to have had a volcanically dominated atmosphere. Which two gases would have been most abundant in the atmosphere at that time, and what became of them?

Answers to Review Questions

1. Contrast the geocentric and heliocentric Universe concepts.
ANS: The geocentric concept placed Earth at the center of the Universe, with the Sun and the other planets revolving around it. The heliocentric concept placed the Sun at the center, with Earth and the other planets revolving around it.

2. What is the ecliptic, and why are the orbits of planets within the plane of the ecliptic? Why is Pluto no longer considered to be a planet?
ANS: The ecliptic is the plane defined by the orbits of the major planets of our Solar System. The planets reside together in this plane because they formed from matter within the rotating protoplanetary disk surrounding the early Sun. Pluto is no longer considered a planet because it has not swept its orbit clear of other objects.

3. Explain the expanding Universe theory.
ANS: When we look at distant galaxies, we find that they are all moving away from our own, with the farthest galaxies moving away the fastest. This movement suggests that the entire observable Universe is expanding outward.

4. What is the Big Bang, and when did it occur?
ANS: The Big Bang is an explosive phase of expansion of matter and space that occurred at the beginning of our Universe, 13.8 billion years ago.

5. Describe the steps in the formation of our Solar System according to the nebular theory.
ANS: The mass in our Sun and the surrounding Solar System condensed from a swirling nebula (cloud of gas and dust). At the center of the nebula, most of the mass condensed to form the Sun, which graduated from protostar status when it became sufficiently massive—and thus hot enough—to fuse hydrogen. Within a flat protoplanetary disk surrounding the Sun, planets arose from gravity-driven accretion and the collisions of

smaller bodies termed *planetesimals* and *protoplanets*. Light gases and other volatiles were ejected from the inner portion of the disk as the Sun's heat intensified, so the terrestrial planets ended up as smaller spheres of relatively high-density refractory substances (rock and metal). Farther out, the gas-giant planets incorporated abundant volatiles such as hydrogen and helium to become much more massive but less dense.

6. Why isn't the Earth homogenous?
ANS: Early in Earth history, all of its matter was molten. Gravity caused the heavier metals (primarily iron) to sink toward the center of the planet, forming a core distinct from the rocky mantle of the Earth.

7. Describe how the Moon was formed.
ANS: The Moon formed when a protoplanet approximately the size of Mars collided with Earth early in the history of the Solar System. The force of the impact ejected material similar in composition to Earth's mantle. This mantle-like mass cooled and solidified, resulting in our Moon.

8. Why is Earth round?
ANS: Gravity forces objects the size of Earth to be nearly spherical (the most compact shape, minimizing the distance of points from the center).

9. What is Earth's magnetic field? Draw a representation of the field on a piece of paper. What causes aurorae?
ANS: The magnetic field of Earth is a region of space affected by the magnetic force of Earth (see Fig. 1.12c for a sketch). Aurorae are caused by high-energy charged particles traveling along Earth's magnetic field lines and interacting with the gases in the atmosphere.

10. What is Earth's atmosphere composed of? Why would you die of suffocation if you were to eject from a fighter plane at an elevation of 12 km without an oxygen tank?
ANS: Earth's atmosphere is mostly nitrogen and oxygen, with minor amounts of argon, carbon dioxide, and other gases. The atmosphere becomes less and less dense with altitude; at 12 km, oxygen molecules are too sparse to support human life.

11. What is the proportion of land area to sea area on Earth?

ANS: Earth consists of 30% land area as opposed to 70% sea area.

12. Describe the major categories of materials constituting the Earth. Does the crust have the same composition as the whole Earth? On what basis do geologists distinguish among different kinds of silicate rock?

ANS: Categories of materials include **organic chemicals**, which make up the majority of living matter. These carbon- and hydrogen-based compounds (including oil and natural gas) can be quite complex, sometimes incorporating oxygen (as in sugars, starches, and fats), sometimes nitrogen (as in proteins), and, occasionally, some phosphorus and sulfur. **Minerals** are solid, inorganic materials in which there is a fixed arrangement of atoms (often termed a *crystalline lattice*). Quartz and calcite are important, familiar examples. Mineral crystals are commonly weathered to produce fragments with rough or rounded surfaces, which are termed *grains*. **Glasses** are physically solid structures in which the atoms are internally disordered (as in liquids, but without the tendency to rapidly flow). Commercial glass is produced when quartz is melted and then cooled rapidly (quenched in cool water), so that atoms cannot align themselves into the quartz crystalline arrangement before the rigidity of cooling sets in. **Grains** are individual mineral crystals within rock or loose fragments of minerals or rocks. **Rocks** are cohesive aggregates of crystals or grains or solid masses of natural glass. Igneous rocks crystallize from molten (liquid) rock. Sedimentary rocks arise from the cementation of loose grains (sand, mud, pebbles, etc.) and through chemical precipitation (from the ocean or continental bodies of water). Metamorphic rocks arise from heat- and pressure-induced alteration of pre-existent rock (without melting). Grains are crystals within rock or loose fragments of crystals. **Sediments** are loose accumulations of mineral grains. **Metals** are solids made up of metallic elements only (to a strong approximation), such as gold, iron, and copper. (Naturally occurring metals are a subset of minerals.) **Melts** are hot liquids that crystallize at surface temperatures to form igneous rocks. Melts within Earth are termed *magma*; melts extruded on the surface are termed *lava*. **Volatiles** are substances that are stable in a gaseous state at the relatively low temperatures of Earth's surface. Geologists distinguish silicate rocks on the basis of silica content and grain size.

13. What are the principal layers of Earth? What happens to earthquake waves when they reach the boundary between layers?

ANS: Major layers of Earth are the very thin crust, the rocky mantle, and metallic core. Earthquake waves reaching boundary layers between these layers may be reflected or refracted (bent).

14. How do temperature and pressure change with increasing depth in the Earth?

ANS: Both temperature and pressure steadily increase with increasing depth.

15. What are meteorites, and how does the study of them provide insight into the character of the Earth's interior?

ANS: Meteorites are objects that have fallen from space and impacted the Earth. Meteorites may be rocky or metallic or a combination of the two. Most meteorites are thought to represent early pieces of our Solar System, and thus, they can be used as a model for the Earth's interior.

16. What is the Moho? Describe the difference between continental crust and oceanic crust.

ANS: The Moho is the crust-mantle boundary, recognized by an abrupt change in seismic-wave velocities. Continental crust is thicker, more silicic, and more variable in chemistry than oceanic crust.

17. What is the mantle composed of? Is there any melt in it?

ANS: The mantle is mostly made of an ultramafic silicate rock termed *peridotite*. There is a small amount of melt in the upper mantle.

18. What is the core composed of? How do the inner and outer cores differ? Which one produces the magnetic field?

ANS: The core is mostly iron; the inner part is solid, whereas the outer part is liquid. Circulation of iron atoms in the liquid outer core generates Earth's magnetic field.