CHAPTER 1—INTRODUCTION TO EARTH HISTORY

CHAPTER OVERVIEW

This chapter provides an introduction to the science of geology from both physical and historical perspectives. Physical geology deals primarily with the physical aspects of the Earth. Historical geology represents a synthesis of different sciences and thought. This chapter examines the contributions of some of the founders of historical geology, i.e. Nicholaus Steno, James Hutton, William Smith, Charles Lyell and Charles Darwin to name a few. It also lays the groundwork for further study by illustrating how conditions of the geologic past can be interpreted from careful observation of the earth and the fossil record. The chapter provides a comprehensive view of the methods used by geologists in constructing a geologic time scale on the basis of relative age and absolute (quantitative dating) methods.

LEARNING OBJECTIVES

By reading and completing information within this chapter you should gain an understanding of the following concepts:

- Discuss the development of the field of historical geology.
- Explain the contributions made by Nicholaus Steno, James Hutton, William Smith, Charles Lyell, Charles Darwin and others.
- Define the principles of Superposition, Original Horizontality, Original Lateral Continuity and other concepts that are associated with relative age dating.
- Explain the Divisions of the Geologic Time Table, i.e. eons, eras, periods, epochs, ages and chronostratigraphic units.
- Describe the different types of quantitative geologic methods, i.e. radio isotopic methods for dating rocks.

CHAPTER OUTLINE

I. Geology: Its Physical and Historical Components
   A. Study of Planet Earth
   B. Physical Geology
   C. Historical Geology

II. The Founders of Historical Geology
   A. Nicholaus Steno (Niels Stensen)
   B. Interpretation of the Geologic Succession
   C. Abraham Gottlob Werner
   D. James Hutton
   E. William “Strata” Smith
   F. George Cuvier and Alexandre Brongniart
   G. Charles Lyell
   H. Charles Darwin

I. Geologists of the New World
   1. William Maclure
   2. Amos Eaton
   3. Louis Agassiz
   4. James Hall
   5. James D. Dana
   6. Ferdinand V. Hayden
   7. John Powell
   8. Clarence King
   9. Othniel C. Marsh
   10. Edwin C. Cope
III. Time and Geology
   A. The Standard Geologic Time Scale
      1. Divisions in the Geologic Time Scale
      2. Recognition of Geochronologic Units
      3. The Geologic Systems
   B. Quantitative Geologic Time
      1. Early Attempts at Quantitative Geochronology
      2. Radio Isotopic Methods of Dating Rocks
      3. The Principle Geologic Timekeepers

IV. The Age of the Earth
**Key Terms** (Pages 1-33)

**Actualism (7):** The principle that natural laws governing both past and present processes on Earth have been the same.

**Agassiz, Louis (12):** He studied glaciers in the Alps and promoted the theory that immense ice sheets once covered much of North America and Eurasia. He was also the founder of the Harvard Museum of Comparative Zoology.

**Age (geologic) (15):** The time represented by the time-stratigraphic unit called a stage. Informally, may indicate any time span in geologic history.

**Alluvium (6):** Unconsolidated, poorly sorted detrital sediments ranging from clay to gravel sizes and characteristically fluvial in origin.

**Alpha Particle (22):** A particle, equivalent to the nucleus of a helium atom, emitted from an atomic nucleus during radioactive decay.

**Archean Eon (15):** Division of the Precambrian time from 3800 million years to 2500 million years.

**Atom (21):** The smallest divisible unit retaining the characteristics of a specific element.

**Atomic Number (22):** The number of protons in the nucleus of an atom of a particular element. (An element is thus a substance in which all of the atoms have the same atomic number).

**Bentonite (24):** A layer of clay, presumably formed by the alteration of volcanic ash. It is composed essentially of montmorillonite and related minerals of the smectite group.

**Beta Particle (23):** A charged particle, essentially equivalent to an electron, emitted from an atomic nucleus during radioactive disintegration.

**Cambrian System (Period) (15):** Exposures of Strata in Wales provide a standard section with which rocks elsewhere in Europe and on other continents can be correlated and are known as the Cambrian System by definition. All other sections deposited during the same time as the rocks in Wales are recognized as Cambrian by comparison to the standard section. The basal unit is 570 million years. Time interval covered is 570 to 505 million years.

**Carbon-14 Method (28):** A method used in determining the age of materials less than about 50,000 years old and using new techniques about 100,000 years old. Carbon-14 is a radioactive isotope of carbon with an atomic mass of 14.

**Carboniferous System (Period) (18):** A division of the Paleozoic Era ranging in geologic time from 360 to 286 million years. It is further divided into the Lower Carboniferous (Mississippian in the U.S., covering 360-320 million years) and the Upper Carboniferous (Pennsylvanian in the U.S., covering 320-286 million years). This system designated strata that included beds of coal in north-central England.

**Cenozoic Era (15):** The era in which we are now living. It began at 66 million years (basal unit).

**Chronostratigraphic Unit (Time-Stratigraphic Unit) (15):** The actual rock formed or deposited during a specific time interval.

**Cretaceous System (Period) (20):** A division of the Mesozoic Era covering a geologic time span from 144 to 66 million years. This system is recognized on the basis of fossils, though chalk beds are prevalent.
Dana, James (13): A professor at Yale who was the author of Manuel of Geology, Textbook of Geology, and System of Minerology which were among the most important texts of his time.

Darwin, Charles (11): Wrote the Origin of Species which recognized that different kinds of animals and plants succeed one another in time because life has evolved continuously. He recognized that because of this continuous change, or evolution, only rocks formed during the same age contain similar assemblages of fossils. Darwin also theorized about the mechanism for evolution which he called natural selection. Those individuals with the most favorable variations would have the best chance of surviving and transmitting their favorable traits to the next generation.

Daughter Element (23): The new atom formed from radioactive decay of another atom.

Devonian System (Period) (18): Included in the Paleozoic Era and covers geologic time from 408 to 360 million years. It was determined to be a new system based on the fauna that was different from that of the underlying Silurian and overlying Carboniferous Systems.

Electron (21): The nucleus of an atom is surrounded by rapidly moving, negatively charged particles called electrons which orbit around the nucleus.

Eocene Epoch (20): Included in the Paleogene subdivision of the Tertiary Period on the geologic time scale. It spans from 58 to 37 million years ago.

Eon (15): A major division of the geologic time scale. All of the geologic periods from the Cambrian to the Holocene comprise the Phanerozoic Eon. The term is also sometimes used to denote a span of 1 billion years.

Epoch (15): A chronological subdivision of a geologic period. Rocks deposited or emplaces during an epoch constitute the series for that epoch.

Era (15): A major division of geologic time, divisible into geologic periods. There are three divisions: Paleozoic Era, Mesozoic Era, and Cenozoic Era.

Fission Track (aka Nuclear Particle Fission Tracks) (30): Sub-microscopic "tunnels" in minerals produced when high-energy particles from the nucleus of uranium are forcibly ejected during spontaneous fission.

Gamma Radiation (23): Emission in the radioactive decay process consisting of a form of invisible electromagnetic waves having even shorter wavelengths than X-rays.

Geochronologic Unit (15): Eras, periods, epochs, and division of epochs, called ages, all represent intangible increments of time called geochronologic units.

Geochronology (14): The study of time as applied to Earth and planetary history.

Hadean Eon (15): Refers to the period of time for which we have no rock record. Began with the origin of the planet 4.6 billion years ago.

Half-Life (25): The time needed for half of the original quantity of radioactive atoms to decay to daughter products.

Historical Geology (2): Addresses the Earth’s evolution, changes in the distribution of lands and seas, growth and destruction of mountains, succession of animals and plants through time, and developmental history of the solar system.
Holocene Series (Epoch) (20): A term sometimes used to designate the period of time since the last major episode of glaciation. The term is equivalent to Recent and ranges from 10,000-12,000 years ago to present.

Hutton, James (6): Edinburgh physician and geologist responsible for the Principle of Uniformitarianism. His method of interpreting rock exposures by observing present-day processes was given the phrase “the present is the key to the past.”

Isochron (27): The line showing the decay curve for a particular radioactive element. The slope of the isochron permits a computation of the age of the rock being examined.

Isotope (22): Variants of mass numbers of atoms of the same substance. Isotopes are two or more varieties of the same element that have the same atomic number and chemical properties but differ in mass numbers because they have a varying number of neutrons in the nucleus.

Jurassic System (Period) (20): A division of the Mesozoic Era covering a geologic time span of 208 to 144 million years ago.


Mass (22): The mass of an atom is approximately equal to the sum of the masses of its protons and neutrons.

Mass Number (22): The nearest whole number to the total number of protons and neutrons in an element. Approximately equal to the sum of the masses of its protons and neutrons.

Mass Spectrometer (23): An instrument that separates ions of different mass but equal charge and measures their relative quantities.

Mesozoic Era (15): Continued for about 179 million years during the Phanerozoic Eon covering the time period from 245 to 66 million years. Its basal unit is 245 million years ago.

Mineral (21): Solid, naturally occurring inorganic material having a definite composition or range of compositions and usually possessing a uniform internal crystal structure (atomic structure).

Miocene Epoch (20): Included in the Neogene subdivision of the Tertiary Period. It spans the geologic time scale from 24 to 5 million years ago.

Mississippian System (Period) (18): Division of the Carboniferous System covering 360 to 320 million years ago. It is equivalent to the English division known as Lower Carboniferous.

Neogene System (20): A subdivision of the Tertiary Period that encompasses the Miocene and Pliocene epochs.

Neutron (22): Electrically neutral particles of matter existing along with protons in the atomic nucleus of all elements except the mass 1 isotope of hydrogen.

Nuclide (22): The different weight configurations of an element caused by atoms of that element having differing numbers of neutrons. Nuclides or isotopes of an element differ in number of neutrons but not in chemical properties.

Oligocene Epoch (20): Included in the Paleogene subdivision of the Tertiary Period. It spans the geologic time table from 37 to 24 million years ago.
Origin of Species (12): Written by Charles Darwin who recognized that different kinds of animals and plants succeed one another in time because life has evolved continuously. He recognized that because of this continuous change, or evolution, only rocks formed during the same age contain similar assemblages of fossils. Darwin also theorized about the mechanism for evolution which he called natural selection. Those individuals with the most favorable variations would have the best chance of surviving and transmitting their favorable traits to the next generation.

Ordovician System (16, 17): Included in the Paleozoic Era and covers geologic time from 505 to 438 million years ago. Portions of the upper Cambrian and the lower Silurian were combined to produce the Ordovician System.

Paleocene Epoch (16): Included in the Paleogene subdivision of the Tertiary Period. It spans the geologic time table from 66 to 58 million years ago.

Paleogene System (20): A subdivision of the Tertiary Period that encompasses the Paleocene, Eocene, and Oligocene epochs.

Paleozoic Era (15): Lasted about 300 millions years covering a portion of the Phanerozoic Eon from 570 to 245 million years ago. Its basal unit is 570 million years.

Pennsylvanian System (Period) (18): Division of the Carboniferous System (period) covering 320 to 286 million years ago. Equivalent to the Upper Carboniferous in England.

Period (geologic) (15): A subdivision of an era.

Permian System (Period) (19): Division of the Paleozoic Era covering geologic time ranging from 286 to 245 million years ago. Named for a Russian province. Fossils were determined to be intermediate between those of the Carboniferous below and the Triassic above.

Phanerozoic Eon (15): The eon of geologic time during which the Earth has been populated by abundant and diverse life. It is subdivided into the Paleozoic, Mesozoic, and Cenozoic eras. The basal unit is 570 (or 544) million years and it continues through the present geologic time.

Physical Geology (2): Deals with the origin, classification, and composition of earth materials, as well as the varied processes that occur on the surface and in the deep interior of the Earth.

Pleistocene Series (Epoch) (20): A subdivision of the Quaternary Period. It spans the geologic time table from 2 millions years to 10-12 thousand years ago.

Pliocene Epoch (20): Included in the Neogene subdivision of the Tertiary Period. It spans the geologic time table from 5 to 2 million years ago.

Potassium-Argon Method (27): A radioactive dating method using electron capture (a proton is transformed into a neutron). The half-life of potassium-40 is 1251 million years (1.251 billion years).

Powell, John (14): Journeyed through the Grand Canyon of the Colorado River in the summer of 1869 and was also the second director of the United States Geological Survey.

Precambrian (15): All of geologic time and its corresponding rocks before the beginning of the Paleozoic Era.

Principle of Biologic Succession (9): Smith’s principle which stipulates that the observed sequence of life forms has changed continuously through time, so that the total aspect of life (as recognized by fossil evidence) for a particular segment of time is distinct and different from that of life of earlier and later times.
Principle of Cross-Cutting Relationships (10): The principle that states that geologic features such as faults, veins, and dikes must be younger than the rocks or features they cut across.

Principle of Inclusions (10): Fragments within larger rock masses are older than the rock masses in which they are enclosed. Whenever two rock masses are in contact, the one containing pieces of the other will be the younger of the two.

Principle of Original Horizontality (4): Steno’s principle which states that most sedimentary particles settle from fluids under the influence of gravity. The sediment must then be deposited in layers that are nearly horizontal and parallel to the surface on which it is accumulating.

Principle of Original Lateral Continuity (4): Steno’s principle which states that as originally deposited, strata extend in all directions until they terminate by thinning at the margin of the basin, end abruptly against some former barrier to deposition, or grade laterally into a different kind of sediment.

Principle of Superposition (3): Steno’s principle which states that in any sequence of undisturbed strata, the oldest layer is at the bottom and successively higher layers are successively younger.

Proterozoic Eon (15): Refers to the time interval from 2500 to 544 million years ago.

Proton (21): An elemental particle found in the nucleus of all atoms that has a positive electric charge and a mass similar to that of a neutron.

Quantitative Geologic Dating (20): Sometimes referred to as actual geologic dating. This dating method expresses the actual age of rocks or geologic events as determined by the decay of radioactive elements.

Quaternary System (Period) (20): A subdivision of the Cenozoic Era. It spans the geologic time table from 2 million years ago to the present.

Radioactive Decay (22): The spontaneous emission of a particle from the atomic nucleus, thereby transforming the atom from one element to another.

Relative Geologic Dating (14): Dating which involves placing geologic events and the rocks representing those events in the order in which they occurred without reference to actual time or dates measured in years. This method tells which event preceded or followed another event, or which rock mass was older or younger relative to others.

Rock (21): Solid, cohesive aggregates of the grains of one or more minerals.

Rubidium-Strontium Method (27): A dating method based on the disintegration by beta decay of rubidium-87 to strontium-87.

Series (15): The time-rock term representing the rocks deposited or emplaced during a geologic epoch. Series are subdivision of systems.

Silurian System (Period) (17): System in the Paleozoic Era determined by the studies of fossiliferous strata outcropping in the hills of south Wales. The geologic time interval is 438 to 408 million years ago.

Smith, William (9): English surveyor and engineer who made a stratigraphic map of England. He is responsible for the Principle of Biologic Succession.

Stage (15): Represents the tangible rock record of an age. A stage is a subdivision of a series.

Steno, Nicholaus (3): Danish physician responsible for the Principals of Superposition, Original Horizontality, and Original Lateral Continuity.
Stratigraphy (5): The study of rock strata, with emphasis on their succession, age, correlation, form, distribution, lithology, fossil content, and all other characteristics useful in interpreting their environment of origin and geologic history.

System (15): Refers to the actual rock record of a period.

Tertiary System (Period) (20): A division of the Cenozoic Era. It spans the geologic time table from 66 to 2 million years ago.

Triassic System (Period) (19): A division of the Mesozoic Era with a basal unit of 245 million years. Geologic time covered is 245 to 208 million years ago. The term Triassic refers to a threefold division of rocks of this age in Germany.

Unconformity (8): An erosional gap or hiatus in a rock record. A surface separating an overlying younger rock formation from an underlying formation and representing an episode of erosion or non-deposition.

Uniformitarianism (6): Principle conceived by James Hutton that states that physical and chemical laws that govern nature are uniform. Present events give clues to the past, but the rates of change and intensity of processes often varied from those to which we are accustomed today and some events of long ago simply do not have a modern analogue. Also known as actualism.

Whole Rock Radiometric Analysis (28): Large samples of the entire rock may be used for age determination when the rock under investigation is so finely crystalline and the critical minerals so tiny and dispersed that it is difficult to obtain a suitable collection of minerals to age a specimen.

Fill in the blanks. (Use page 16 of the textbook to answer).
MULTIPLE CHOICE QUESTIONS

1. The principle which stipulates that in any sequence of undisturbed strata, the oldest layer is at the bottom and successively higher layers are successively younger is the:

2. His method of interpreting rock exposures by observing present day processes was given the phrase “the present is the key to the past” is:
   a. Charles Lyell c. William Smith
   b. James Hutton d. Baron Cuvier

3. The observation that an igneous intrusion or fault that intrudes or cuts a younger rock is called the Principle of:

4. Nicholas Steno formulated all of these basic principles except:

5. The principle that states the past history of the earth can be interpreted in accordance with our knowledge of natural processes still operating today is called:
   a. Biologic Continuity c. Law of Uniformitarianism
   b. Law of Superposition d. Law of Biologic Succession

6. The principle that fossils can be used to correlate strata from different localities that separate strata into different ages is called:
   a. Stratigraphic Succession. c. Lateral Continuity.

7. The geologic time scale was originally based on:
   a. the succession of fossil assemblages.
   b. the theory of organic evolution.
   c. the rock record.
   d. the absolute age of rocks based on isotope age dates.

8. The concept that the history of life as recorded in the fossil record was marked by sudden periods of continental floods or abrupt crustal upheavals is called:

9. The correct order of time stratigraphic units from largest to smallest is:
   a. age, era, epoch, period. c. age, epoch, era, age.
   b. period, epoch, age, era. d. era, period, epoch, age.

10. The Carboniferous Systems of Europe and Britain correspond to what systems of North America?
    a. Triassic and Jurassic c. Cretaceous and Tertiary
    b. Cambrian and Ordovician d. Mississippian and Pennsylvanian

11. The system the French geologist Jules Desnoyers in 1829 established as a new geologic system based on certain volcanic sediments exposed in northern France was called:
    a. Tertiary. c. Quaternary.
12. The stratigraphic relationship where flat-lying strata overlies the eroded edges of inclined older strata is called:
   a. unconformity.
   b. non-conformity.
   c. disconformity.
   d. angular unconformity.

13. A body of rock that can be recognized wherever it occurs by the characteristics of composition, texture, or color is a:
   a. time rock.
   b. rock interval.
   c. formation.
   d. rock unit.

14. The dating method that places geologic events in a chronological order as determined from their position in the rock record.
   a. relative dating
   b. absolute dating
   c. isotopic dating
   d. neutron dating

15. An alpha particle is composed of:
   a. 2 electrons.
   b. 2 neutrons.
   c. 2 neutrons, 2 protons.
   d. 2 protons, 2 electrons.

16. The atomic number of an atom is the number of:
   a. protons and neutrons in the nucleus.
   b. neutrons in the nucleus.
   c. protons in the nucleus.
   d. electrons in the outer shell.

17. An element that has the same atomic number, but different atomic weights is an:
   a. ion
   b. isotope
   c. atom
   d. element

18. The use of radioactive elements has proven successful for determining absolute (Quantitative) ages because:
   a. most have very long half-lives.
   b. they are easily found in the field.
   c. they are abundant in the earth’s crust.
   d. the rate of decay is constant for a particular element.

19. An isotope is an atom of an element with:
   a. the same atomic number, a different number of electrons, but the same number of neutrons.
   b. the same atomic number, but different numbers of protons and electrons.
   c. the same atomic number, the same number of electrons, but a different number of neutrons.
   d. a different atomic number, but the same number of electrons and neutrons.

20. The type of radioactive decay that involves the emission of a high velocity electron from the nucleus is:
   a. alpha decay.
   b. beta decay.
   c. gamma emission.
   d. electron reflection.
FILL-IN THE BLANK

1. The oldest rocks of our planet that make up the Archean and Proterozoic are collectively referred to as the ____________________________.

2. The system (period) that represents a subdivision of the Cenozoic Era and spans from 2 million years to the present is the ____________________________.

3. The epoch that represents a subdivision of the Quaternary Period and spans from 2 million years to 10-12 thousand years ago is ____________________________.

4. The system that takes its name from a province in Russia, but exceptional exposures can be seen in the Guadalupe Mountains of West Texas and New Mexico is the ____________________________.

5. The English geologist who established the Principles of Cross-Cutting Relationships and the Principle of Inclusions is ____________________________.

6. The Danish physician who proposed the principles of Superposition, Original Horizontality, and Original Lateral Continuity is ____________________________.

7. The sedimentary feature that represents a thin sedimentary layer or pair of layers representing the depositional record of a single year is ____________________________.

8. Founder of the Harvard Museum of Comparative Zoology, his early glacial studies of the Alps promoted the glaciation of North America and Eurasia ____________________________.

9. Professor at Yale University among whose more important textbooks where Manuel of Geology, Textbook of Geology, and System of Mineralogy ____________________________.

10. The new atom formed from another by radioactive decay, is called ____________________________.

11. The number of protons in the nucleus of an atom establishes its number of positive charges and is called ____________________________.

12. When atoms of the same substance have different mass numbers these variations are called ____________________________.

13. Emission in the radioactive decay process, consisting of a form of invisible electromagnetic waves having even shorter wavelengths than X-rays, is called ____________________________.

14. The radioactive dating method using electron capture (where a proton is transformed into a neutron) and whose half life is 1251 million years is called ____________________________ method.

15. The method of age dating that is based on the content of radiocarbon, which has a short half-life of 5730, found in a particular rock is ____________________________.
TRUE/FALSE

1. ______ Fission tracks are formed by the passage of nuclear particles emitted during the spontaneous fission of uranium.

2. ______ The half-life of Carbon 14 is 5730 years.

3. ______ A beta emission is a form of radioactive decay where an electron is emitted from the nucleus of a radioactive isotope.

4. ______ The Phanerozoic has been divided into three major subdivisions called periods.

5. ______ The first three eons in chronologic sequence of the geologic time are the Hadean, Archean, and the Proterozoic.

6. ______ Jules Desnoyers proposed the term tertiary for sediments and volcanics exposed in northern France.

7. ______ The rocks of the Cambrian System take their names from the Latin name for Wales.

8. ______ Eras may be further subdivided into shorter time units called epochs, which in turn can be further subdivided into periods.

9. ______ The number of protons in the nucleus of an atom establishes its number of positive charges and is called its atomic number.

10. ______ The daughter Nuclide of Potassium ‘40 is strontium ‘87.
## Answer Key

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RESPONSES TO QUESTIONS ACCOMPANYING SELECTED FIGURES

FIGURE 1-4 (p. 4) By superposition, the youngest stratum visible in the photograph would be at the top of the sequence of strata exposed in the bluff above the river, where it turns off to the right.

FIGURE 1-6 (p. 5) The source area lay to the west. Because of their larger size and weight, sand grains were deposited near the shoreline. Finer particles were carried in suspension farther into the basin of deposition and were ultimately deposited, providing that graduation from nearshore sandstones to offshore shales.

FIGURE 1-8 (p. 8) Although deposited horizontally, both the strata above and those below the erosional surface are now tilted. Therefore, Steno’s principal of lateral continuity is illustrated.

FIGURE 1-11 (p. 11) The intrusion labeled C occurred after faulting because the intrusive body cuts across the fault.

FIGURE 1-12 (p. 11) The sandstone in (A) is younger than 150 million years but older than 100 million years. Because the sandstone in (B) occurs as inclusions within the granitic body, it must have been there before the intrusion and is hence older than the granitic body. It also is older than the shale that lies superpositionally above it.

FIGURE 1-16 (p. 17) The Devonshire strata contained a fossil assemblage characteristic of rocks elsewhere in Europe that were superpositionally higher (hence, younger) than those described as Silurian in southern Wales by Murchison.

FIGURE 1-22 (p. 24) The stratum beneath the ash must be older than 453.7 million years.

FIGURE 1-25 (p. 26) If a graph were prepared showing how much sand passed through an hourglass in each unit of time, the graph would display an inclined straight line, indicating that the amount of original material lost from the top of the hourglass to the lower half is the same during each unit of time. Because the amount of original radioactive material that is lost diminishes with time, the curve on a graph showing radioactive decay would consist of an inclined concave curve.

\[ \frac{207}{206} \]

FIGURE 1-26 (p. 27) The age of a rock having a \( \frac{207}{206} \) of 0.15 would be 2.6 billion years old.