1 **Geologic Time**

Earth, Chapter 9

2 ***Chapter 9 – Geologic Time***

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- The Importance of a Time Scale
  - Interpreting Earth's history is an important goal of the science of geology
  - Rocks record geologic and evolutionary changes throughout Earth's history
  - Without a time perspective, these events have very little meaning

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- Numerical and Relative Dates
  - Numerical dates specify the number of years that have passed since an event occurred
    - Example: The limestone is 250 million years old
    - Prior to the discovery of radioactivity, geologists had no reliable method for numerical dating
  - Relative dates place rocks in a *sequence of formation*
    - Example: The Hermit Shale is older than the Coconino Sandstone
    - Uses a few basic principles, still accurate today

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- Principle of Superposition
  - In an undeformed sequence of sedimentary rocks, each bed is older than the one above and younger than the one below
  - This principle also applies to surface features like lava flows and beds of ash
  - Developed by Steno in 1669

6 ***Superposition illustrated in the Grand Canyon***

7 **Superposition**

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- Principle of Original Horizontality
  - Layers of sediment are generally deposited in a horizontal position
  - Rock layers that are flat have not been disturbed
  - Rock layers that are deformed, must have been *deformed after deposition*

9 **Original Horizontality**

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- Principle of Lateral Continuity
  - Beds originate as continuous layers that extend in all directions until they eventually thin out or grade into a different sediment type
  - When a river carves a canyon, we can assume that similar strata on either side were once connected across the span of the canyon

11 **Lateral Continuity in the Grand Canyon**

12 **Lateral Continuity in the Grand Canyon**

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- Principle of Cross-Cutting Relationships
  - Younger features cut across older features
  - Features that cut across rocks (*faults*, intrusions) must have formed after the rocks they cut through

14 **Cross-Cutting Fault**

15 **Cross-Cutting Dikes**

16 ***Cross-cutting***

17 **Cross-cutting**

18 **Cross-cutting**

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- Principle of Inclusions

- *Inclusions* are fragments of one rock unit that are enclosed within another rock unit
- The rock containing the inclusion is younger
  - When magma intrudes a rock mass, blocks of that rock may become dislodged and incorporated into the magma
  - These inclusions are called *xenoliths*
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20 **Inclusions**

21 **Inclusions**

22 **Inclusions**

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- Unconformities
  - Layers of rock that have been deposited without interruption are called conformable layers
  - An unconformity is a break in the rock record produced by nondeposition and erosion of rock units
    - Uplift and erosion is followed by subsidence and renewed deposition
    - Three basic types: angular unconformity, nonconformity, disconformity

24 ***Formation of an angular unconformity***

25 **Siccar Point, Scotland**

26 ***Unconformity***

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- Unconformities
  - Angular unconformity
    - Tilted rocks are overlain by flat-lying rocks
  - Disconformity
    - Sedimentary strata on either side of the unconformity are parallel
  - Nonconformity
    - Sedimentary strata overlay metamorphic or igneous rocks
  - All three types of unconformities can be seen in the Grand Canyon

28 **Unconformity**

29 ***Any unconformities in this picture?***

30 ***Unconformities present in the Grand Canyon***

31 ***Starting at the bottom: nonconformity***

32 ***Starting at the bottom: angular unconformity***

33 ***Toward the top: disconformities***

34 **Unconformity (story-telling)**

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41 **Fossils: Evidence of Past Life**

- Fossils are traces or remains of prehistoric life preserved in rock
- Paleontology is the study of fossils
- Knowing the nature of life that existed at a particular time helps researchers understand past environmental conditions
  - Fossils play a key role in correlating rocks of similar ages from different places on Earth

42 **Fossils: Evidence of Past Life**

- Types of Fossils
  - Permineralization
    - Mineral-rich groundwater flows through porous tissue (e.g., bone or wood) and precipitates minerals

- *Petrified* literally means “turned to stone”
- – Molds and Casts
  - A *mold* is created when a shell is buried in sediment and then dissolved by underground water
  - A *cast* is created when the hollow spaces of a mold are filled with mineral matter

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45 **Fossils: Evidence of Past Life**

- Types of Fossils
  - – Carbonization and Impressions
    - Carbonization occurs when an organism is buried and compressed, which squeezes out gases and liquids leaving a thin film of carbon behind
      - –Effective at preserving leaves and delicate animals
    - Impressions remain in the rock when the carbon film is lost
  - – Amber
    - Amber is the hardened resin of ancient trees
      - –Effective at preserving insects
  - – Trace Fossils
    - Indirect evidence of prehistoric life
      - –Includes tracks, burrows, coprolites, and gastroliths

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50 **Fossils: Evidence of Past Life**

- Conditions favoring preservation
  - – Most organisms are not preserved, two special conditions are necessary for most fossil preservation:
    - Rapid burial and
    - The possession of hard parts

51 **Correlation of Rock Layers**

- Correlation involves matching of rocks of similar ages from different regions
- Correlation provides a more comprehensive view of the rock record
  - – Often accomplished by noting the position of the bed in a sequence of strata
  - – Involves matching of rocks of similar ages from different regions
  - – To correlate over larger areas, fossils are used for correlation

52 **Correlation**

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54 ***Relative dating***

55 **Correlation of Rock Layers**

- Fossils and Correlation
  - – Principle of Faunal Succession
    - Used by William Smith, British canal builder
    - The principle of fossil succession states that fossils are arranged according to their age
      - –Example: Age of Trilobites, Age of Fishes, Age of Reptiles, Age of Mammals
  - – Index Fossils and Fossil Assemblages
    - Index fossils are widespread geographically and limited to a short period of geologic time
    - Fossil assemblages can be used to identify a rock bed that does not contain an index fossil

56 **Index Fossils**

57 **Fossil Assemblage**

58 **Correlation of Rock Layers**
- Environmental Indicators
  - Fossils can be used to infer information about past environments
    - Shells of organisms can be used to infer positions of ancient shorelines and seawater temperatures
    - Corals can be used to indicate former temperature of the water

59 **Dating with Radioactivity**
- Reviewing Basic Atomic Structure
  - The nucleus contains *protons* and *neutrons*
    - Protons are positively charged particles with mass
    - Neutrons are a combination of a proton and electron and have a neutral charge
  - *Electrons* are negatively charged particles that orbit the nucleus
  - The *atomic number* is the number of protons in the nucleus

60 **Dating with Radioactivity**
- Reviewing Basic Atomic Structure
  - The mass number is the number of protons and neutrons in a nucleus
  - Isotopes have
    - Same number of protons
    - Different numbers of neutrons
    - Different atomic mass

61 **Dating with Radioactivity**
- Radioactivity is the spontaneous decay in the structure of an atom’s nucleus
  - Types of radioactive decay
    - Alpha emission—an *alpha particle* (two protons and two neutrons) are ejected from the atom
      - Mass number is reduced by 4, and the atomic number is lowered by 2
    - Beta emission—a *beta particle* (an electron) is ejected from the atom
      - A neutron is composed of an electron and a proton. When the electron is ejected, the mass number remains unchanged and the atomic number is increased by 1
    - Electron capture—an electron is captured in the nucleus
      - The electron combines with the proton and changes into a neutron. The mass number remains unchanged and the atomic number is decreased by 1

62 **Dating with Radioactivity**
- Radioactivity
  - Unstable radioactive isotope is called the *parent*
  - Isotopes resulting from the decay of a parent are termed the *daughter products*
    - The ratio between parent and daughter isotopes in a rock is used to determine its numerical age
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63 **Common Types of Radioactive Decay**

64 ***Types of radioactive decay****

65 **Dating with Radioactivity**
- Radioactivity
  - Radiometric dating
    - Uses the decay of isotopes in rocks to calculate the age of that rock
- Half-Life
  - A half-life is the amount of time required for half of the radioactive isotope to decay
    - Radioactive parent isotopes decay to stable daughter isotopes
    - When the ratio of parent to daughter is 1:1, one half-life has passed

66 **Radioactive Decay Curve**

67 **Dating with Radioactivity**
- Using Various Isotopes

- With each passing half-life, 50 percent of the remaining parent decays to daughter atoms
  - As the parent atoms decrease, the daughter atoms increase
  - Several naturally occurring radioactive isotopes are useful for dating rocks
- Potassium-argon: commonly used example
  - Has a half-life of 1.3 billion years
  - Can date rocks as young as 100,000 years
  - Potassium-40 (^{40}K) decays to argon-40 (^{40}Ar) and calcium-40 (^{40}Ca)
  - ^{40}Ar is a gas and only present in rocks as the daughter product of the decay of ^{40}K

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70 **Isotopes Frequently Used in Radiometric Dating**

71 **Dating with Radioactivity**

- A Complex Process
  - Determining the quantities of parent and daughter isotopes must be precise
  - Some radioactive materials do not decay directly into stable daughter isotopes
    - Uranium-238 has 14 steps to ultimately decay to the stable daughter lead-206
    -
    -

72 **Radioactive Decay of U-238 to Pb-206**

73 **Dating with Radioactivity**

- Sources of Error
  - The system must be closed
    - No external addition or loss of parent or daughter isotopes
    - Fresh, unweathered rocks are ideal to use for radiometric dating
- Earth's Oldest Rocks
  - Oldest rocks are found on the continent
    - All continents have rocks exceeding 3.5 billion years
    - Confirms the idea that geologic time is immense

74 **Dating with Radioactivity**

- Dating with Carbon-14
  - Radiocarbon dating uses the radioactive isotope carbon-14 to date geologically recent events
    - The half-life of carbon-14 is 5730 years
      - Can be used to date events from the historic past to events as old as 70,000 years
    - Carbon-14 is produced in the upper atmosphere from cosmic-ray bombardment
      - Carbon-14 is incorporated into carbon dioxide and absorbed by plants through photosynthesis
      - *Carbon-14 is only useful in dating organic matter*
        - »All organisms contain a small amount of carbon-14

75 **Carbon-14**

76 **The Geologic Time Scale**

- The geologic time scale encompasses all of Earth's history
  - Subdivides geologic history into units with meaningful time frames
  - Originally created using relative dates
  - Numerical dates applied to it in the twentieth century

77 **Geologic Time Scale**

78 **The Geologic Time Scale**

- Structure of the Time Scale
  - An eon represents the greatest expanse of time
    - The Phanerozoic eon ("visible life") is the most recent eon, which began about 542 million years ago.
  - Eons are divided into eras

- The Phanerozoic eon is divided into three eras
  - –Paleozoic era (“ancient life”)
  - –Mesozoic era (“middle life”)
  - –Cenozoic era (“recent life”)

79 **The Geologic Time Scale**
- Structure of the Time Scale (continued)
  - Each Phanerozoic era is divided into periods
    - The Paleozoic era has seven periods
    - The Mesozoic and Cenozoic eras each have three periods
  - Each period is divided into epochs
    - Except for the seven recent epochs in the Cenozoic, most epochs are termed early, middle, and late

80 **Geologic Time Scale**

81 ***More Detail:***

82 **The Geologic Time Scale**
- Precambrian Time
  - Most detail in the geologic time scale is in the Phanerozoic eon
  - The 4 billion years (88% of Earth’s history) prior to the Cambrian period are divided into two eons and often collectively refereed to as the Precambrian
    - Proterozoic – “Original“ or “Primitive” Life
    - Archean – “Ancient”
  - Less is known about Earth further back in geologic time

83 **The Geologic Time Scale**
- Precambrian Time (continued)
  - During the Precambrian, simple life-forms that lacked a hard part (algae, bacteria, worms, fungi) dominated
    - First abundant fossil evidence does not appear until the beginning of the Cambrian period
  - Many Precambrian rocks are highly deformed metamorphic rocks—destroying any evidence of past environments

84 **The Geologic Time Scale**
- Terminology and the Geologic Time Scale
  - *Precambrian* is an informal name for the eons before the Phanerozoic
  - *Hadean* refers to the earliest interval of Earth’s history—BEFORE the oldest known rocks
  - Geologic timescale is continuously updated
  - *Anthropocene*—referring to human history—is suggested to identify the time since the 1800s that the Earth has seen human-caused global environmental change

85 **Determining Numerical Dates for Sedimentary Strata**
- Sedimentary rocks can rarely be dated directly by radiometric means
  - Geologists must rely on igneous rocks in the strata
    - Radiometric dating determines the age of the igneous rocks
    - Relative dating techniques assign date ranges to sedimentary rocks
    - This is referred to as “bracketing” various episodes in Earth’s history
    - Shows the necessity of combining laboratory dating methods with relative dating principles

86 **Dating Sedimentary Strata**

87 ***End of Chapter 9***