1 **Geologic Time**

Earth, Chapter 9

2 **Geologic Time: summary in haiku form**

Superposition
and horizontality
tell stories in rocks.

3 **Creating a Time Scale—Relative Dating Principles**

- The Importance of a Time Scale
  - Rocks record geologic and evolutionary changes throughout Earth's history
  - Without a time perspective, these events have very little meaning

4

- 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
  - Relative dates place rocks in a sequence of formation
    - Example: The Hermit Shale is older than the Coconino Sandstone

5

- 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

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

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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
- 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
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9 **Original Horizontality**

10 **Original Horizontality**

11 **Lateral Continuity in the Grand Canyon**

12 **Lateral Continuity in the Grand Canyon**

13

- Principle of Cross-Cutting Relationships
  - Younger features cut across older features
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14 **Cross-Cutting Dike**

15 **Cross-Cutting Fault**

16 ***Cross-cutting***

17 ***Relative Geologic Dating***

18 **Cross-cutting**

19 **Cross-cutting**

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- Inclusions
  - Inclusions are fragments of one rock unit that are enclosed within another rock unit
  - The rock containing the inclusion is younger
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21 **Inclusions**

22 **Inclusions**

23 **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
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25 ***Principles of relative dating***

- *Unconformities*
- Types:
  - Angular unconformity
    - Tilted rocks are overlain by flat-lying rocks
  - Disconformity
    - Strata on either side of unconformity are parallel
  - Nonconformity
    - Metamorphic or igneous rocks are overlain by sedimentary rocks
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26 **Siccar Point, Scotland**

27 ***Unconformity***

28 ***Formation of an angular unconformity***

29 ***Unconformity Types***

30 ***Any unconformities in this picture?***

31 ***Unconformities present in the Grand Canyon***

32 ***Starting at the bottom: nonconformity***

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

34 ***Toward the top: disconformities***

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42 ***Correlation of rock layers***

- Role of *fossils*
  - William Smith (late 1700's):
  - sedimentary strata in separated areas could be correlated by fossil content

43 **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
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44 **Fossils: Evidence of Past Life**

- Types of Fossils
  - Permineralization
    - Mineral-rich groundwater flows through porous tissue and precipitates minerals
    - Example: petrified wood
  - Molds and casts
    - A mold is created when a shell is buried and then dissolved by underground water
    - A cast is created when the hollow spaces of a mold are filled
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47 **Fossils: Evidence of Past Life**

- Types of Fossils
  - Carbonization and impressions
    - Carbonization happens when an organism is buried, followed by compression, which squeezes out gases and liquids leaving a thin film of carbon
      - Effective at preserving leaves and delicate animals
    - Impressions remain in the rock when the carbon film is lost
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49 **Fossils: Evidence of Past Life**

- Types of Fossils
  - 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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52 **Fossils: Evidence of Past Life**

- Types of Fossils
  - Conditions favoring preservation
    - Most organisms are not preserved
    - Rapid burial and the possession of hard parts increases the chances of preservation

53 **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

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55 ***Relative dating***

56 **Correlation of Rock Layers**

- Correlation Within Limited Areas

- 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

57 **Correlation of Rock Layers**

- Fossils and Correlation
  - Principle of fossil succession
    - 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

58 **Index Fossils**

59 **Correlation of Rock Layers**

- Fossils and Correlation
  - Index fossils and fossil assemblages
    - A fossil assemblage is a group of fossils used to determine a rock's age
  - Environmental indicators
    - Fossils can be used to infer information about past environments
      - Example: Shells of organisms can be used to infer positions of ancient shorelines and seawater temperatures

60 **Fossil Assemblage**

61 ***Using radioactivity in dating***

- Reviewing basic atomic structure
  - Nucleus
    - Protons
      - Positively-charged particles with mass of 1 a.m.u.
    - Neutrons
      - Neutral particles with mass of 1 a.m.u.
  - Electrons
    - Negatively-charged particles that orbit the nucleus

62 ***Using radioactivity in dating***

- Reviewing basic atomic structure
  - Atomic number
    - An element's identifying number
    - Equal to the number of protons in the atom's nucleus
  - Mass number
    - Sum of the number of protons and neutrons in the atom's nucleus

63 ***Using radioactivity in dating***

- Reviewing basic atomic structure
  - Isotope
    - Variant of the same parent atom
    - Differs in the number of neutrons
    - Results in a different mass number than the parent atom

64 ***Using radioactivity in dating***

- Radioactivity
  - Spontaneous changes (decay) in the structure of atomic nuclei
- Types of radioactive decay
  - Alpha emission
    - Emission of 2 protons and 2 neutrons (an alpha particle)
    - Mass number is reduced by 4 and the atomic number is lowered by 2

65 ***Using radioactivity in dating***

- Types of radioactive decay

- Beta emission
  - An electron (beta particle) is ejected from the nucleus
  - Mass number remains unchanged and the atomic number increases by 1

66 ***Using radioactivity in dating***

- Types of radioactive decay
  - Electron capture
    - An electron is captured by the nucleus
    - The electron combines with a proton to form a neutron
    - Mass number remains unchanged and the atomic number decreases by 1

67 ***Types of radioactive decay****

68 ***Using radioactivity in dating***

- Parent
  - An unstable radioactive isotope
- Daughter product
  - The isotopes resulting from the decay of a parent

69 **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

70 **Radioactive Decay Curve**

71 ***Radioactive Decay***

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74 **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

75 **Dating with Radioactivity**

- Using Various Isotopes
  - Potassium-argon
    - 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

76 **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

77 **Isotopes Frequently Used in Radiometric Dating**

78 **Dating with Radioactivity**

- Using Various Isotopes
  - 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
  - Example: uranium-238 has 14 steps to ultimately decay to the stable daughter lead-206

79 ***Uranium – 238 decay series***

80 **Dating with Radioactivity**

- Using Various Isotopes
  - 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

81 **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

82 **Carbon-14**

83 **The Geologic Time Scale**

- The geologic time scale encompasses all of Earth history
  - Subdivides geologic history into units
  - Originally created using relative dates
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84 **Geologic Time Scale**

85 **The Geologic Time Scale**

- Structure of the Geologic 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")

86 **The Geologic Time Scale**

- Structure of the Geologic Time Scale
  - 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

87 **The Geologic Time Scale**

- Precambrian Time
  - Most detail in the geologic time scale is in the Phanerozoic eon
  - The 4 billion years prior to the Cambrian period are divided into two eons and often collectively refereed to as the Precambrian
    - –Proterozoic—“Before Life”
    - –Archean—“Ancient”
  - Less is known about Earth further back in geologic time
    - –

88 **The Geologic Time Scale**

- Precambrian Time
  - 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

89 **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
  - Geologic timescale is continuously updated

90 **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

91 **Dating Sedimentary Strata**

92 ***End of Chapter 9***