Geologic Time

Earth, Chapter 9

Geologic Time: summary in haiku form
Superposition
and horizontality
tell stories in rocks.

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
• 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
• 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

Superposition illustrated in the Grand Canyon

• 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

Original Horizontality

Lateral Continuity in the Grand Canyon

• Principle of Cross-Cutting Relationships
  - Younger features cut across older features

Cross-Cutting Dike

Cross-Cutting Fault

Cross-cutting

Relative Geologic Dating

Cross-cutting

Cross-cutting
• Inclusions
  – Inclusions are fragments of one rock unit that are enclosed within another rock unit
  – The rock containing the inclusion is younger

• 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

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

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

35 Correlation of rock layers
  → Role of fossils

36 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: 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

Fossils: Evidence of Past Life
• Types of Fossils
  – Carbonization and impressions
    • Carbonization happens when an organism is buried, followed by compression, which squeeze 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

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

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

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

Relative dating

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

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

Types of radioactive decay*

Using radioactivity in dating
Parent
An unstable radioactive isotope
Daughter product
The isotopes resulting from the decay of a parent

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

Radioactive Decay Curve

Radioactive Decay

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

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 (40K) decays to argon-40 (40Ar) and calcium-40 (40Ca)
• 40Ar is a gas and only present in rocks as the daughter product of the decay of 40K

Dating with Radioactivity
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Isotopes Frequently Used in
Radiometric Dating
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.

**Uranium - 238 decay series**

**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

**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

**Carbon-14**

**The Geologic Time Scale**

- The geologic time scale encompasses all of Earth history
  - Subdivides geologic history into units
  - Originally created using relative dates

**Geologic Time Scale**

**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")

**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
• 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 referred to as the Precambrian
    - Proterozoic—"Before Life"
    - Archean—"Ancient"
  • Less is known about Earth further back in geologic time

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

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

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

Dating Sedimentary Strata
End of Chapter 9