Chapter 9
Geologic Time

Relative dating

- Law of superposition
  - Developed by Nicolaus Steno in 1669
  - In nondeformed sequence of sedimentary rocks (or volcanic rocks), oldest rocks are on bottom

Superposition illustrated by strata in Grand Canyon

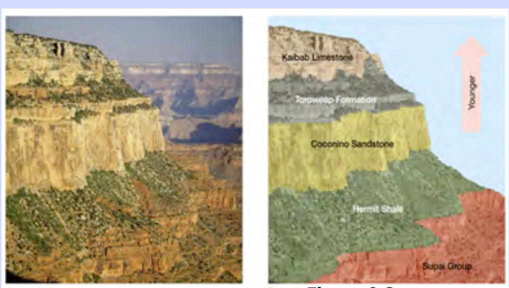


Figure 9.2

Relative dating

- Principle of original horizontality
  - Layers of sediment *generally* deposited in horizontal position
  - Rock layers that are flat have not been disturbed
- Principle of cross-cutting relations
  - Younger features cut across older features

Cross-cutting relations

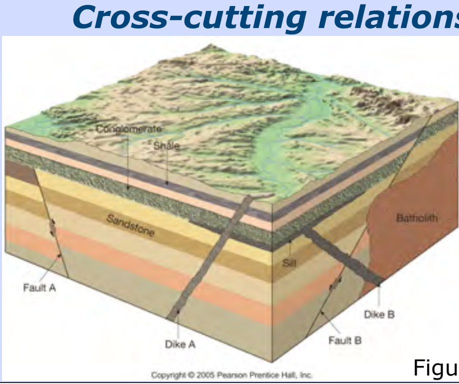


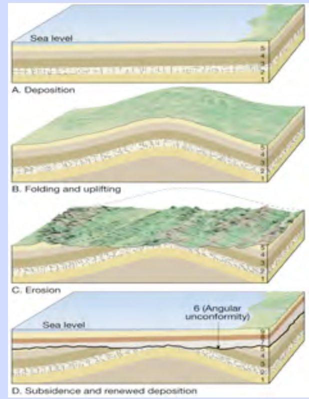
Figure 9.4

Relative dating

- Inclusions
  - Inclusion: piece of rock enclosed within another rock
  - Rock *containing* inclusion is younger
- Unconformity
  - Unconformity is break in rock record produced by erosion and/or nondeposition of rock units

Relative dating

- Unconformity
  - Types of unconformities
    - Angular unconformity – tilted rocks overlain by flat-lying rocks
    - Disconformity – strata on either side of unconformity are parallel
    - Nonconformity – metamorphic or igneous rocks in contact with sedimentary strata



Formation of angular unconformity

Figure 9.7

Unconformities in Grand Canyon

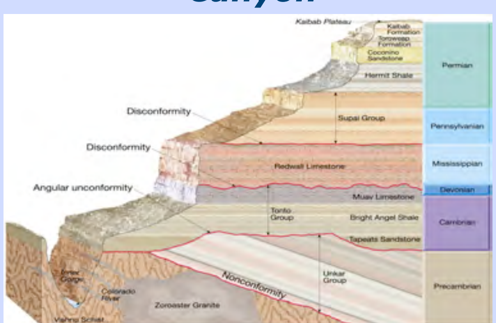


Figure 9.6

Figure 9.7E

Fossils: Evidence of past life

- Fossil = traces or remains of prehistoric life now preserved in rock
- Fossils generally found in sediment or sedimentary rock
- Paleontology = study of fossils

Fossils: Evidence of past life

- Geologically fossils are important because they
  - Serve as important time indicators
  - Allow for time correlation of rocks from different places

Fossils: Evidence of past life

- Types of fossils
  - Remains of relatively recent organisms – teeth, bones, etc.
  - Given enough time, remains may be petrified (literally "turned into stone")
  - Molds and casts

Fossils: Evidence of past life

- Types of fossils
  - Others
    - Tracks (trace fossil)
    - Burrows (trace fossil)
    - Coprolites (fossil dung)
    - Gastroliths (polished stomach stones)

Fossils: Evidence of past life

- Conditions favoring preservation
  - Rapid burial
  - Possession of hard parts (skeleton, shell, etc.)

Natural casts of shelled invertebrates

Figure 9.11 B

Dinosaur footprint in limestone

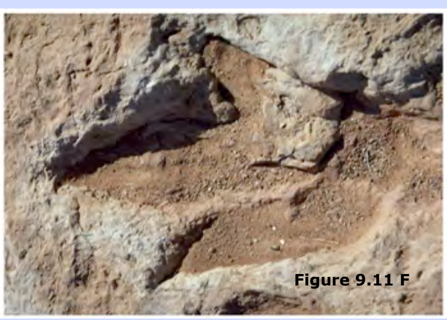
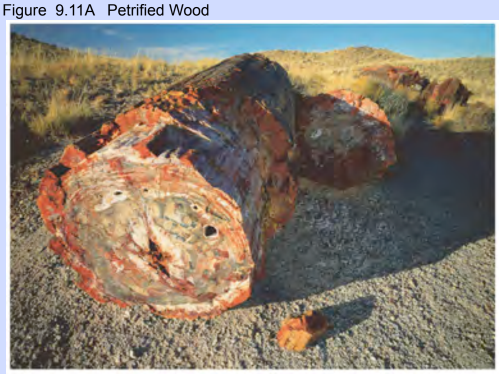


Figure 9.11 F

Figure 9.11A Petrified Wood



A

Figure 9.11E Amber

Fossils and correlation

- Matching of rocks of similar ages in different regions is known as correlation
- Correlation often relies upon fossils

Fossils and correlation

- Principle of fossil succession – fossil organisms succeed one another in definite and determinable order, and therefore any time period can be recognized by its fossil content
- Index fossil – geographically widespread fossil that is limited to short span of geologic time

Dating rocks using overlapping fossil ranges

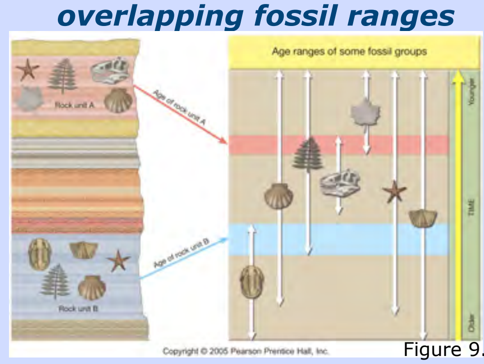


Figure 9.12

Dating with radioactivity

- Reviewing basic atomic structure
  - Nucleus
    - Protons = + charged particles with mass
    - Neutrons = neutral particles with mass
    - Electrons = - charged particles that orbit nucleus

Dating with radioactivity

- Reviewing basic atomic structure
  - Atomic number
    - Element's identifying number
    - Equal to number of protons
  - Mass number
    - Sum of number of protons and neutrons

Dating with radioactivity

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

Dating with radioactivity

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

Dating with radioactivity

- Types of radioactive decay
  - Beta-minus emission
    - Electron (beta particle) ejected from nucleus
    - Mass number remains unchanged and atomic number increases by 1 by changing neutron to proton
    - Beta-plus decay also occurs
  - Electron capture
    - Electron captured by nucleus and combines with proton to form neutron
    - Mass number remains unchanged and atomic number decreases by 1

Dating with radioactivity

- **Parent** –unstable radioactive isotope
- **Daughter product** –isotopes resulting from decay of parent
- **Half-life** –time required for one-half of radioactive nuclei in sample to decay

Dating with radioactivity

- Isotopic dating
  - Principle of radioactive dating
    - Percentage of radioactive atoms that decay during one half-life is always same (50 percent)
    - However, actual number of atoms that decay continually decreases
    - Comparing ratio of parent to daughter yields age of sample

Figure 9.14

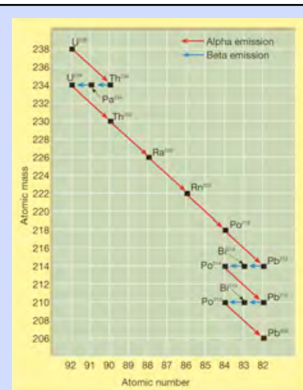


Table 9.A

TABLE 9.A Decay Products of Uranium-238		
Some Decay Products of Uranium-238	Decay Particle Produced	Half-Life
Uranium-238	alpha	4.5 billion years
Radium-226	alpha	1600 years
Radon-222	**alpha**	**3.82 days**
Polonium-218	alpha	3.1 minutes
Lead-214	beta	26.8 minutes
Bismuth-214	beta	19.7 minutes
Polonium-214	alpha	1.6×10^{-4} second
Lead-210	beta	20.4 years
Bismuth-210	beta	5.0 days
Polonium-210	alpha	138 days
Lead-206	none	stable

Radioactive decay curve

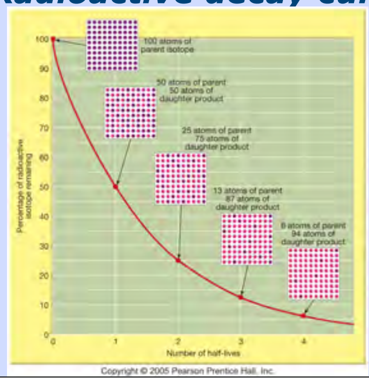


Figure 9.15

TABLE 9.1 Isotopes Frequently Used in Radiometric Dating		
Radioactive Parent	Stable Daughter Product	Currently Accepted Half-life Values
Uranium-238	Lead-206	4.5 billion years
Uranium-235	Lead-207	713 million years
Thorium-232	Lead-208	14.1 billion years
Rubidium-87	Strontium-87	47.0 billion years
Potassium-40	Argon-40	1.3 billion years

Common datable minerals

- Zircon, monazite: U-Pb
- Monazite: Th-Pb
- Feldspar, micas, hornblende: K-Ar

Dating with radioactivity

- **Dating with carbon-14 (radiocarbon dating)**
  - **Half-life = 5730 years**
  - **Can only be used to date recent events (last 30 ka)**
  - **Carbon-14 produced in upper atmosphere**
  - **Useful tool for archeologists, volcanologists, Quaternary geologists**

The geologic time scale

- **Geologic time scale – "calendar" of Earth history**
  - **Subdivides geologic history into units**
  - **Originally created using relative dates**
- **Structure of geologic time scale**
  - **Eon –greatest expanse of time**

The geologic time scale

- **Structure of geologic time scale**
  - **Names of eons**
    - **Phanerozoic** (“visible life”) –most recent eon, began about 540 million years ago
    - **Proterozoic**
    - **Archean**
    - **Hadean** –oldest eon

The geologic time scale

- **Structure of geologic time scale**
  - **Era** – subdivision of eon
  - **Eras of Phanerozoic eon**
    - **Cenozoic** (“recent life”)
    - **Mesozoic** (“middle life”)
    - **Paleozoic** (“ancient life”)
  - **Eras subdivided into periods**
  - **Periods subdivided into epochs**

Figure 9.17

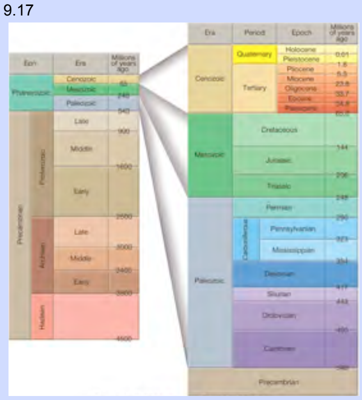


Figure 9.G

Figure 9.H

One possible explanation for K/T dinosaur extinction (but lots of evidence to contrary)

TABLE 9.2 Major Divisions of Geologic Time

Cenozoic Era (Age of Recent Life)	Quaternary period	The several geologic eras were originally named Primary, Secondary, Tertiary, and Quaternary. The first two names are no longer used; Tertiary and Quaternary have been retained but used as period designations.
	Tertiary period	
Mesozoic Era (Age of Middle Life)	Cretaceous period	Derived from Latin word for chalk (creta) and first applied to extensive deposits that form white cliffs along the English Channel (see Figure 7.11).
	Jurassic period	Named for the Jura Mountains, located between France and Switzerland, where rocks of this age were first studied.
	Triassic period	Taken from word “trias” in recognition of the threefold character of these rocks in Europe.
Paleozoic Era (Age of Ancient Life)	Permian period	Named after the province of Perm, Russia, where these rocks were first studied.
	Pennsylvanian period*	Named for the state of Pennsylvania where these rocks have produced much coal.
	Mississippian period*	Named for the Mississippi River Valley where these rocks are well exposed.
	Devonian period	Named after Devonshire County, England, where these rocks were first studied.
	Silurian period Ordovician period	Named after Celtic tribes, the Silures and the Ordovices, that lived in Wales during the Roman Conquest.
	Cambrian period	Taken from Roman name for Wales (Cambria), where rocks containing the earliest evidence of complex forms of life were first studied.
Precambrian		The time between the birth of the planet and the appearance of complex forms of life. About 88 percent of Earth's estimated 4.5 billion years fall into this span.

SOURCE: U.S. Geological Survey.
*Outside of North America, the Mississippian and Pennsylvanian periods are combined into the Carboniferous period.

Geologic Time Scale

- Precambrian time
  - Nearly 4 billion years prior to Cambrian period
  - Not divided into smaller time units because events of Precambrian history not known in great enough detail
  - Only abundant life was cyanobacteria preserved as stromatolites

The geologic time scale

- Difficulties in dating geologic time scale
  - Not all rocks can be dated by isotopic methods
    - Grains composing detrital sedimentary rocks not same age as rock in which they formed
    - Age of particular mineral in metamorphic rock may not necessarily represent time when rock formed

The geologic time scale

- Difficulties in dating geologic time scale
  - Datable materials (such as volcanic ash beds and igneous intrusions) often used to bracket various episodes in Earth history and arrive at ages