Geologic Time

- **Challenge**: Using geological evidence, work out a history of the 4.6 billion year-old Earth.

- **Problem**: Most evidence of early Earth history has been removed by weathering, erosion and tectonic processes. The further back in time we look, the less evidence of Earth History we find.

- **Consequence**: Geologists know details of ‘recent’ Earth history (~550 my), but relatively little about ‘ancient’ Earth history (4.6 by ~550 my).

Characters in the Story

- **James Usher** (1581 – 1656) – Anglican Bishop who in the mid-1600’s proposed that Earth was formed in year 4004 BC. Based his idea upon study of the Old Testament. His theory assumes that Earth’s surface has been shaped by a series of great catastrophies, as described in the Old Testament.

Characters in the Story

- **Nicholas Steno** (1638-1686) – Catholic priest was the first person to systematically study Earth history using the fossilized remains of living organisms. His research resulted in the basic geologic principles upon which studies of Earth’s history are based.

- **James Hutton** (1726 – 1797) – Scottish physician and farmer, in the late 1700’s proposed the **Principle of Uniformitarianism**. Geologic change occurs over a long period of time by a sequence of almost imperceptible events. Geologic forces shaping the Earth today are the same forces that have shaped Earth over its entire history, and those forces have been operating at the same rates over the Earth’s entire history.

Characters in the Story

- **Catastrophists** – believed the teachings of Usher and supported his argument

- **Uniformitarianists** – believed the teachings of Steno and Hutton and supported their argument

- **Significance of the debate**: Initiated a (controversial?) scientific investigation of the age and history of the Earth, which continues today.

Geologic Age Dating Techniques

- **Relative Dating**: Determination of the order in which geologic events occurred without reference to absolute time.

- **Absolute Dating (Radiometric Dating)**: Determination of the number of years passed since occurrence of a geologic event.
Basic Principles of Relative Dating

• Nicolas Steno – ‘Steno’s Laws’
  – Principle of Superposition
  – Principle of Original Horizontality
  – Principle of Cross-Cutting Relationships
• Inclusions
• Principle of Faunal Succession
• Unconformities
  – Angular Unconformity
  – Disconformity
  – Nonconformity

Principle of Superposition and Original Horizontality

Principle of Cross-Cutting Relationships

Inclusions

Principle of Faunal Succession

• Fossil organisms succeed one another through time in a definite and recognizable order

• Index Fossil – Widespread geographically, but limited to a short span of geologic time. Are useful for correlation of rocks of same age over a wide geographic region.
Unconformities

• ‘Time Gaps’ in the geologic record. Are caused by major geologic events, such as orogenesis, *transgression* (rise in sea level), and *regression* (drop in seal level).
• Three types:
  – Angular Unconformity
  – Disconformity
  – Nonconformity

Formation of an Angular Unconformity

Angular Unconformity at Siccar Point, Scotland

Angular Unconformity

Disconformity
Using basic principles and techniques of relative dating, geologists were able to work out a fairly detailed history of the Earth.

However, the history was worked out without reference to absolute time. In other words, geologists did not know how many years passed between the geologic events they observed in the rock record. There was also no knowledge of the exact age of the Earth.

The solutions to these problems were achieved through the discovery that ratios of isotopes in geologic materials can be used to determine their exact age.
Absolute (Radiometric) Dating

- Calculation of the age of a rock/mineral based upon ratios of certain chemical isotopes.
- **Isotopes** – Atoms with the same number of protons, but varying numbers neutrons

\[ ^{12}\text{C} \text{ - 6 protons + 6 neutrons} \]

\[ ^{14}\text{C} \text{ - 6 protons + 8 neutrons} \]

Isotopes

- **Unstable (Parent) Isotope** – spontaneously changes its numbers of protons and/or neutrons by the process of radioactive decay
- **Stable (Daughter) Isotope** – isotope created by radioactive decay of a parent isotope; undergoes no change in its numbers of protons and/or neutrons over long periods of time

Parent: \(^{238}\text{U}\)  
Daughter: \(^{206}\text{Pb}\)

Half Life

- The time required for exactly one half of the parent isotopes in a sample to decay to daughter isotopes

\[
\begin{array}{c|c|c}
\frac{1}{2} \text{ lives} & \text{Fract. P remaining} & \text{P:D} \\
0 \text{ (formation)} & 1/1 = 1 & 1:0 \\
1 & 1/2 & 1:1 \\
2 & 1/4 & 1:3 \\
3 & 1/8 & 1:7 \\
4 & 1/16 & 1:15 \\
\end{array}
\]

Since the exact number of parent atoms in a sample at time of formation cannot be known, the parent to daughter ratio must be measured in order to calculate the age of the sample.

Age Equation

\[
\text{AGE} = \text{HALF LIFE} \times \text{HALF LIVES PASSED}
\]

Half Life – constant (determined in laboratory)  
Half Lives Passed – determined from P:D in sample

Example: What is the age in years of a mineral with P:D = 1:15 and a parent isotope half life = 10 my?

P:D = 1:15 indicates that 4 half lives half passed since formation of the mineral. So,

\[
\text{Age} = 10 \text{ my} \times 4 = 40 \text{ my}
\]
Radioactive Decay Mechanisms

- **Electron Capture** – nucleus captures an electron which combines with a proton to create a neutron (atomic number decreases by one; mass number does not change).

Radioactive Decay Mechanisms

- **Beta Emission** – a neutron expels an electron (beta particle), changing the neutron to a proton (atomic number increases by 1; mass number does not change).

Radioactive Decay Mechanisms

- **Alpha Emission** – nucleus expels two protons and two neutrons (alpha particle) (atomic number decreases by two; mass number decreases by four).

Important Assumptions

1. No daughter isotope atoms were ‘trapped’ in the sample at time of formation (frequently violated)
   - Mathematical correction must be made to parent:daughter, otherwise calculated age will be incorrect.

2. No parent or daughter isotopes have been ‘lost’ from the sample since time of formation (sometimes violated)
   - May occur to heating during metamorphism, in which case the calculated age will represent time passed since metamorphism.

**Important Assumptions**

3. The decay rate of the parent to daughter isotope (the half life) is constant (never violated).

4. The parent-daughter isotope pair measured in the sample has an appropriate half life for the age of the sample (never violated assuming geologists have common sense).
   - Very old samples – use long half life isotopes.
   - Very young samples – use short half life isotopes.

| Table 10.1: Radioactive isotopes frequently used in radiometric dating. |
|---|---|---|
| **Parent** | **Daughter** | **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 |
Geologic Time Scale

- History of the Earth was divided into blocks of time, based upon major evolutionary and extinction events observed in the rock record.
  - Accomplished prior to development of radiometric dating techniques, so original time scale had no reference to absolute time.
    - Result: blocks of time are unequal in length
  - Little information could be gained from rocks that did not contain fossilized remains of plants and animals, or from rocks that could not be correlated to those containing fossilized remains.
    - Result: less detail known about most of Earth history (prior to ~ 550 my)

Units of Time

- Eon – longest
- Era
- Period
- Epoch – shortest

Remember: Each eon, era, period and epoch contains a different number of years

Important Time Boundaries

- **Mesozoic – Cenozoic = 65 my**
  - Characterized by a major extinction
    - Extinction of dinosaurs and other species, probably by meteorite impact
- **Paleozoic – Mesozoic = 248 my**
  - Characterized by a major extinction
    - Extinction of many shallow water marine invertebrates, possibly related to tectonic induced rapid sea level changes
- **Precambrian – Phanerozoic = 540 my**
  - Organisms with 'hard parts' become abundant

Paleozoic Era

- **Late Paleozoic – Formation of Pangaea**
  - Orogenesis of Appalachian Mountains
- **Mississippian – Pennsylvanian = Carboniferous**
  - Abundant coal, natural gas, and oil forming swamps
- **Mississippian – Pennsylvanian – Permian**
  - Age of Amphibians
    - First reptiles
- **Silurian – Devonian**
  - Age of Fishes
    - First land plants and insects
- **Cambrian – Ordovician**
  - Age of Marine Invertebrates
    - Late Ordovician – First fish

Note that most detail in the time scale is included in the last ~550 my of Earth history.

Ages of time scale boundaries were added after development of radiometric dating techniques.
**Mesozoic Era – ‘Age of Reptiles’**

- Cretaceous
  - First flowering plants
- Jurassic
  - First birds
- Triassic
  - Dinosaurs become dominant land animal

**Cenozoic Era – ‘Age of Mammals’**

- Quaternary
  - First humans
  - Current epoch = Holocene (Recent)
  - THE ice age = Pleistocene epoch
- Tertiary
  - Mammals become dominant land animal