Absolute Time

Radiometric Dating: the source of the dates on the Geologic Time Scale
Radiometric Dating

• Actually a simple technique.
• Only two measurements are needed:
• 1. The parent:daughter ratio measured with a mass spectrometer.
• 2. The decay constant measured by a scintillometer (detects gamma rays).
Lab for extracting parent and daughter elements.

Mass spectrometer to measure ratio of parent and daughter elements.
Basis of the Technique

• Radioactive elements “decay.” Decay occurs as an element changes to another element, e.g. uranium to lead.
• The parent element is radioactive, the daughter element is stable.
• The decay rate is constant.
What is Radioactivity?

• Radioactivity occurs when certain elements literally fall apart.
• Usually protons and neutrons are emitted by the nucleus.
• Sometimes an electron is emitted by the nucleus, which changes a neutron to a proton.
• Sometimes an electron is captured, which changes a proton to a neutron.
<table>
<thead>
<tr>
<th></th>
<th>Uranium 238</th>
<th>Alpha Particle</th>
<th>Thorium 234</th>
</tr>
</thead>
<tbody>
<tr>
<td>Protons</td>
<td>92</td>
<td>2</td>
<td>90</td>
</tr>
<tr>
<td>Neutrons</td>
<td>146</td>
<td>2</td>
<td>144</td>
</tr>
</tbody>
</table>
Uranium-238 decay chain

Thorium-234
Electron emission

Alpha particle emission

Nucleus

Electron emission

Rubidium–87 (nucleus)

Proton

Neutron

Parent

37 Protons
50 Neutrons

Strontium–87 (nucleus)

38 Protons
49 Neutrons

Daughter
What causes radioactivity?

• Carbon-14 is produced by cosmic ray bombardment of Nitrogen-14 in the atmosphere.

• All other radioactive elements were produced by supernova explosions before our solar system formed. This is called explosive nucleosynthesis.
Common Radioactive Elements, Parents and Daughters

- Carbon-14, C$^{14}$
- Uranium-235, U$^{235}$
- Potassium-40, K$^{40}$
- Uranium-238, U$^{238}$
- Rubidium-87, Rb$^{87}$
- Nitrogen-14, N$^{14}$
- Lead-207, Pb$^{207}$
- Argon-40, Ar$^{40}$
- Lead-206, Pb$^{206}$
- Strontium-87, Sr$^{87}$
Basis of the Technique

- As the parent element decays, its amount decreases while the amount of the daughter element increases. This gives us a ratio of parent:daughter elements.

- The decay rate is geometric rather than linear. Unaffected by heat or pressure.
Web site graphically showing radioactive decay:

http://lectureonline.cl.msu.edu/~mmp/applist/decay/decay.htm
Key Term

• Half-Life: the amount of time for half the atoms of a radioactive element to decay. Doesn’t matter how many atoms started, half will decay.
Figure 6-8
Earth System History, Second Edition
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A mineral sample containing radioactive atoms, which decay into daughter atoms.

Percentage of radioactive and daughter atoms in the mineral.

Percentage remaining:

- 1/2 remain
- 1/4 remain
- 1/8 remain

Percentage of radioactive atoms remaining:

Age in half-lives:

0 1 2 3 4 5 6
On a log scale, geometric depletion plots as a straight line.
Radioactive decay for an isotope that has a decay constant of 2% a year (2.0x10^{-2}). The half life is 35 years (e.g., Strontium 90, or Cesium 137).
Radioactive decay is the opposite of geometric growth by compound interest. At 2% interest the money doubles every 35 years.
Half-Lives

- Counting half-lives:
- Half-lives: 1, 2, 3, 4
- Parent: 1/2, 1/4, 1/8, 1/16, etc.
- Daughter: 1/2, 3/4, 7/8, 15/16, etc.
- P:D Ratio: 1:1, 1:3, 1:7, 1:15
Measuring Half-Lives

• Ratios of 1:3, 1:7, 1:15, etc. are for whole half lives, but any ratios can be measured; e.g. 1:4.2, or 8.6:1
The Decay Constant, $\lambda$

- The rate of decay is called the decay constant. It determines the half-life of a radioactive element.
- The decay constant is unique for each radioactive element.
- Measured with a scintillometer.
The Decay Constant, $\lambda$

- Some values of the decay constant:
  - $^{14}_C$: $1.21 \times 10^{-4}$ atoms per year
  - $^{235}_U$: $9.72 \times 10^{-10}$ atoms per year
  - $^{40}_K$: $5.34 \times 10^{-10}$ atoms per year
Calculating a Half Life

- \[ t = \frac{\ln (P+D)}{P} \frac{\lambda}{\lambda} \quad (P+D = \text{starting material}) \]

- What is the half life of Carbon-14?
- \[ t = \frac{\ln ((1+1)/1)}{1.21 \times 10^{-4}} \]
- \[ t = (\ln 2)/1.21 \times 10^{-4} \]
- \[ t = 5,730 \text{ years} \]
Some Half Lives

• Carbon-14: 5,730 years
• Uranium-235: 704 MY
• Potassium-40: 1.3 BY
• Uranium-238: 4.5 BY
• Rubidium-87: 48.8 BY
Calculating a Radiometric Date

\[ t = \frac{\ln \left( \frac{P+D}{P} \right)}{\lambda} \quad (P+D = \text{starting material}) \]

- A volcanic ash bed just below the Dev.- Carb. Boundary has a Pb\textsuperscript{207}:U\textsuperscript{235} ratio of 0.4192 +/- 0.0010

\[ t = \frac{(\ln \left( 1+0.4192 \right))/1)}{9.72 \times 10^{-10}} \]

\[ t = \frac{(\ln 1.4192)}{9.72 \times 10^{-10}} \]

\[ t = 0.350 \times 1.029 \times 10^9 \]

\[ t = 360,178,000 +/- 859,000 \text{ years} \]
Setting the Radiometric Clock

- When an igneous melt crystallizes, parent and daughter elements are chemically separated into different crystals.
- Further radioactive decay keeps the parent and daughter elements in the same crystal.
A mineral sample containing radioactive atoms, which decay into daughter atoms.

Percentage of radioactive and daughter atoms in the mineral.

Percentage remaining:

- 100
- 50
- 0

Age in half-lives

- 0
- 1
- 2
- 3
- 4
- 5
- 6

Percentage of radioactive atoms remaining:

- 1/2 remain
- 1/4 remain
- 1/8 remain
Setting the Radiometric Clock

• Individual crystals of the same mineral are dated to give the age of crystallization or cooling. Examples include zircon, muscovite, and biotite.

• Note that whole rock analysis would not give the age of cooling.
Zircon crystals with laser beam holes from radiometric dating
Setting the Radiometric Clock

- Carbon-14 is different in that it occurs in organic remains rather than in rocks.
- Clock is set when an organism dies.
- Carbon-14 is absorbed by all living organisms from the atmosphere or the food they eat.
- Useful for about 10 half lives, or only about 57,000 years.
Cosmic Radiation

Cosmic rays enter the earth's atmosphere and collide with an atom, creating an energetic neutron.

When the neutron collides with a nitrogen atom, a nitrogen-14 (seven protons, seven neutrons) atom turns into a carbon-14 atom.

Neutron capture

Nitrogen 14

Neutron

Carbon 14

Proton

Plants absorb carbon dioxide and incorporate carbon-14 through photosynthesis.

Animals and people eat plants and take in carbon-14.

Following death and burial, wood and bones lose C-14 as it changes to N-14 by beta decay.

Carbon 14

Beta decay

Nitrogen 14

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Materials dated using the Carbon-14 method

Charcoal, wood, twigs and seeds.
Bone.
Marine, estuarine and riverine shell.
Leather.
Peat
Coprolites.
Soil.
Pollen.
Hair.
Pottery.
Wall paintings and rock art works.
Avian eggshell.
Corals and foraminifera.
Speleothems.
Blood residues.
Textiles and fabrics.
Paper and parchment.
Fish remains.
Insect remains.
Resins and glues.
Antler and horn.
Water.
Calibrating the Geologic Time Scale

• Radiometric dates from igneous rocks can be used to indirectly date sedimentary rocks and their fossils. Principles such as superposition and cross-cutting relationships come into play.

• Thousands of radiometric dates have been obtained.
Lava flow 1
80 MY old

Lava flow 2
90 MY old

Layer?
What we want to date

Cretaceous fossils
Examples of conodonts, the teeth of primitive chordates
Age of the Earth: 4.55 BY

- The oldest rocks found on earth are 4.0 BY from NW Canada.
- 4.4 BY zircons have been found in younger sandstones in Australia.
- Meteorites are 4.55 BY.
- Lunar rocks are 4.4-4.5 BY.
- Rocks older than 4.0 BY on earth have apparently been destroyed by weathering and plate tectonics.
4.40 BY zircon grain from Australia, found in 3 BY sandstone