How old is Earth?
Bishop of Ireland James Ussher

Not so long ago, the Bible was regarded as the ultimate source of truth.

Through the 18th and 19th centuries it was believed that the world was brought rapidly into existence exactly 4004 years before the birth of Christ.

Monday, October 23, 2004 B.C. at 9 a.m., London time – or midnight in the Garden of Eden (the delta region of the Tigres and Euphrates Rivers in Iraq).

Bishop Ussher used a combination of astronomical cycles, historical accounts, and sources of biblical chronology reported in the Book of Genesis.

The beginning of Creation was placed 2,000 years before the birth of Christ. The last "4" was date for Christ's birth as 4 B.C.
But Ussher’s ideas were not without some doubt in the world.

Two hundred years earlier Leonardo da Vinci calculated sedimentation rates in the Po River of Italy and concluded it had taken some 200,000 years to form nearby rock deposits.

In 1760 the Frenchman Georges-Louis Leclerc de Buffon estimated Earth’s age to be 75,000 years by calculating its time of cooling from the molten state.

In 1831 Charles Lyell arrived at an age of 240 million years based on changes recorded in fossils found in rock of the English countryside.

In 1901, John Joly calculated the rate of salt delivery from rivers to the ocean and estimated the time needed to make seawater. His answer was 90 to 120 million years.

Now, based on modern understanding of the phenomenon of radioactivity, scientists have concluded that Earth is approximately 4.6 billion years old.

Geologists have developed two methods of dating geologic events:

Relative Dating
The ranking or ordering of a sequence of geologic events.

“What came first? What came second?”

Absolute Dating
The measurement of an actual age of a geologic event.

“How many years ago did this geologic event occur?”

Geologic Events in Earth History
1. Deposition of sediment and formation of rock strata.
2. Erosion of the crust such that a gap is formed in the record of past events.
3. Intrusion of plutonic and volcanic igneous rocks
Geologic Events in Earth History

4. **Faulting** of crust rocks. A fault is a break of fracture where rock layers on one side of the break are moved relative to layers on the other side.

5. **Deformation** of crust rocks such that they become folded, tilted, or even inverted.

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Relative Dating is performed by the application of seven stratigraphic principles

1. **Principle of Superposition**
   In a sequence of sedimentary rocks, the oldest layer is at the bottom and the youngest layer is at the top.

2. **Principle of Original Horizontality**
   Sedimentary rocks are deposited in layers parallel to Earth’s surface. There are some exceptions to this rule, but they are uncommon and can be recognized. When rocks are found in a non-horizontal configuration one may conclude that some geologic event has tilted them.

3. **Principle of Cross-Cutting Relationships**
   Rocks or other geologic features (i.e., erosion, intrusions) that cut across pre-existing rocks are younger than the rocks that they cut across.
4. Principle of Original Lateral Continuity

Sedimentary beds are originally laterally continuous within their environment of deposition. Hence, similar rock units at different locations may, in fact, be the same although they are now not connected. Faulting, severe folding and erosion may have separated the originally continuous beds into what now appears to be separate units.

Original Lateral Continuity

5. Principle of Fossil Succession

Fossils in lower layers are older than those in overlying layers. Plants and animals change through time and so rock layers can contain fossils of plants and animals that will not be found in layers of different age. This succession of fossils serves as a relative dating tool. That is, the assemblage of fossils occurring in a rock can serve to identify and date that rock.

6. Principle of Inclusions

Any part of an existing rock that is incorporated into another sedimentary layer or igneous intrusion is older than the sedimentary layer or intrusion into which it has been incorporated.

7. Principle of Unconformities

Unconformities are surfaces of erosion or non-deposition that interrupt the continuity of the geologic record. The presence of an unconformity indicates that a portion of the rock record of Earth history has been removed.

Siccar Point, Scotland
An example of relative dating

The step by step sequence of geologic events producing a segment of crust.
A) deposition of sedimentary strata A-I by high sea level;
B) igneous intrusion of sill G;
C) igneous intrusion of dike J;
D) sedimentary and igneous layers tilted by tectonic forces, erosion forms an angular unconformity;
E) deposition of sedimentary strata L-N by a high sea level;
F) igneous intrusion of batholith K;
G) partial erosion of strata L-N.

Can you do this one? List the sequence of geologic events and identify the Stratigraphic Principles you use – as you use them.

Absolute Dating

The decay of radioactive isotopes has certain characteristics that allow us to determine the age of rocks:

1) radioactive decay always occurs at the same rate for a given radioactive isotope,
2) radioactivity produces new atoms in a mineral or other material (called daughter isotopes) and they can be counted, and
3) it is possible to know the original amount of a radioactive isotope that decays (called parent isotopes).

The idea behind absolute dating is that by counting the amount of daughter isotope in a rock and comparing that to the original amount of parent isotope, the constant rate of decay allows geologists to calculate the amount of time that has passed since the mineral first crystallized and trapped the parent isotopes in its crystalline structure.
What is half-life?

<table>
<thead>
<tr>
<th>Parent</th>
<th>Daughter</th>
<th>Half-Life</th>
</tr>
</thead>
<tbody>
<tr>
<td>Samarium-147</td>
<td>Neodymium-143</td>
<td>106 billion yrs</td>
</tr>
<tr>
<td>Rubidium-87</td>
<td>Strontium-87</td>
<td>48.8 billion yrs</td>
</tr>
<tr>
<td>Thorium-232</td>
<td>Lead-208</td>
<td>14 billion yrs</td>
</tr>
<tr>
<td>Uranium-238</td>
<td>Lead-206</td>
<td>4.5 billion yrs</td>
</tr>
<tr>
<td>Potassium-40</td>
<td>Argon-40</td>
<td>1.26 billion yrs</td>
</tr>
<tr>
<td>Uranium-235</td>
<td>Lead-207</td>
<td>0.7 billion yrs</td>
</tr>
<tr>
<td>Beryllium-10</td>
<td>Boron-10</td>
<td>1.52 million yrs</td>
</tr>
<tr>
<td>Chlorine-36</td>
<td>Argon-36</td>
<td>300,000 yrs</td>
</tr>
<tr>
<td>Carbon-14</td>
<td>Nitrogen-14</td>
<td>5730 yrs</td>
</tr>
<tr>
<td>Uranium-234</td>
<td>Thorium-230</td>
<td>248,000 yrs</td>
</tr>
<tr>
<td>Thorium-230</td>
<td>Radium-226</td>
<td>75,400 yrs</td>
</tr>
</tbody>
</table>

Decay is often complicated by production of a radioactive daughter that must decay. The daughter then becomes a parent.
Radon, Silent Killer

Radon is a naturally-occurring, cancer-causing radioactive gas produced by radioactive decay of uranium-238 in rock and soil of Earth’s crust.

Radon in indoor air is estimated to cause between 15,000 and 22,000 lung cancer deaths each year in the United States.

How does Carbon-14 work?

By God’s will, after a long voyage from the island of Greenland to the south toward the mouth of the distant remaining parts of the western ocean sea, sailing southward amidst the ice, the companions Bjarni and Leif Eriksson discovered a new land, extremely fertile and even having vines, ... which island they named Vinland.”
Chondrites contain 3 lead isotopes but no U or Th. Hence, these amounts are thought to represent the original abundances in the solar nebula.

Thought to represent most primitive chemistry of solar system (original lead abundances)

Modern lead is a mixture of four stable lead isotopes: Pb204, Pb206, Pb207, Pb208, three of these come from decay of U238, U235, Th232. But Pb204 is not produced by radioactive decay and it has been present on Earth since its inception.

Pb204 unchanging abundance through time

A tiny mineral grain of zircon from Australia (circle) dates 4.4 billion years old. Because this grain is sedimentary in origin, it suggests the presence of liquid water on Earth’s surface. This may contradict current ideas that the surface was a magma ocean around this time.

Moon Rocks

Apollo 17 Rb-Sr 4.55 +/- 0.1
Apollo 17 Rb-Sr 4.60 +/- 0.1
Apollo 17 Rb-Sr 4.49
Apollo 17 Rb-Sr 4.43 +/- 0.05
Apollo 17 Sm-Nd 4.34 +/- 0.05
Apollo 16 40Ar/39Ar 4.47
Apollo 1440Ar/39Ar

Billions of years