THE AGE OF THE EARTH

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GEOLOGICAL SURVEY
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The Earth is a constantly changing planet. Its crust is continually being created, modified, and destroyed. As a result, rocks that record its earliest history have not been found and probably no longer exist. Nevertheless, there is substantial evidence that the Earth and the other bodies of the Solar System are 4.5-4.6 billion years old, and that the Milky Way Galaxy and the Universe are older still. The principal evidence for the antiquity of Earth and its cosmic surroundings is:

1. The oldest rocks on Earth, found in western Greenland, have been dated by four independent radiometric dating methods at 3.7-3.8 billion years. Rocks 3.4-3.6 billion years in age have been found in southern Africa, western Australia, and the Great Lakes region of North America. These oldest rocks are metamorphic rocks but they originated as lava flows and sedimentary rocks. The debris from which the sedimentary rocks formed must have come from even older crustal rocks. The oldest dated minerals (4.0-4.2 billion years) are tiny zircon crystals found in sedimentary rocks in western Australia.

2. The oldest Moon rocks are from the lunar highlands and were formed when the early lunar crust was partially or entirely molten. These rocks, of which only a few were returned by the Apollo missions, have been dated by two methods at between 4.4-4.5 billion years in age.

3. The majority of the 70 well-dated meteorites have ages of 4.4-4.6 billion years. These meteorites, which are fragments of asteroids and represent some of the most primitive material in the solar system, have been dated by 5 independent radiometric dating methods.

4. The "best" age for the Earth is based on the time required for the lead isotopes in four very old lead ores (galena) to have evolved from the composition of lead at the time the Solar System formed, as recorded in the Canyon Diablo iron meteorite. This "model lead age" is 4.54 billion years.

5. The evidence for the antiquity of the Earth and Solar System is consistent with evidence for an even greater age for the Universe and Milky Way Galaxy. A) The age of the Universe can be estimated from the velocity and distance of galaxies as the universe expands. The estimates range from 7 to 20 billion years, depending on whether the expansion is constant or is slowing due to gravitational attraction. B) The age of the Galaxy is estimated to be 14-18 billion years from the rate of evolution of stars in globular clusters, which are thought to be the oldest stars in the Galaxy. The age of the elements in the Galaxy, based on the production ratios of osmium isotopes in supernovae and the change in that ratio over time due to radioactive decay, is 8.6-15.7 billion years. Theoretical considerations indicate that the Galaxy formed within a billion years of the beginning of the Universe. C) Combining the data from A) and B), the "best, i.e., most consistent, age of the universe is estimated to be 14-17 billion years.

RADIOMETRIC DATING

Spontaneous breakdown or decay of atomic nuclei is termed radioactive decay that is the basis for all radiometric dating methods. Radioactivity was discovered in 1896 by French physicist Henri Becquerel. By 1907 study of the decay products of uranium (lead and intermediate radioactive elements that decay to lead) demonstrated to B. B. Boltwood that the lead/uranium ratio in uranium minerals increased with geologic age and might provide a geological dating tool.

As radioactive Parent atoms decay to stable daughter atoms (as uranium decays to lead) each disintegration results in one more atom of the daughter than was initially present and one less atom of the parent. The probability of a parent atom decaying in a fixed period of time is always the same for all atoms of that type regardless of temperature, pressure, or chemical conditions. This probability of decay is the decay constant. The time required for one-half of any original number of parent atoms to decay is the half-life, which is related to the decay constant by a simple mathematical formula.

All rocks and minerals contain long-lived radioactive elements that were incorporated into Earth when the Solar System formed. These radioactive elements constitute independent clocks that allow geologists to determine the age of the rocks in which they occur. The radioactive parent elements used to date rocks and minerals are:

PARENT	DAUGHTER	HALF-LIFE
Uranium-235	Lead-207	0.704 billion years
Uranium-238	Lead-206	4.47
Potassium-40	Argon-40	1.25
Rubidium-87	Strontium-87	48.8
Samarium- 147	Neodymium- 143	106
Thorium-232	Lead-208	14.0
Rhenium- 187	Osmium- 187	43.0
Lutetium- 176	Hafnium- 176	35.9

Radiometric dating using the naturally-occurring radioactive elements is simple in concept even though technically complex. If we know the number of radioactive parent atoms present when a rock formed and the number present now, we can calculate the age of the rock using the decay constant. The number of parent atoms originally present is simply the number present now plus the number of daughter atoms formed by the decay, both of which are quantities that can be measured. Samples for dating are selected carefully to avoid those that are altered, contaminated, or disturbed by later heating or chemical events.

In addition to the ages of Earth, Moon, and meteorites, radiometric dating has been used to determine ages of fossils, including early man, timing of glaciations, ages of mineral deposits, recurrence rates of earthquakes and volcanic eruptions, the history of reversals of Earth's magnetic field, and the age and duration of a wide variety of other geological events and processes.