93
MEASURING TIME: THE NUCLEAR CLOCK

For a long time, geologists guessed at the ages of various deposits from their depth or thickness or from the kind of rocks and fossils they contained. And the ages of these same fossils were often estimated from the age of geologic deposits. It is not surprising that until recently many estimates of evolutionary events were inaccurate. Just as the molecular clock revolutionized the study of biological evolution, the discovery of radioactive clocks has revolutionized the earth sciences and dating of evolutionary events.

Radioactive isotopes decay at constant rates, unaffected by temperature, acidity, moisture, or other conditions that may affect rocks, minerals, and fossils and may make them appear older or younger than their actual age. A *parent* isotope decays into one or more *daughter* isotopes. If one knows the decay rate, expressed as a "half-life," and the ratio of *daughter* to *parent* isotopes, one can accurately calculate the time since the process began.

The most commonly used radioactive clocks are carbon 14 (^{14}C) and *potassium 40* (^{40}K). Carbon 14 is being constantly "created" by solar bombardment of the upper atmosphere; it is incorporated into plants as they absorb carbon dioxide. When the plant dies, carbon 14 decays into nitrogen 14, with a half-life of 5,370 years; so wood, for example, can be dated by measuring the ratio of carbon 14 to the normal carbon isotope, carbon 12. Because of the relatively short half-life, this method can date specimens not older than 50,000 years.

Potassium 40 has a much longer half-life (1.3 billion years); so it can be used to date events as old as the formation of the earth 4.5 billion years ago, as well as lava flows only a few thousand years old.

Color the top picture, noting that potassium 40 decays into two daughter isotopes, calcium 40 (^{40}Ca) and argon 40 (^{40}Ar). The proportions of represented atoms is diagrammatic only.

Because *calcium 40* is widely distributed in rock and soil, its presence is not informative. *Argon 40,* a gas, is rarely found in rocks unless it was trapped in lava by the decay of *potassium 40.* In liquid lava, inside the earth, the gaseous *argon 40* boils off; so the clock of the *argon 40* to *potassium 40* ratio begins when the lava flows out and solidifies. At that time, the ratio is zero, as there is no *argon 40* present. One half-life (1.3 billion years) later, 50 percent of the *potassium 40* has decayed; 89 percent of the *daughters* are *calcium 40,* and 11 percent *argon 40,* giving an *argon* to *potassium* (Ar:K) ratio in the lava of 0.11; this ratio will continue to increase with time, and when measured can be used to date the lava.

Color the chart in the center of the plate. Notice how the amount of potassium 40 decreases with time as it decays into its daughter isotopes.

This chart shows the fate of *potassium 40* in rocks formed 3.8 billion years ago, when the earth's crust first formed. Notice that for each time period of earth history, there is a characteristic ratio of ^{40}Ar to ^{40}K.

Color the picture on the bottom of the plate, noticing how volcanic tuffs (lava flows) laid down 20 mya contain a higher ratio of argon to potassium than those in more recent deposits.

Luckily, the East African Rift Valley, where so many human fossils have been found, has been a volcanically active region for millions of years, so that many fossils can be dated accurately by measuring the Ar:K ratio in the lava found with them or in layers above or below them. By comparing the Ar:K ratio with a chart similar to the one here, the age of the fossils can be determined.

Other radioactive methods for dating rocks, fossils, and artifacts include uranium and fission-track dating. Uranium 238 (half-life 4.5 million years) decays in a complex manner, eventually ending up as stable lead isotopes. As with *potassium-argon* dating, the ratio of *daughter* to *parent* isotopes measures the time elapsed since the uranium clock was "set" when the minerals in which it is found first crystallized. Uranium isotopes also undergo spontaneous fission. When they do, heavy energetic fragments of the uranium atom fly apart and leave "tracks" in certain minerals that can be seen with a microscope and counted. The number of tracks indicates the elapsed time since the mineral was formed.

THE NUCLEAR CLOCK★

POTASSIUM 40 (K) (PARENT)A
CALCIUM 40 (Ca) (DAUGHTER)B
ARGON 40 (Ar) (DAUGHTER)C