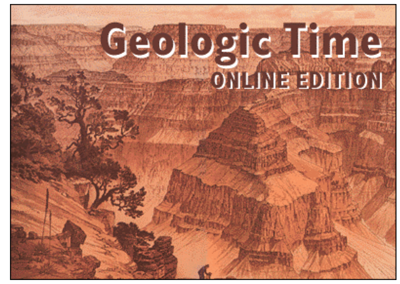
Time and Geology

Dating the geological past is based on two basic concepts:

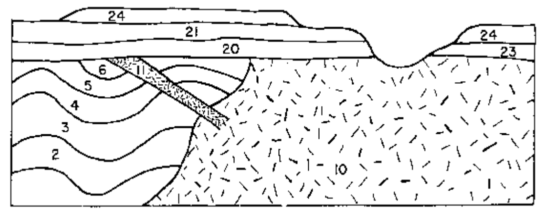
- the *principle of uniformitarianism*, that the "present is the key to the past" (i.e., the geological processes now are as they have always been); and
- the *principle of superposition of strata*, i.e., the younger formations in an undisturbed succession of layers overlie the older ones.



Browse this USGS online publication at http://pubs.usgs.gov/gip/geotime/

Measuring *relative* time implies determining

- the order in which a given succession of geological events occurred, even if their precise dates are unavailable;
- interrelationships between the different geological events using the laws of (a) *original horizontality*, (b) *superposition* and (c) *cross-cutting relationship*; and
- sequential relation (or "correlation") of the spatially separated rock formations or geological events using the evidences of (a) physical continuity, (b) lithostratigraphic similarity, and (c) fossil assemblages (i.e., the *principle of faunal and floral succession*).



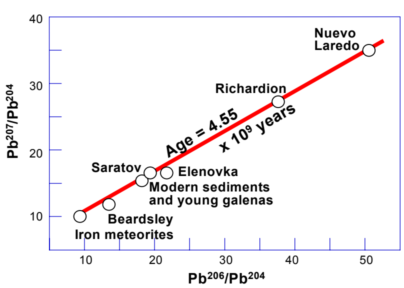
Thus, in the geological section shown above (http://www.mhhe.com/earthsci/geology/plummer/student/olc/chap08chact.mhtml), the relative ages of the formations are as follows (starting with the youngest): 24, 23, 21, 20, 11, 10, 6, 5, 4, 3, 2 and 1.

The *absolute* time is measured by radiometric dating, a method that

- uses the "half life" (i.e., the time taken by a radioactive parent isotope to decay to one-half of its initial quantity) of radioactive parent isotopes tabulated here; and thus
- estimates the age of a rock from the relative abundance of these parent and daughter isotopes in it.

Radioactive Parent Isotope	Radiogenic Daughter Isotope	Half-life (years)
Potassium-40	Argon-40	1.25 billion
Uranium-235	Lead-207	713 million
Uranium-238	Lead-206	4.5 billion
Rubidium-87	Strontium-87	49 billion

Estimating Earth's Age



Lead-ratio (or the Pb^{207}-Pb^{206} isochron) method is the most direct means to estimate the Earth's age. As Pb^{207} comes from radioactive decay of U^{235} and Pb^{206} from that of U^{238}, the plot of these two lead isotopes (relative to nonradiogenic Pb^{204} or Pb^{208}) should be linear if the solar system formed from a common pool of matter that was uniformly distributed in terms of the Pb isotope ratios and the higher the uranium-to-lead ratio of a rock, the more the Pb^{206}/Pb^{204} and Pb^{207}/Pb^{204} values will change with time. The slope of the staight-line fit to 5 meteorite and one terrestrial data thus yields an estimate of 4.55 Ga, as do the data on dating meteorite samples by Rb-Sr and the other radiometric methods.

Source: http://www.talkorigins.org/faqs/faq-age-of-earth.html#dal01

Thus, if Zoraster Granite in the Grand Canyon is ~1250 Ma old then, because ~10% of K^{40} decays to the exclusively radiogenic Ar^{40} and ~90% to the Ca^{40} isotope that can also have other parentage, we should find 10 nanograms of K^{40} for each nanogram of Ar^{40} in it. Likewise, if the earth is indeed ~4.5 Ga old and these half-life values are valid, then we should find as much Pb^{206} as U^{238} and nearly 32 times as much U^{238} as U^{235}. The observed data corroborate these expectations.

Years since the onset of the process	K-40 (grams)	Ar-40 (nano-grams)
0	1.0000000000	0.0000
1	0.9999999992	0.0555
2	0.9999999984	0.1109
3	0.9999999976	0.1664
4	0.9999999968	0.2218
5	0.9999999960	0.2773
6	0.9999999952	0.3327
7	0.9999999944	0.3882
8	0.9999999936	0.4436
9	0.9999999928	0.4991
10	0.9999999920	0.5545

We do need to examine if our time scales of interest are not too long to be physically verifiable, particularly as establishing such long half-life values itself seems so hard to accomplish. What makes this possible is a simple trick called logarithms. Mathematically, for instance, if N is the number of nuclides of a radioisotope at any time t, and N_0 is its initial quantity, then $N = N_0 \exp(-t/T_{½})$ where $T_{½}$ denotes half-life, i.e., $t = T_{½} \ln(N/N_0)$. With $T_{½}$ = 1.25 billion years for the K^{40} - Ar^{40} decay series, the Table above thus shows that we can expect to find 0.056 nanogram of Ar^{40} for each gram of K^{40} one year after the onset of the process, or 0.28 nanogram of Ar^{40} for each gram of K^{40} five years after the onset of the process. With today's highly accurate mass spectrometers, these numbers are easy to establish and experimentally verifiable.