GEOLOGIC TIME

This course is about evolution and life history. Understanding the evolutionary history of life requires understanding geologic time because evolution is, by definition, change through time.

To make sense of what can be observed in the rock record, we have to have some frame of reference. The frame of reference for geology is what we can observe now: the way rivers transport mud and silt, volcanic eruptions, the rates of chemical reactions, radioactivity, and many other empirical observations. In this sense, the present is the key to the past. We should not expect process that affected the Earth in the past to have been different from what we might expect - and can explain - from processes and phenomena observable today. This **principle of uniformitarianism** was first expressed by James Hutton.

The concept of measuring geologic time has its foundation in the **principle of superposition** elucidated by Nicholas Steno. Steno was an anatomist trying to explain why tongue stones were found in rock. The problem was trying to figure out how one solid body gets inside another solid body. His solution: It doesn't. One body was originally solid, the other originally fluid but later solidified. It follows that

- a layer, or stratum of rock, such as one containing tongue stones, was originally deposited in a fluid state;
- a stratum of rock must be deposited on a consolidated surface;
- no stratum can be deposited upon the first until the original stratum is solid;
- therefore, in a sequence of sedimentary rocks (i.e., a stratigraphic section), the oldest bed is on the bottom, the youngest at the top, and the age decreases progressively from the former to the latter;
- Steno further reasoned that strata are originally deposited horizontally and laterally continuously throughout their extent.

What about tongue stones?

- from his knowledge of anatomy and his dissections of the head of a great white shark, Steno knew that tongue stones looked like - and are - shark teeth
- this leads us to the **principle of faunal (or floral) succession**, made a practical reality by the canal builder, William Smith.
- If strata conform to the law of superposition, the fossils contained in them will be distributed through the sequence of strata according to their relative ages;
- faunal succession is the fundamental concept underlying the empirical statement that life changes through time;
- Different fossils occur in higher and lower beds - older and younger rocks - so different species of organisms succeed each other in stacked layers of rock, and through time.

Superposition and faunal succession allow the definition of a relative time scale, which is the basis of the **Geologic Time Scale**:

Abbreviated Geologic Time Scale

EON	ERA	PERIOD	EPOCH
Phanerozoic	Cenozoic	Quaternary	Recent/ Holocene
			10,000 ——
			Pleistocene
		2 Ma ——	
		Tertiary	
	66 Ma ——		
	Mesozoic	Cretaceous	
		144 Ma ——	
		Jurassic	
		208 Ma ——	
		Triassic	
	245 Ma ——		
	Paleozoic		
570 Ma ——			
Precambrian			
4.6 Billion ——			

The absolute dates on the geologic time scale do not come from superposition or faunal succession, which yield only relative time.

Absolute dates derive from **radiometric dating techniques**, which utilize the natural and spontaneous decay of radioactive minerals.

- Atoms are the smallest chemically indivisible particles of an element

- the nucleus has protons (the number of protons in the nucleus equals the atomic number) and neutrons

- the number of protons plus neutrons equals the mass of the atom

- masses of atoms of the same element vary because the number of neutrons is different in alternative forms (isotopes) of the element

- isotopes are alternative variants of an element (same atomic number, different mass)

-Some isotopes are unstable; therefore, they break down, or decay into more stable isotopes or elements

Radioactivity

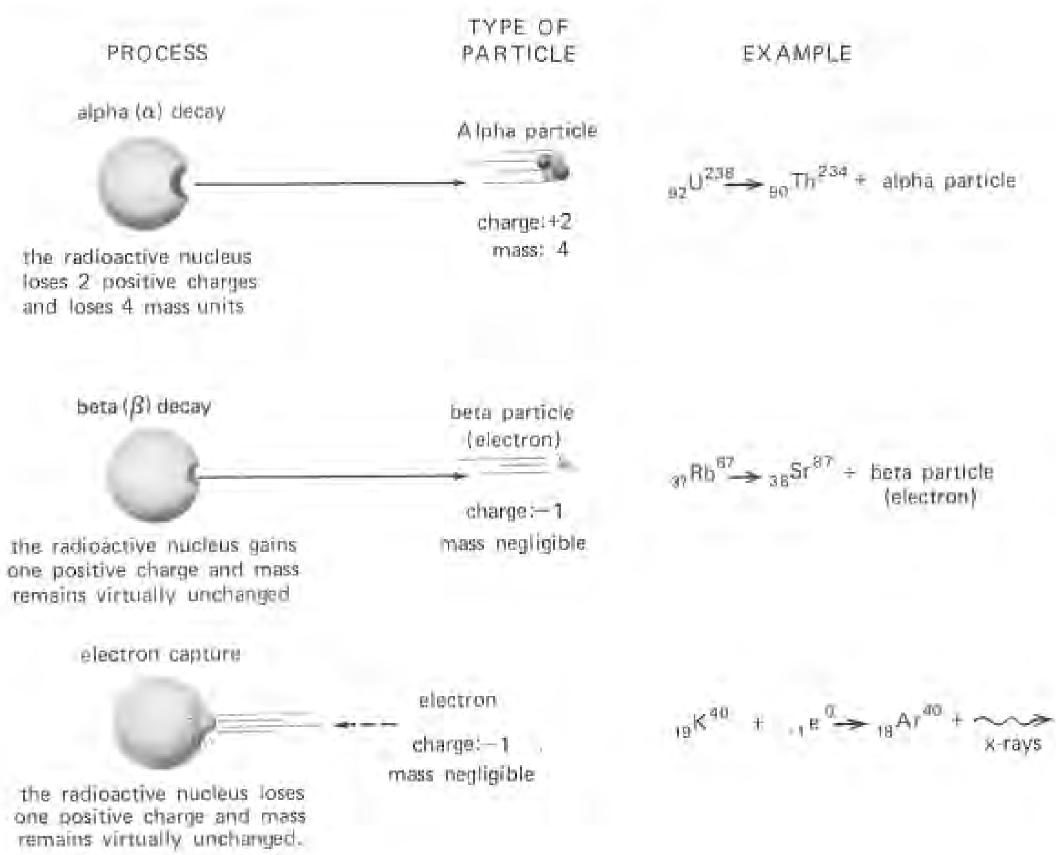
- decay of unstable (parent) isotope into stable (daughter) product

- rate of decay is uniform, not affected by pressure, temperature, chemical environment (remember the principle of uniformitarianism)

- rate of decay is specific for a given isotope

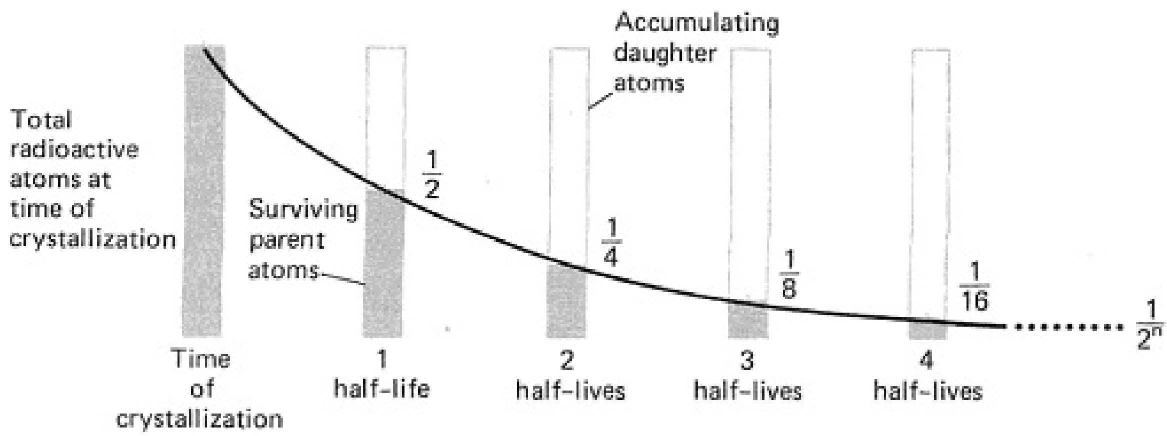
- Half life is the length of time necessary for one-half the amount of parent isotope to decay into daughter isotope

FIG. 1-8 Examples of the three principal processes of radioactive decay. The examples shown are long-lived nuclides used for radiometric dating.



Absolute ages are determined radiometrically by calculating the amount of time necessary to produce a measured amount of daughter product from an original quantity of parent isotope at the specific rate of decay (half-life) for the parent.

FIG. 1-9 Changing ratios of parent and daughter atoms as a result of radioactive decay. With the passage of each half-life period, half of the parent atoms that existed at the beginning of the period decay. As the parent atoms decay, they are replaced by daughter atoms.



The mathematical expression that relates radioactive decay to geologic time is called the age equation (see http://pubs.usgs.gov/gip/geotime/radiometric):

$$t = 1/l \ln (1+D/P)$$

where t is the age of the rock or mineral specimen
D is the number of atoms of a daughter product today
P is the number of atoms of the parent isotope today
ln is the natural logarithm (logarithm to base e) and
l is the appropriate decay constant

The decay constant for each parent isotope is related to its half-life
$t^{1/2} = \ln 2/ l$

There are many unstable elements that can be utilized in radiometric age determinations, for example:

Uranium 238 – Lead 206 ($t^{1/2}$ = 4.5 billion)
Potassium 40 – Argon 40 ($t^{1/2}$ = 48.8 billion)
Rubidium 87 – Strontium 87 ($t^{1/2}$ = 1.25 billion)
Carbon 14 ($t^{1/2}$ = 5730)

Most radiometric dates are derived from elements incorporated into the crystal structure of minerals formed from melts. Therefore, volcanic ashes, basalts, or other igneous rocks are most useful for radiometric dating. Dating of mineral grains found in sedimentary rocks yield the ages of the rocks from which they were derived.

The use of radioactive elements bound in mineral crystals is important because it insures that the quantities of parent and daughter isotopes can be accurately estimated for the time of formation of the crystal.

Because radioactivity occurs in crystal that has a definite structure, and because subatomic particles given off in radioactive decay can damage crystal structure, the amount of damage present allows the determination of an absolute date. This is called fission track dating.

The age of the Earth has been determined to be 4.2 billion years based on detrital (sedimentary) grains of zircon crystals. The age based on meteroites is 4.6 billion.

What is so special about carbon 14 dating?

- Crystals of igneous rock are not dated because carbon 14 is not found in molten rock

- Carbon 14 is continuously formed in the upper atmosphere as a result of the bombardment of nitrogen atoms with cosmic rays.

- radioactive carbon 14 combines with oxygen to form carbon dioxide, just like stable carbon 12 does

- A percentage of all the carbon dioxide utilized by plants in photosynthesis to produce sugar will be radioactive

- Actual organic matter, including fossils can be dated

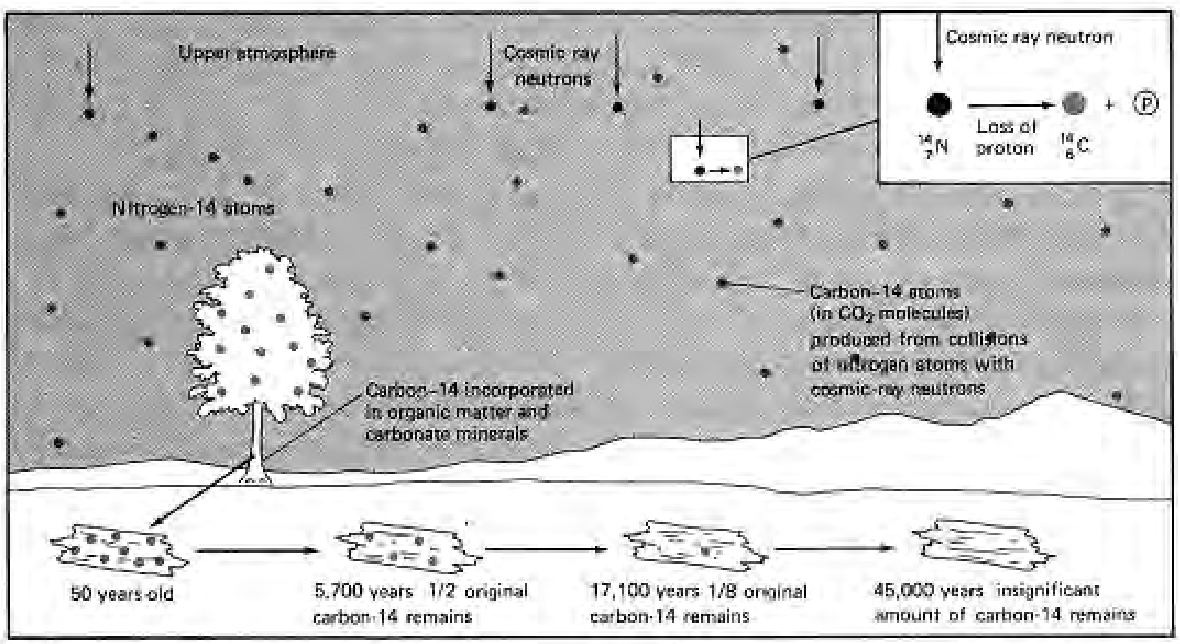
-When a plant dies, it no longer takes up carbon dioxide, so dead plant material (charcoal, basketry, sandles, roof beams) can be used as samples for radiometric dating

- The half-life of carbon 14 is short (a bit more than 5730 years) so only relatively young dates can be obtained.

- C 14 dates do not go back much over 50,000 years so the technique is most useful for archeological and Quaternary studies

- Dinosaurs and most other fossils cannot be dated with Carbon 14

FIG. 1-10 The carbon-14 cycle. Radioactive carbon-14 is produced from atmospheric nitrogen by cosmic rays (inset). It then enters into carbon dioxide molecules and becomes incorporated into growing plants and thence into animals. When the plant or animal containing the carbon-14 dies, no new carbon-14 is incorporated into its tissues or skeleton. The amount of carbon-14 decreases as radioactive decay proceeds and the amount of carbon-14 remaining is used to date the wood, bone, or shell fragment.



UNITING STRATIGRAPHY AND RADIOMETRIC DATES USING MAGNETOSTRATIGRAPHY

Magnetic Polarity Stratigraphy is a precise method of correlation that facilitates the assignment of absolute ages to strata that cannot themselves yield radiometric dates.

The Earth has a magnetic field like a big dipole magnet.

There is a north pole and a south pole. The white end of your compass needle seeks north today.

The Earth's magnetic field affects the entire Earth.

Tiny mineral grains that contain iron (e.g., magnetite) become aligned with the Earth's magnetic field as they are deposited from water in calm sedimentary processes, or as they crystallize out of melts.

The direction of the Earth's magnetic field in the past can be determined by measuring the direction of magnetic minerals frozen in stone.

The Earth's magnetic field has reversed at random intervals (at statistically random times) in the past. At certain times in the past, what is now the north-seeking end of the compass would point to the south.

Determining the polarity through a stratigraphic section shows the pattern of magnetic reversals through time.

Because reversals happen at random times, any specific time interval in the past of sufficiently long duration will have a characteristic pattern - a "fingerprint," if you will, of normal and reversed polarity signals.

Because the Earth's magnetic field is global, if a specific "fingerprint" interval can be recognized anywhere in the world, it will demonstrate equivalency in time for the rocks exhibiting the pattern.

If a radiometric date is placed within a magnetic polarity stratigraphy context, that date is applicable anywhere its position in the magnetic reversal sequence can be recognized

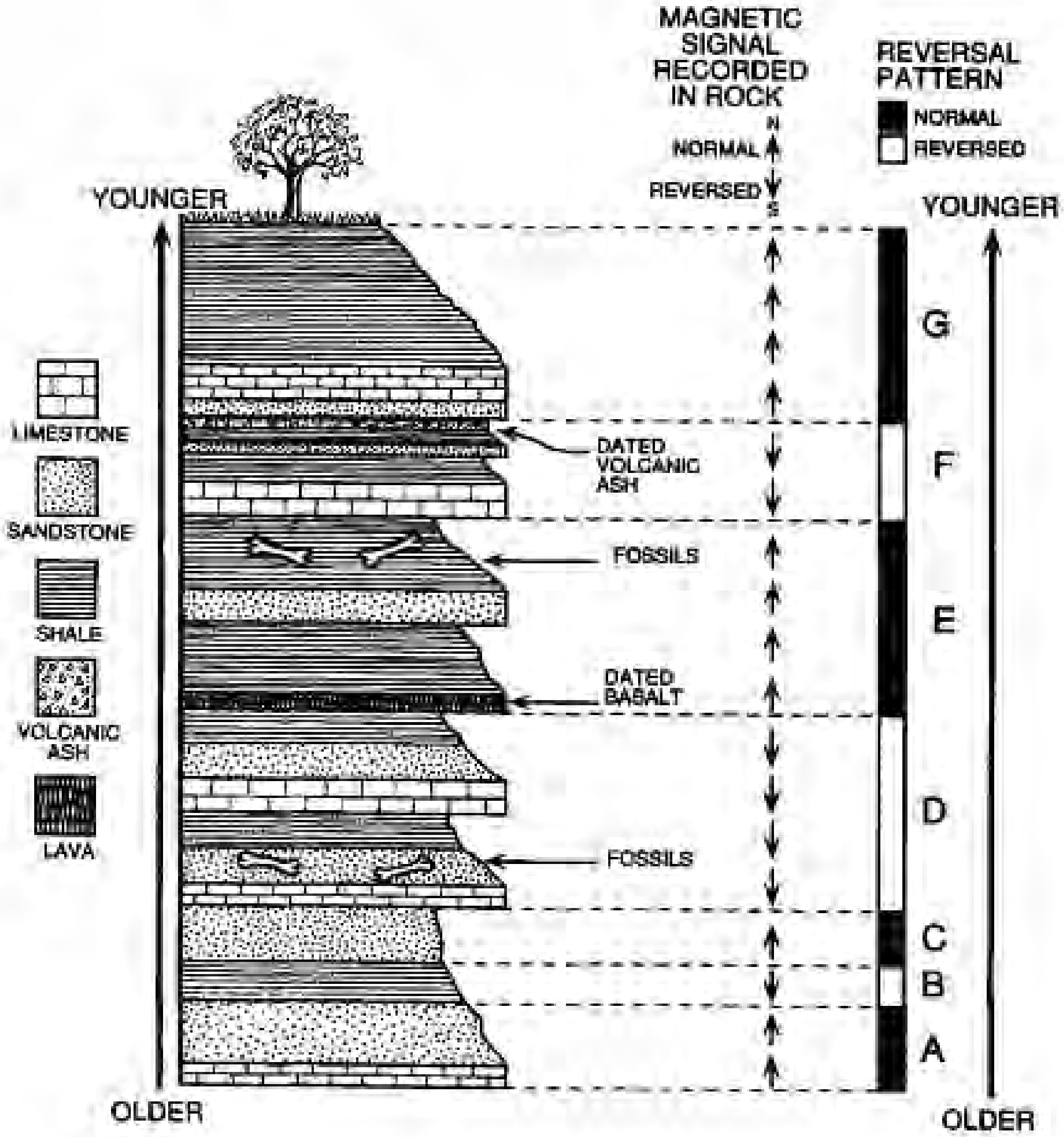


FIGURE 6: How to date fossils. On the left is a sequence of layered rocks as shown by the patterns of lava, ash, shale, sandstone, and limestone. The rock layers are oldest at the bottom and progressively younger toward the top. Fossils that occur lower in a sequence of layered rock are older than those that occur higher in the sequence. Volcanic rocks like basalt and ash can be dated using radioactive decay of their constituent minerals. They set older and younger limits on the absolute age, in numbers of years, of a fossil that occurs above, below, or between dated rocks. The Earth's magnetic signal preserved in a sequence of rock is used to compile a reversal pattern that can be matched with other rocks of the same age anywhere in the world that the pattern might be recognized.

Figures for Geologic Time from:

Eicher, D.L., McAlester, A.L., and Rottman, M.L. 1984. The history of the Earth's crust. Prentice-Hall, Engelwood Cliffs, New Jersey.

Jacobs, L.L. 1993. *Quest for the African Dinosaurs*, Villard Books, New York.