

GY 112L Earth History

Lab 3

Radiometric Dating

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Fifth Edition: August 2009©

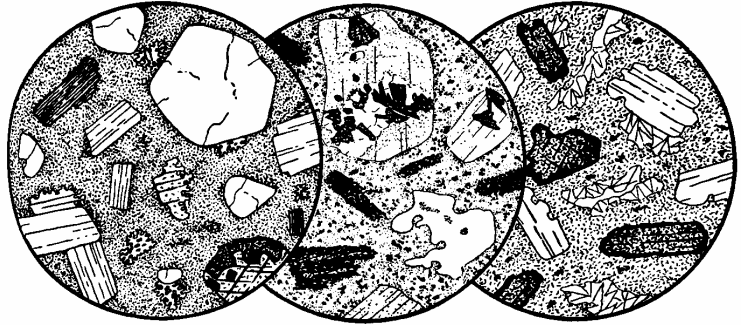
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The recipes that are included in some sections are intended to prove that you can eat anything as long as you serve it with plenty of ketchup. Neither Haywick, nor the Connors are responsible for any food poisoning that might occur if you actually try them.

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Lab Three

Radiometric Dating

Background: Geologists have to be able to age rocks. They need to do this in order to establish the sequence of events responsible for that rock and ultimately, the entire geological history of an area. There are several ways that geologists can age rocks and you were introduced to some of these in the lectures last week. Principles such as **Superposition**, **Cross-cutting Relationships** and **Original Horizontality** allow you to establish a relative sequence of geological events and hence, give what we refer to as a **relative date**. For example, if an igneous dike cuts across a sandstone, the dike must be younger than the sandstone. Paleontologists use fossils to age rocks. A limestone containing the bryozoan *Archimedes*, which you last saw in lab 1, would be Mississippian in age. By establishing the fossil content of a rock, paleontologists can generally put an age on it. But once again this is a relative date rather than an **absolute date**. Paleontologists cannot look at a fossil in a rock and say that that rock is 175.5 million years old, unless there has been some independent and absolute dating technique used to establish that age. The most common absolute dating technique used by geologists is **radiometric dating** (also called **radioisotopic dating**). The origins of radiometric dating can be traced back to early 20th century laboratories in Europe and North America. Physicists began to realize that some **isotopes** of elements were unstable and over time, broke down to other elements (called **daughter atoms**) and particles (**radioactivity**). This **decay** was consistent for a particular isotope and totally independent of any outside variables. Earnest Rutherford¹, a New Zealand-born Canadian Physicist in Montreal, was the first scientist to realize that radioactive decay could be used to establish the age of materials. All you needed to know was the **half life** of the radioactive isotope ($t_{1/2}$), its **rate of decay** (λ) and the following additional variables: (1) the number of **parent atoms** present in the rock when it formed (N_0), (2) the number of daughter

¹ Figure shows microscopic views of porphyritic felsic rocks that are suitable for radiometric dating. Each field of view is 4 mm across. From Williams, H., et al., 1954. Petrography, W.H. Freeman and Co. San Francisco, 406p.

atoms present in the rock when it first formed (D_0), (3) the number of parent atoms in the rock today (N), and (4) the number of daughter atoms in the rock today (D). Before we get to the **age formula**☀ that relates these variables together, let's first consider $t_{1/2}$ and λ . An isotope's half life is defined as the amount of time required for half of the parent isotope to decay to its daughter isotope. These data have been firmly established (see Table 3-1). The rate of decay of each unstable isotope is different but is always determined by the following formula:

$$[1] \quad \lambda = \frac{0.693}{t_{1/2}}$$

It ends up being a very small number because the half life of most unstable elements is usually a very big number. Radioactive decay is **exponential**. Exactly one half of the amount of radioactive isotope present in a rock decays after each half life. The amount of daughter isotope *increases* in the same exponential way (Figure 3-1). The half life of ^{235}U is 713 MA (million years), so after 713 MA, only 50% of the original ^{235}U in a rock would still be present (50% of the original uranium would alter to ^{207}Pb). After another 713 MA, 50% of that ^{235}U would decay leaving only 25% of the original amount (75% ^{207}Pb). After another 713 MA, only 12.5% of the ^{235}U would be left (50% of 50% of 50%). Get the picture? Since the Earth formed approximately 4.6 GA (billion years) ago, about six ^{235}U half lives have passed. Therefore only 1.6% of the original ^{235}U still exists on our planet. In contrast, we still have about 50% of the original ^{238}U that formed back when the Earth was condensing from the solar nebula. Its half life is almost as long as the Earth is old (4.5 GA).

Anyway, let's get back to the age relationship. The following formula was established to relate the number of parent atoms to rock age and is the basic formula by which radiometric dating works:

$$[2] \quad N = N_0 e^{-\lambda t}$$

Relationships like this can be intimidating at first because they involve mathematical components that we don't deal with on a daily basis. However, even if you are a math-phobe like most geologists, you have to agree that it doesn't look *all that bad* as far as mathematical formulas go. Can a few variables and constants plugged into a scientific calculator really give you the age of rocks? Ultimately the answer is yes, but there is quite a lot of work that needs to be done to derive those few variables and

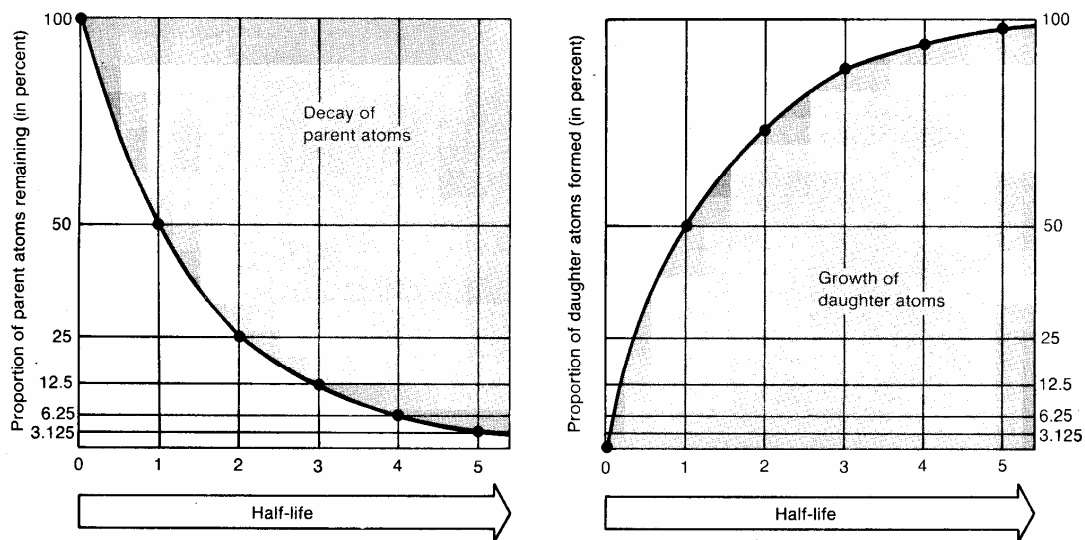


Figure 3-1: Radioactive decay of parent atoms and subsequent increase of daughter atoms compared to isotope half life. From Brice, J.C. et al., 1993. *Laboratory Studies in Earth History*. Wm. C. Brown, 242 pp.

constants. N and D (the number of parent and daughter atoms, respectively, in the rock today) are easily measured with a mass spectrophotometer. With a mass spec., you put your samples in, you get numbers out. But N_0 and D_0 (the number of parent atoms and daughter atoms, respectively, in the rock when it first formed) are tricky to determine². After all, no one was around when the rock formed, so both of these variables have to be estimated. Luckily there is a relatively simple way to do this. If you take 3 or more samples from a rock that you know *formed from the same magma at the same time*, you can determine N_0 and D_0 through a simple graphing procedure using N and D data (the variables that you can easily measure in rocks today). All of the samples will have different ratios of parent and daughter atoms, but they should all plot along a single line if they were formed at the same time (refer to Figure 3-2). Using extrapolation, it is possible to determine how much original daughter material was in the rock when it first formed. Figure 3-2 plots N versus D data for a series of analyses. D is plotted on the Y axis of the graph.

² Isotopic data are not normally reported as actual counts of atoms as the definition implies. These data are instead reported as ratios and are evaluated relative to another similar, but stable isotope. For example, when rocks are dated using $^{87}\text{Rb} - ^{87}\text{Sr}$, N_0 and N data are reported as $^{87}\text{Rb}/^{86}\text{Sr}$ and D_0 and D data are reported as $^{87}\text{Sr}/^{86}\text{Sr}$ (^{86}Sr is stable). This also negates any units, which would otherwise be a pain in the butt.

Isochron Diagram

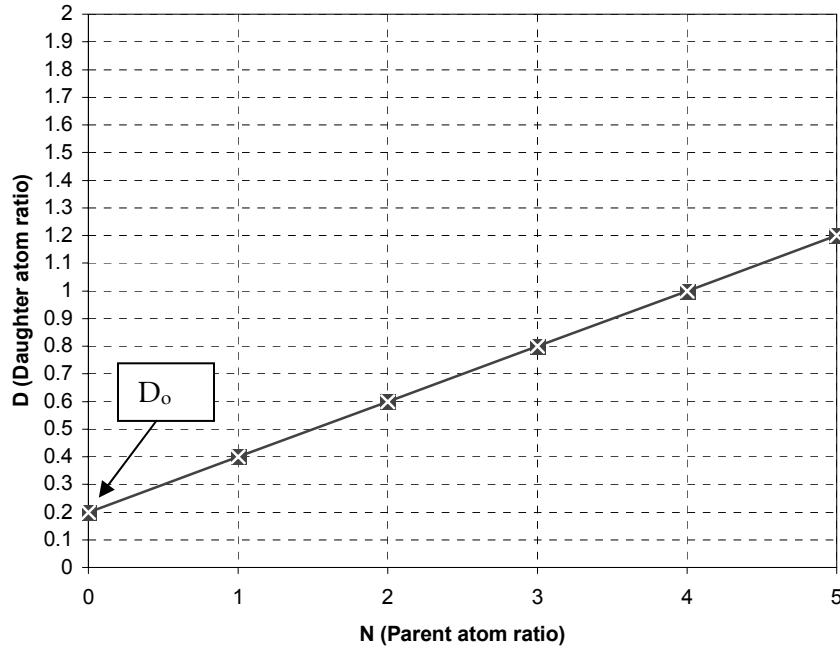


Figure 3-2: An isochron diagram used to establish D_0 . See the text for details

Where the line crosses the Y axis (i.e., when $N = 0$) corresponds to D_0 . For the example given, D_0 is 0.2000. This type of graph is called an **isochron diagram** and is a necessary first step when attempting to date rocks.

The dating formula that was given earlier is the basic template for dating rocks, but it is difficult to use as written. Instead, we use the following relationship (be calm, it's not as bad as it looks):

$$[3] \quad \text{Rock age} = \frac{1}{\lambda} \times \ln\left[\frac{(D_0 - D) + 1}{N}\right]$$

Here's an example of the formula in use. Suppose you found a granite with datable minerals in it like uranite (a uranium-bearing mineral). You opt to use the $^{238}\text{U} - ^{206}\text{Pb}$ dating method. The data you got from the lab was as follows: $D = 0.1100$; $N = 0.1200$. You determined earlier that $D_0 = 0.2000$.

1) The first step is to determine the decay constant for ^{238}U :

$$\lambda = 0.693 \div 4,500,000,000$$

$$= 1.54 \times 10^{-10}$$

2) Now it is a simple matter of plugging in all of these data:

$$\text{Rock age} = 1 \div 1.54 \times 10^{-10} \times \ln[((0.2000 - 0.1100) \div 0.1200) + 1]$$

$$= 3,630,000,000 \text{ years}$$

So the rock is roughly 3.6 billion years old (3.6 GA). Not bad huh?

Any way, this lab is all about radiometric dating and the stuff you can do with it. You will have an opportunity to obtain dates on rocks, evaluate sequences of events and apply these data to relevant geological questions. The skills you learn here will help you to understand some of the arguments and ideas that we will discuss about earth history later in the class. They might even make you like mathematics (when hell freezes over).

Table 3-1: Table of radioactive isotopes of use for radiometric dating, their daughter products, approximate half lives and applications.

Parent Isotope	Daughter Isotope	Half Life (years)	Datable Material(s)
^{14}C (Carbon-14)	^{14}N (Nitrogen-14)	5,730	Wood, shells and organic material
^{235}U (Uranium-235)	^{207}Pb (Lead-207)	713,000,000	Metamorphic, igneous rocks, Zircon, U-bearing minerals
^{40}K (Potassium-40)	^{40}Ar (Argon-40)	1,310,000,000	Metamorphic, igneous & sedimentary rocks; feldspar-bearing minerals
^{238}U (Uranium-238)	^{206}Pb (Lead-206)	4,500,000,000	Metamorphic, igneous rocks, Zircon, U-bearing minerals
^{232}Th (Thorium-232)	^{208}Pb (Lead-208)	13,890,000,000	Metamorphic, igneous rocks, Zircon, U-bearing minerals
^{87}Rb (Rubidium-87)	^{87}Sr (Strontium-87)	48,800,000,000	Various igneous & metamorphic rocks and minerals
^{147}Sm (Samarium-147)	^{143}Nd (Neodymium-143)	106,000,000,000	Very old igneous rocks, REE bearing minerals