DETERMINING AGE OF ROCKS AND FOSSILS
(MODIFIED FROM FRANK K. MCKINNEY)

Background: Fossils are interesting remnants of times passed. It is useful to know how old a fossil is, but also how that age was determined. Some very straightforward principles are used to determine the age of fossils. Students should be able to understand the principles and have that as a background so that age determinations by paleontologists and geologists don't seem like black magic.

There are two types of age determinations. Geologists in the late 18th and early 19th century studied rock layers and the fossils in them to determine relative age. William Smith was one of the most important scientists from this time who helped to develop knowledge of the succession of different fossils by studying their distribution through the sequence of sedimentary rocks in southern England. It wasn't until well into the 20th century that enough information had accumulated about the rate of radioactive decay that the age of rocks and fossils in number of years could be determined through radiometric age dating.

PURPOSE AND OBJECTIVES

This activity will help students to have a better understanding of the basic principles used to determine the age of rocks and fossils. This activity consists of several parts. Objectives of this activity are:

1) To have students determine relative age of a geologically complex area.

2) To familiarize students with the concept of half-life in radioactive decay.

3) To have students see that individual runs of statistical processes are less predictable than the average of many runs (or that runs with relatively small numbers involved are less dependable than runs with many numbers).

4) To demonstrate how the rate of radioactive decay and the buildup of the resulting decay product is used in radiometric dating of rocks.

5) To use radiometric dating and the principles of determining relative age to show how ages of rocks and fossils can be narrowed even if they cannot be dated radiometrically.

MATERIALS:

1)Lab paper for each student (with all needed graphs and figures)
2)PENCIL to write with, colored pencils for graph
3) One package of 100 M & M's per team
4) Large cup or other container in which M & M's can be shaken.
5)Paper towel or other clean surface to count materials on
6) Watch or clock that keeps time to seconds. (A single watch or clock for the entire class will do.)

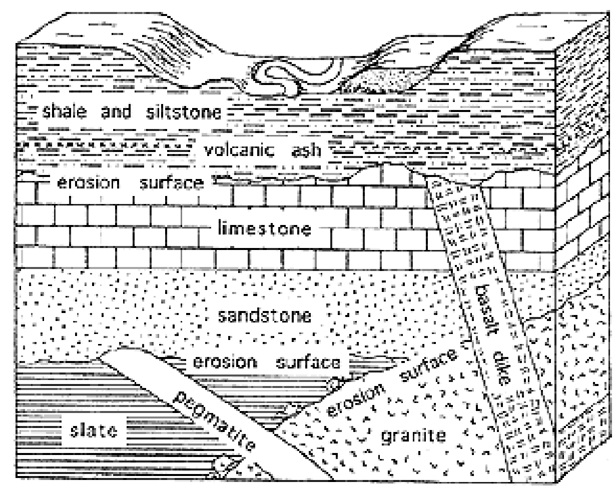
NAME____
LAB PARTNER(S)____________________________________

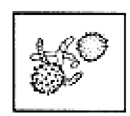
7) Piece of paper marked with a number of half-lives your team will carry out.
8) 128 small colored chips, marked with "U-235" all on one side and "Pb-207" on the opposite side that has some contrasting color.

PART 1: DETERMINING RELATIVE AGE OF FOSSILS

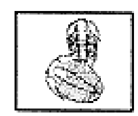
PROCEDURE: With your team, discuss how to determine the relative age of each of the rock layers in the figure below. Remember the Principles of Superposition (older layers are lower in the strata) and Cross-cutting relations (Faults and Intrusions are younger than the layers they cut through).

Figure 1. Block diagram

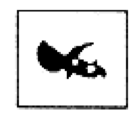




Highly magnified view of single-celled fossils found in the slate (acritarchs and bacteria)



Trilobites found in the limestone



Triceratops dinosaur fossils found in the shale and siltstone

List the rocks from oldest to most recently formed.

	Rock	Radiometric age
Most recent rock formed:	__________	_____
	__________	_____
	__________	
	__________	
	__________	_____
	__________	
Oldest rock:	__________	_____

PART 2: RADIOMETRIC DATING

BACKGROUND:

Some elements have forms (called isotopes) with unstable atomic nuclei that have a tendency to change, or decay. For example, U-235 is an unstable isotope of uranium that has 92 protons and 143 neutrons in the nucleus of each atom. Through a series of changes within the nucleus, it emits several particles, ending up with 82 protons and 125 neutrons. This is a stable condition, and there are no more changes in the atomic nucleus. A nucleus with that number of protons is called lead (chemical symbol Pb). The protons (82) and neutrons (125) total 207. This particular form (isotope) of lead is called Pb-207. U-235 is the parent isotope of Pb-207, which is the daughter isotope.

Many rocks contain small amounts of unstable isotopes and the daughter isotopes into which they decay. Where the amounts of parent and daughter isotopes can be accurately measured, the ratio can be used to determine how old the rock is, as shown in the following activities.

Part 2 Activity A — At any moment there is a small chance that each of the nuclei of U-235 will suddenly decay. That chance of decay is very small, but it is always present and it never changes. In other words, the nuclei do not "wear out" or get "tired". If the nucleus has not yet decayed, there is always that same, slight chance that it will change in the near future.

Very careful measurements in laboratories, made on VERY LARGE numbers of U-235 atoms, have shown that each of the atoms has a 50:50 chance of decaying during about 704,000,000 years. In other words, **during 704 million years, half the U-235 atoms that existed at the beginning of that time will decay to Pb-207.** This is known as the half life of U- 235. Many elements have some isotopes that are unstable, essentially because they have too many neutrons to be balanced by the number of protons in the nucleus. Each of these unstable isotopes has its own characteristic half life. **Some half lives are several billion years long, and others are as short as a ten-thousandth of a second.**

PROCEDURE:

Each team should obtain 100 pieces of "regular" M & M candy. On a piece of paper towel, each piece should be checked that it is printed with a letter M. This side represents the daughter isotope. The blank side represents the parent isotope. The candy should be poured into a container (ie cup) large enough for them to bounce around freely, it should be shaken thoroughly, then poured back onto the paper so that it is spread out instead of making a pile.

This first time of shaking represents one half life, and all those pieces of candy that have the printed M facing up represent a change to the daughter isotope. The team should pick up and set aside ONLY those pieces of candy that have the M facing up. Then, count the number of pieces of candy left with the M facing down or with the blank side up. These are the parent isotope that did not change during the first half life.

Record how many pieces of parent isotope remain in the first row of the decay table (Figure 2). Once all data is collected and displayed on the class chart, record the number from other teams on your lab paper. Then determine the class average number. The same procedure of shaking, counting the "survivors", and filling in the next row on the decay table should be done seven or eight more times. Each shaking time represents a half life. After the results of the final "half life" of the M& M are collected, the candies are no longer needed. (DO NOT DISPOSE OF THAT LAB MATERIAL UNTIL CLASS IS OVER.)

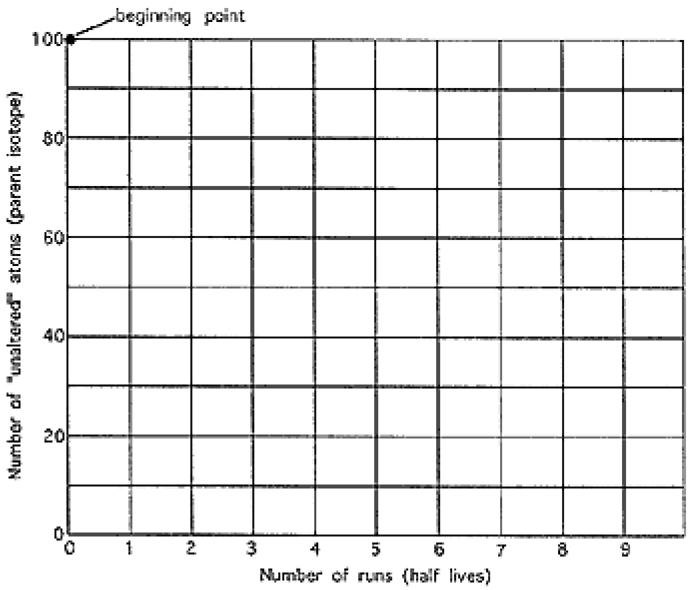
Figure 2. Decay table

Run	Class total	Number of "unchanged" pieces (parent isotope atoms)								Class average
		Team 1	Team 2	Team 3	Team 4	Team 5	Team 6	Team 7	Team 8	
1										
2										
3										
4										
5										
6										
7										
8										
9										

Each student should plot 3 lines on a graph (Figure 3). Use different symbols or colors to represent each data line. Create a key to show those. One line is the number of pieces of candy remaining after each of their team "shakes"; the second line should show the CLASS AVERAGE values and the third line should show a STANDARD CURVE to compare the others to. **The standard line begins at 100; the next point is 100/ 2, or 50; the next point is 50/2, or 25; etc.**

KEY

Figure 3. Graph of M&M half lives



QUESTIONS:

1) Why didn't each group get the same results?

2) Which follows the mathematically calculated line better? Is it the single group's results, or is it the line based on the class average?

Why?

3) Did your team have an easier time guessing (predicting) the results when there were a lot of pieces of candy in the cup, or when there were very few?

Why?

U-235 is found in most igneous rocks. Unless the rock is heated to a very high temperature, both the U-235 and its daughter Pb-207 remain in the rock. A geologist can compare the proportion of U-235 atoms to Pb-207 produced from it and determine the age of the rock. The next part of this exercise shows how this is done.

Part 2 Activity B — Each team receives 128 flat pieces, with U-235 written on one side and Pb-207 written on the other side. Each team is given a piece of paper on which is written 1, 2, 3, 4, or 5 half-lives. The team should place each marked piece so that the blue "U-235" is showing. This represents Uranium-235, which emits a series of particles from the nucleus as it decays to Lead-207 (Pb- 207). When each team is ready with the 128 pieces all showing blue "U-235", a timed interval should start. Time can be kept within each team/group. During that time each team turns over half of the blue U-235 pieces so that they now show the white Pb-207. This represents one "half-life" of U-235, which is the time for half the nuclei to change from the parent U-235 to the daughter Pb-207. A new timed interval begins. During this time the team should turn over HALF OF THE U-235 THAT WAS LEFT AFTER THE FIRST INTERVAL OF TIME. Each team should continue based on how many half-lives your team was to carry out. After all the timed intervals have occurred, teams should exchange places with one another as instructed by the teacher. The task now for each team is to determine how many half-lives the set of pieces they are looking at has experienced.

As a team, determine the number of half-lives the other team's pieces are displaying. Record the team number in the row with the correct number of half-lives and then calculate the age of the rock sample in millions of years. The half life of U-235 is 704 million years. Do this for all teams that participated and record them in the table below.

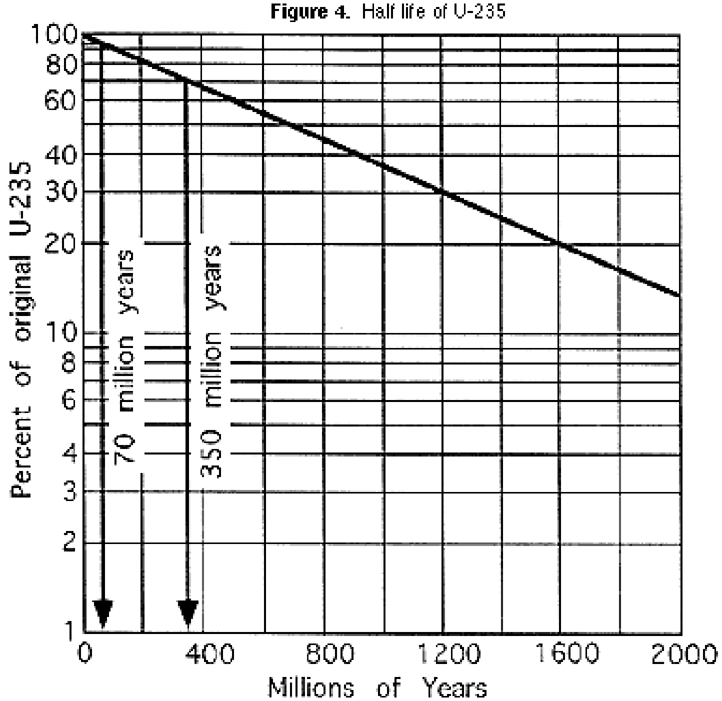
Team	# of half-lives	Age in millions of yrs (mya)
	1	
	2	
	3	
	4	
	5	
	6	

PART 3: PUTTING DATES ON ROCKS AND FOSSILS

For the block diagram (Figure 1) at the beginning of this exercise, **the ratio of U-235:Pb-207 atoms in the pegmatite is 1:1, and their ratio in the granite is 1:3.** Using the same reasoning about proportions as in Part 2b above, <u>your team should determine how old the pegmatite and the granite are. Write the ages of the pegmatite and granite beside the names of the rocks in the list below the block diagram</u> (Figure 1).

By plotting the half life on a type of scale known as a logarithmic scale, the curved line like that for the M & M activity can be straightened out, as you can see in the graph in Figure 4. This makes the curve more useful, because it is easier to plot it more accurately. That is especially helpful for ratios of parent isotope to daughter isotope that represent less than one half life. For the block diagram (Figure 1), **if a geochemical laboratory determines that the volcanic ash that is in the siltstone has a ratio of U-235:Pb-207 of 47:3 (94% of the original U-235 remains), this means that the ash is 70 million years old** (see Figure 4). **If the ratio in the basalt is 7:3 (70% of the original U-235 remains), then the basalt is 350 million years old** (again, see Figure 4).

Figure 4. Half life of U-235



<u>Your team should write the age of the volcanic ash beside the shale, siltstone and basalt on the list below the block diagram. The strata (layers) with the lines out to the right side will be the ones for which your team will need to determine the radiometric dates.</u>

QUESTIONS FOR DISCUSSION

1) Based on the available radiometric ages, can you determine the possible age of the rock unit that has acritarchs and bacteria?

What is it?

Why can't you say exactly what the age of the rock is?

2) Can you determine the possible age of the rock unit that has trilobites?

What is it?

Why can't you say exactly what the age of the rock is?

3) What is the age of the rock that contains the Triceratops fossils?

Why can you be more precise about the age of this rock than you could about the ages of the rock that has the trilobites and the rock that contains acritarchs and bacteria?

Note for teachers: Based on cross-cutting relationships, it was established that the pegmatite is younger than the slate and that the slate is younger than the granite. Therefore, the slate that contains the acritarch and bacteria is between 704 million years and 1408 million years old, because the pegmatite is 704 million years old and the granite is 1408 million years old. The slate itself cannot be radiometrically dated, so can only be bracketed between the ages of the granite and the pegmatite.

The trilobite-bearing limestone overlies the quartz sandstone, which cross-cuts the pegmatite, and the basalt cuts through the limestone. Therefore the trilobites and the rock that contains them must be younger than 704 million years (the age of the pegmatite) and older than 350 million years (the age of the basalt). The limestone itself cannot be radiometrically dated, so can only be bracketed between the ages of the granite and the pegmatite.

The Triceratops dinosaur fossils are approximately 70 million years old, because they are found in shale and siltstone that contain volcanic ash radiometrically dated at 70 million years. Any Triceratops found below the volcanic ash may be a little older than 70 million years, and any found above may be a little younger than 70 million years. The age of the Triceratops can be determined more closely than that of the acritarchs and bacteria and that of the trilobites because the rock unit that contains the Triceratops can itself be radiometrically dated, whereas that of the other fossils could not.

Atomic nuclei are held together by an attraction between the large nuclear particles (protons and neutrons) that is known as the "strong nuclear force", which must exceed the electrostatic repulsion between the protons within the nucleus. In general, with the exception of the single proton that constitutes the nucleus of the most abundant isotope of hydrogen, the number of neutrons must at least equal the number of protons in an atomic nucleus, because electrostatic repulsion prohibits denser packing of protons. But if there are too many neutrons, the nucleus is potentially unstable and decay may be triggered. This happens at any time when addition of the fleeting "weak nuclear force" to the ever-present electrostatic repulsion exceeds the binding energy required to hold the nucleus together.