

Half-Lives and Ash Layers: Putting Years on a Cliff

Learning target: I can graph the decay of a radioactive element, use half-lives to calculate the age of igneous rock, and use dated ash layers to bracket the ages of the sedimentary layers between them.

Data and graphing About 45 min Individual MS-ESS1-4 · practice data analysis independent practice

Standards connections

MS-ESS1-4 (practice, the time-scale half (how ages in years are attached to the rock record)): MS-ESS1-4 is a California Grade 8 performance expectation that this Grade 7 lesson previews. Calculating ages from half-lives and using them to bracket sedimentary layers is how relative order gets tied to Earth's 4.6-billion-year history.

Purpose: practice · **Time:** about 45 minutes · **Format:** individual

Answers with reasoning

Part A: How a radioactive clock runs down

When a zircon crystal forms in cooling magma, it traps atoms of uranium-235 and almost no lead. From that moment the uranium-235 atoms decay, one by one, into lead-207 at a steady rate that heat and pressure do not change. The time for half of the uranium-235 to decay, its **half-life**, is 704 million years. The table shows what fraction of the original uranium-235 is left after each half-life.

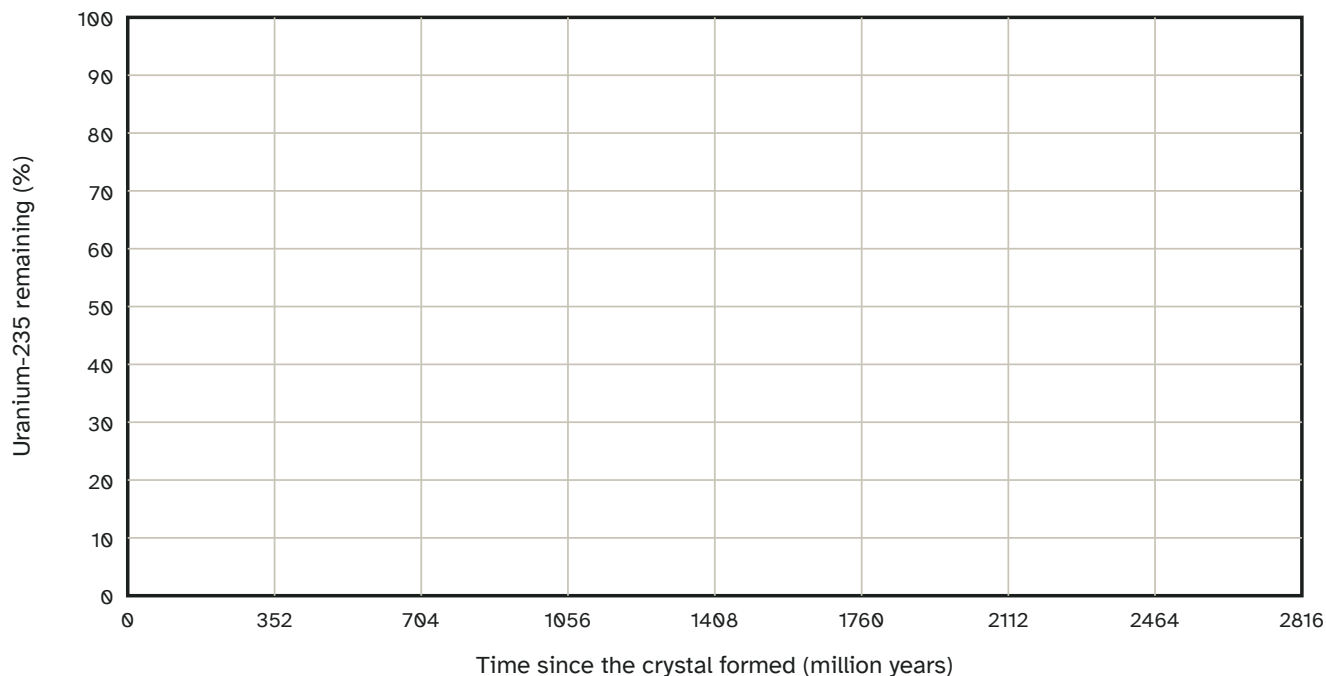
Decay of uranium-235 in a zircon crystal (teaching dataset)

Simulated teaching dataset: the numbers are invented to be realistic, not measured.

Time since the crystal formed (million years)	Half-lives passed	Uranium-235 remaining (%)	Lead-207 formed (%)
0	0	100	0
704	1	50	50
1408	2	25	75
2112	3	12.5	87.5
2816	4	6.25	93.75

Teaching dataset. The half-life of uranium-235 (704 million years) is real; the percentages are calculated from it, assuming the crystal has not gained or lost any atoms since it formed.

Uranium-235 remaining versus time



1. How many half-lives of uranium-235 fit into 2,816 million years? Show the division.

1 pt

Answer: $2,816 \div 704 = 4$ half-lives.

Why: Direct division; this confirms the last row of the table.

Also acceptable: None.

2. Extend the table one more row. After 5 half-lives, what percent of the uranium-235 remains, and how old is the crystal? Show both calculations.

2 pts

Answer: After 5 half-lives: $6.25\% \div 2 = 3.125\%$ of the uranium-235 remains. Age: $5 \times 704 = 3,520$ million years.

Why: Students must halve once more and multiply the count of half-lives by 704 million years. Accept 3.1% if rounded.

Also acceptable: Accept the age written as 3.52 billion years.

3. Describe the shape of your curve. Why does it drop quickly at first and then flatten, instead of falling in a straight line to zero?

2 pts

Answer: The curve drops steeply at first and then flattens, getting closer and closer to zero without reaching it. Each half-life removes half of what is left, not a fixed amount: the first half-life removes 50 percentage points, the second only 25, the third 12.5, and so on. Because the amount removed keeps shrinking, the curve bends instead of falling in a straight line.

Why: The key idea is 'half of what remains' versus 'a fixed amount each time'. A straight line would mean a constant number of atoms decaying per million years.

Also acceptable: 'It is like folding paper in half over and over; each fold is smaller' is an acceptable analogy if the halving idea is explicit.

- Describes a steep drop that flattens
- Explains that each half-life removes half of what is left, so the amount removed shrinks

4. At 1,408 million years, what is the ratio of lead-207 atoms to uranium-235 atoms in the crystal? Write it as a ratio in lowest terms.

1 pt

Answer: 75% lead to 25% uranium = 75:25 = 3:1.

Why: At two half-lives three quarters has decayed. Lowest terms is 3:1.

Also acceptable: Accept '3 to 1' or 'three lead atoms for every uranium atom'.

5. A crystal is measured and 35% of its uranium-235 remains. Use your curve to estimate its age. Describe how you read the graph (find 35 on the vertical axis, go across to the curve, go down to the time axis).

2 pts

Answer: About 1,050 to 1,100 million years (the exact value is about 1,066 million years). Reading: 35% is between 50% (704 million years) and 25% (1,408 million years); following the curve from 35% down to the time axis lands a little past the halfway tick at 1,056.

Why: 35% is between one and two half-lives. The precise answer is $704 \times \log_2(100/35) = 704 \times 1.515 = 1,066$ million years; any hand-drawn curve reading between 1,000 and 1,150 million years earns full credit, with the reading process described.

Also acceptable: A student who reasons 'between 704 and 1,408, closer to 1,056 because 35 is closer to 25 than to 50' without a precise reading has the right idea; give most of the credit.

- Age between 1,000 and 1,150 million years
- Reading process described (across from 35, down to time)

Part B: Dated ash in the Red Gulch cliff

Red Gulch (an invented cliff) exposes five flat, undisturbed layers. Two of them are volcanic ash, which contains zircon crystals that formed when the ash erupted. A geologist sent three samples to a lab. The lab measured the percentage of uranium-235 remaining in each.

Zircon results from Red Gulch (teaching dataset)

Simulated teaching dataset: the numbers are invented to be realistic, not measured.

Layer (top to bottom)	Rock	Sample sent to the lab	Uranium-235 remaining (%)
1	White volcanic ash (0.2 m)	Zircon from the ash	50
2	Gray shale, thin-bedded, no fossils (3 m)	none (no zircon formed here)	-
3	Tan sandstone (2 m)	One zircon sand grain	12.5
4	White volcanic ash (0.3 m)	Zircon from the ash	25
5	Blue-gray limestone (4 m, bottom not exposed)	none	-

Teaching dataset: the layers and lab results are invented to be realistic. Layers are listed from the top of the cliff downward.

6. Calculate the age of ash layer 1 and the age of ash layer 4 in million years. Show how you turned each percentage into a number of half-lives and then into years. 2 pts

Answer: Layer 1: 50% remaining = 1 half-life = $1 \times 704 = 704$ million years. Layer 4: 25% remaining = 2 half-lives = $2 \times 704 = 1,408$ million years.

Why: The table in Part A gives both directly; students should still show the half-life count and the multiplication.

Also acceptable: None.

7. What range of ages is possible for the shale (layer 2) and the sandstone (layer 3)? Explain which rule lets you use the two ash ages as limits. 2 pts

Answer: Layers 2 and 3 are between the two ashes, so by the law of superposition they are younger than ash 4 (1,408 million years) and older than ash 1 (704 million years). Each has an age somewhere between 704 and 1,408 million years; the data cannot say where in that window.

Why: Superposition is the rule: the layers are undisturbed, so position gives order, and the dated ashes turn that order into an age window (bracketing).

Also acceptable: A student who adds that layer 2 is probably younger than layer 3 (it is higher) is correct, though neither can be pinned to a number.

- Range 704 to 1,408 million years
- Superposition named
- Recognizes the exact ages are unknown within the window

8. A student calculates the sand grain's result (12.5% remaining) and announces, 'The sandstone is 2,112 million years old.' The grain's number is right, but the conclusion is wrong, and it even contradicts your answer to q7. Explain where the grain's clock started, why that makes the grain older than the sandstone, and what the sandstone's real age range is. 3 pts

Answer: The grain's clock started when the zircon crystallized in some older igneous rock, 2,112 million years ago ($12.5\% = 3 \text{ half-lives} = 3 \times 704$). That rock was later weathered, and the grain was carried by water and dropped into the sand that became layer 3. So the grain is older than the sandstone; the sandstone is only as old as the time the sand was deposited and cemented. The sandstone's real age range is the one from q7: between 704 and 1,408 million years, because it lies between the two dated ashes. A grain's age is a maximum for the layer, never the layer's age.

Why: This is the accurate version of the textbook's point that absolute dating applies to igneous rock. Students should connect the grain to an older source rock and use the bracket from q7.

Also acceptable: Accept 'the grain is a pebble-sized clue that is older than the layer it is in' as the recycling idea.

- Grain's clock started in an older igneous rock
- Grain is older than the sandstone because it was recycled into it
- Sandstone's age range is 704 to 1,408 million years

9. What can you say about the age of the limestone (layer 5)? Give the one limit the data supports and explain why there is no second limit. 2 pts

Answer: The limestone is below ash 4, so by superposition it is older than 1,408 million years. There is no second limit because nothing datable lies below it in the exposed cliff; the data give only a minimum age, not a maximum.

Why: One-sided brackets are common in real cliffs; students should notice that a lower limit needs a dated layer beneath.

Also acceptable: A student who proposes digging or drilling to find a datable layer beneath has the right fix.

- Older than 1,408 million years
- No upper limit because nothing dated lies below

Teacher notes

Uranium-235 decays to lead-207 with a half-life of about 704 million years, the value the textbook uses on p. 102 (PDF 138). Part A's percentages are exact halvings and assume a closed system (no atoms gained or lost), an assumption the textbook's clock model leaves unstated. Part B's layers and results are invented. The sand-grain item (q8) addresses the lesson's unexplained claim that only igneous rock can be dated: grains in sedimentary rock carry clocks that started in their source rocks, so bracketing between dated ashes is how sedimentary layers get age ranges. The precise q5 answer uses a logarithm; students are expected to read the curve, not compute it. The extension points toward short-half-life methods (carbon-14, about 5,730 years) without naming them.

Scaffold offered to students: A halving table

If the percentages are confusing, build a halving table on scrap paper: start at 100, halve it (50), halve again (25), again (12.5), again (6.25), again (3.125). Each halving is one half-life, and each half-life is 704 million years. To find an age, count how many halvings it takes to reach the measured percentage, then multiply that count by 704. For q5, the answer is between the first and second halving, so the age is between 704 and 1,408 million years; the curve tells you where.

Extension: Choosing a clock

A lava flow is only about 10,000 years old. Explain why uranium-235, with its 704-million-year half-life, is a poor choice for dating it (think about how much of the uranium would have decayed in 10,000 years and whether a lab could measure that tiny change). Then describe what kind of half-life, long or short, you would want in an element used to date something that young, and what kind you would want for something 3 billion years old.