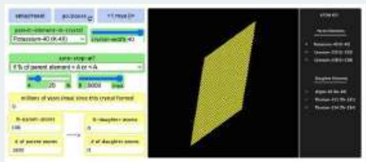
Lesson 8: Is the rock at Afar radioactive, and what can that tell us?

Previous Lesson *We wanted to know where the heat comes from that drives mantle convection. We read a series of articles that answer this question from forces, matter, and energy perspectives. We developed a cause-effect model to explain the mechanism that results in energy release from radioactive decay.*

This Lesson

Investigation

3 days



Wilensky, U. 1999. NetLogo. http://ccl.northwestern.edu/netlogo/. Center for Connected Learning and Computer-Based Modeling, Northwestern University. Evanston, IL.

We analyze the radioactive element composition of rocks from Afar. We plan and carry out an investigation using a simulation to collect data on how the amount of radioactive material in a rock crystal changes over time. We use mathematical thinking to compare patterns in our graphs to those in an equation of exponential decay, and we use that equation to determine the age of rocks from Afar.

Next Lesson *We will look at the crustal ages of rocks around the world in both oceans and continents, and notice a number of patterns, including that the continental rock is significantly older, and that the farther the rock is from some plate boundaries in the ocean, the older it is. We will determine the density of basalt (oceanic crust) and granite (continental crust) and wonder about how that affects forces and energy transfer. We will add questions to the Driving Question Board about plate boundaries and types of crust.*

BUILDING TOWARD NGSS

HS-PS1-8, HS-ESS1-5, HS-ESS2-1, HS-ESS2-3

What students will do

8.A Sketch and describe graphs for percent of parent and daughter elements versus time; use a spreadsheet to graph and compare patterns across different crystal sizes and different parent elements and compare these to patterns predicted by an exponential decay law. (SEP: 5.2; CCC: 1.4; DCI: PS1.C.2)

8.B Analyze data using a spreadsheet and an exponential decay law to find the age of various rock samples using relationships (half-lives) discovered in prior investigations; interpret the patterns across the ages of these samples and the sites where these are located to reconstruct the geologic history of Afar over the last 700 million years. (SEP: 4.1; CCC: 1.5; DCI: PS1.C.2)

What students will figure out

- Radioactive decay of elements follows a characteristic exponential decay law, with a specific lifetime (timescale) for each; we can use this to determine the ages of rocks and other materials from the ratio of parent to daughter elements present.
- Some of the rock on the western and eastern edges of Afar formed hundreds of million years ago. But most of the rock in the middle of the Afar region is very young, appearing over the last few million years.

Lesson 8 • Learning Plan Snapshot

Part	Duration		Summary	Slide	Materials
1	2 min		**NAVIGATE** Review what we figured out was the main source of energy for mantle convection.	A	
2	5 min		**CONSIDER PRESENCE OF RADIOACTIVE MATERIALS IN AFAR** Discuss the possibility of finding radioactive materials in Afar, and how that can help us reconstruct the past and predict the future of this region.	B-D	
3	8 min		**ANALYZE AND INTERPRET DATA** Orient to the map of rock sample sites and analyze the composition of rock samples.	E-H	*Rock Sample Site Map*
4	6 min		**DISCUSS RELATED PHENOMENA AND INTRODUCE RELATED TOOLS AND PROCESS** Summarize the rock transformation process to make sense of patterns across the volcanic rock samples. Learn that spectrometers are used to analyze the element composition of crystals.	I-P	*Rock Transformation Process* (optional)
5	6 min		**MAKE PREDICTIONS AND CONNECT TO OUR ANCHORING PHENOMENON** Record predictions individually and discuss questions related to the Afar region.	Q-R	*Predicting Composition Trends*
6	8 min		**PLAN AN INVESTIGATION** Orient to the simulation and spreadsheet. Plan an investigation for condition 1 as a group.	S-U	group copy of radioactive decay data collection spreadsheet from https://docs.google.com/spreadsheets/d/1-7OYiN8LLC7JHzeSvRCMUc66T78H5lNx3uVqWc2e68Y/edit?usp=sharing, https://youtu.be/r6C3VnDUaq8?si=q5A3b4M3tXha5b5O, https://youtu.be/vfJkpqKkUqI (optional)
7	10 min		**COLLECT DATA FOR THE FIRST CONDITION** Collect and record initial data for condition 1.	V	https://openscied-static.s3.amazonaws.com/HTML+Files/Radioactive+Element+Decay.html, group copy of data collection spreadsheet

End of day 1

8	6 min	**NAVIGATE** Remind students where we left off last time.	W-X	https://openscied-static.s3.amazonaws.com/HTML+Files/Radioactive+Element+Decay.html, group copy of data collection spreadsheet
9	10 min	**COLLECT DATA FOR ADDITIONAL CONDITIONS** Modify the spreadsheet to support data collection for additional trials and conditions. Collect additional data using the simulation.	Y-Z	https://openscied-static.s3.amazonaws.com/HTML+Files/Radioactive+Element+Decay.html, group copy of data collection spreadsheet
10	8 min	**ANALYZE THE DATA** Produce and analyze graphs of the data from the spreadsheet.	AA-BB	*Analyzing Decay Trends*
11	7 min	**COMPARE RESULTS** Compare results in Jigsaw groups to determine whether crystal size affects the time at which there is a certain fraction of the parent material left.	CC	*Analyzing Decay Trends*
12	3 min	**ARGUE FROM EVIDENCE** Share arguments for whether crystal size affects the time at which a certain fraction of the parent material is left.	DD-EE	*Analyzing Decay Trends*
13	10 min	**USE MATHEMATICAL THINKING TO ANALYZE RADIOACTIVE DECAY GRAPHS** Turn and talk about patterns noticed between the time for decay to 50% and the time for decay to 25%. Use these ideas to develop a mathematical model as a class, and use the model to test predictions.	FF-GG	*Analyzing Decay Trends*, *Age of Rocks*, calculator, *Rock Sample Site Map*, https://youtu.be/Y-GP_AedXBQ?si=kbwYEQAitgwrxnRN, https://youtu.be/H9CPgtaorzE?si=iFOyrWZSbnGGotu1, chart paper (optional), chart paper markers (optional)
14	1 min	**NAVIGATE** Highlight limitations of our data in calculating the age of rocks.	HH	

End of day 2

15	20 min		**USE MATHEMATICAL THINKING TO MAKE SENSE AND USE A MODEL OF RADIOACTIVE DECAY** Recall our data's limitations to motivate exploring a mathematical model.	HH-NN	
16	10 min		**DETERMINE THE AGES OF ROCKS IN AFAR** Orient to the rock sample data. Determine the age of rock samples in groups.	OO-QQ	*Age of Rocks*, *Rock Sample Site Map*
17	8 min		**ANALYZE AND INTERPRET DATA** Work in partners to use the *Rock Sample Site Map* and the calculated rock ages to discuss patterns in the locations of older versus younger volcanic rocks in the Afar region.	RR	*Age of Rocks*, *Rock Sample Site Map*
18	4 min		**UPDATE THE SCALE CHART POSTER** Add ideas to the Scale Chart poster.	SS	Scale Chart poster
19	3 min		**NAVIGATE** Discuss the rocks in Afar to motivate expanding our scale to consider the age of rocks found in other parts of the world.	TT	*Rock Sample Site Map*, *Age of Rocks*

End of day 3

Lesson 8 • Materials List

	per student	per group	per class
Lesson materials	• science notebook • *Rock Transformation Process* (optional) • *Predicting Composition Trends* • group copy of radioactive decay data collection spreadsheet from https://docs.google.com/spreadsheets/d/1-7OYiN8LLC7JHzeSvRCMUc66T78H5lNx3uVqWc2e68Y/edit?usp=sharing • https://openscied-static.s3.amazonaws.com/HTML+Files/Radioactive+Element+Decay.html • group copy of data collection spreadsheet • *Analyzing Decay Trends* • *Age of Rocks* • calculator • *Rock Sample Site Map*	• *Rock Sample Site Map*	• https://youtu.be/r6C3VnDUaq8?si=q5A3b4M3tXha5b5O • https://youtu.be/vfJkpqKkUqI (optional) • https://youtu.be/Y-GP_AedXBQ?si=kbwYEQAitgwrxnRN • https://youtu.be/H9CPgtaorzE?si=iFOyrWZSbnGGotu1 • chart paper (optional) • chart paper markers (optional) • Scale Chart poster

Materials preparation (30 min minutes)

Review teacher guide, slides, and teacher references or keys (if applicable).

Make copies of handouts and ensure sufficient copies of student references, readings, and procedures are available.

Make 1 color copy of the *Rock Sample Site Map* for every 2 students in your largest class. Place these in sheet protectors. You will collect and reuse these across classes.

Three-hole-punch handouts so they can be added to students' science notebooks.

Make copies of the handouts for this lesson:

- *Predicting Composition Trends* - 1 per student
- *Analyzing Decay Trends* - 1 per student
- *Age of Rocks* - 1 per student
- *Rock Transformation Process* - 1 per student (optional, as it contains the same information presented in **slides K-M**)

Conduct the following tests of the videos for this lesson:

- Spin off a copy of the radioactive decay data collection spreadsheet, https://docs.google.com/spreadsheets/d/1-7OYiN8LLC7JHzeSvRCMUc66T78H5lNx3uVqWc2e68Y/edit?usp=sharing . You will share this copy with the class. Each group will then spin off a copy to share within the group so each member can contribute a row of data.
- Run the simulation, https://openscied-static.s3.amazonaws.com/HTML+Files/Radioactive+Element+Decay.html .
- View the simulation and spreadsheet orientation videos:
  - Using the sim, https://youtu.be/r6C3VnDUaq8?si=q5A3b4M3tXha5b5O
  - Collecting data using the spreadsheet, https://youtu.be/vfJkpqKkUqI
  - Identifying half-life patterns, https://youtu.be/Y-GP_AedXBQ?si=kbwYEQAitgwrxnRN
  - Using equation to identify age of rock samples, https://youtu.be/H9CPgtaorzE?si=iFOyrWZSbnGGotu1

Reserve enough computers for each student to use on days 1 and 2.

Lesson 8 • Where We Are Going and NOT Going

Where We Are Going

This lesson is designed to coherently build ideas related to the following disciplinary core idea (DCI):

- **PS1.C: Nuclear Processes.** Spontaneous radioactive decays follow a characteristic exponential decay law. Nuclear lifetimes allow radiometric dating to be used to determine the ages of rocks ~~and other materials~~. (secondary to HS-ESS1-5, secondary to HS-ESS1-6)

Students sketch the shape of a predicted relationship as a graph in this lesson. Most will probably draw a linear relationship. Later in the lesson, students see that their graphs show the relationships they predicted are actually nonlinear. Students who have completed the high school OpenSciEd Chemistry course have seen a nonlinear relationship in data.

This is the only time in this unit that students use a graph and an exponential decay law to determine the age of rock. They focus on the ages of rocks and do not extend this to other materials.

Students use a spreadsheet to accomplish several tasks. One task is to plan conditions to investigate and collect data, the second is to graph the data, and the third is to solve an equation. Students who have completed the high school OpenSciEd Chemistry course have had multiple experiences with these uses.

This lesson is designed to support students toward the Next Generation Science Standards (NGSS) Nature of Science Understanding titled **Scientific Investigations Use a Variety of Methods** (Appendix H). The relevant understanding element reads:

- Scientific inquiry is characterized by a common set of values that include: logical thinking, precision, open-mindedness, objectivity, skepticism, replicability of results, and honest and ethical reporting of findings.

Students assess the accuracy and replicability of their results as they investigate radioactive decay using a simulation. Working in groups and as a class, they discuss the importance of accuracy and replicability in scientific investigations.

Students encounter and/or co-develop definitions for several terms during this lesson, and may choose to add these words to their Personal Glossaries: *crystal, spectrometer, parent element, daughter element.* **Do not** ask students to define or keep track of any words until after the class has developed a shared understanding of their meaning. Then, create an opportunity to add new meanings to Personal Glossaries, if desired.

Where We Are NOT Going

Though the data analyzed in this lesson are largely based on measured samples from Afar, some simplifications have been made. One was to site locations in the *Rock Sample Site Map*. For details on this modification and why it was made, see the *Site Location Modifications* reference. Another was to the parent-to-daughter-element proportions in rock samples in the *Age of Rocks* handout. For details on this modification and why it was made, see the *Rock Composition Modifications* reference.

LEARNING PLAN for LESSON 8

1 · NAVIGATE

2 min

MATERIALS: None

Navigate. Present **slide A**. Revisit the last question in the Electronic Exit Ticket from Lesson 7:

- *Radioactivity drives mantle convection deep inside Earth. But there is also naturally occurring radioactive material on Earth's surface, and humans use radioactive materials in technology.*
    - *Where else have you heard about radioactivity occurring naturally or being used?*

Have students share out. Accept all answers. Say, *We know there is radioactive material in some places of Earth's surface, but what about Afar?*

2 · CONSIDER PRESENCE OF RADIOACTIVE MATERIALS IN AFAR

5 min

MATERIALS: None

Discuss the possibility of radioactive material in Afar. Present **slide B**. Elicit 1-2 ideas with the prompt:

- *In some regions, such as Afar, magma reaches the surface and cools, forming solid rocks. Based on our ideas, would we expect to find evidence of radioactive materials in the rocks in Afar?*

Accept all answers, but listen for students to say that we saw evidence of volcanic eruption in the Afar region, and that the lava should probably contain radioactive material. If no one suggests volcanic regions, ask them to think back to Lesson 7, and remind them that they had learned about radioactive material deep inside Earth. Direct students to consider where this material might appear on the surface, guiding them to consider that volcanic areas might be of interest.

Consider the purpose of measuring radioactive materials. Present **slide C.** Read the text at the top:

- *All rocks that contain radioactive elements undergo radioactive decay at a known rate, acting like a clock. By measuring the amount of radioactive elements in a rock sample, scientists can determine its age when it first solidified.*

Then give the class a moment to consider the slide's prompt:

- *How can comparing the amounts of radioactive materials in rocks help us reconstruct past processes that have shaped a place, and predict its future?*

Invite a few students to share their ideas with the class. Accept all answers.

Revise the Driving Question Board. Present **slide D**. Point to the DQB and elicit ideas with the prompt:

- *What questions from our DQB involve reconstructing the past or predicting the future in Afar?*

Accept all answers. Say, *I have data that can help us shed light on those questions.*

3 · ANALYZE AND INTERPRET DATA

8 min

MATERIALS: *Rock Sample Site Map*

Orient to the rock sample site map. Display **slide E**. Distribute the *Rock Sample Site Map* (in a sheet protector) to each pair of students. Have them locate the relief map in the top right corner first, then identify the red rectangle. Explain that the color map is of that red region in Afar. Help students make sense of the map with the prompt:

- *What do the colors indicate?*

Listen for them to say that the colors show similar rock formations or alluvial sediments.

Explain the difference between rock formations and alluvial sediments. Mention that similar rock formations are places where there is solid rock on the surface and the type of rock that makes it up is the same. Explain that this solid rock is volcanic in origin, whereas alluvial sediments are areas where solid rock is not visible on the surface, because it is covered by layers of sediments like dirt or sand.

Orient to the sites on the map. Tell students that the letters represent sites where scientists have collected rock samples to look for evidence of radioactive materials. Say that we will look at data for samples from all of the sites over the course of the lesson, but we are starting with a small set.

Analyze rock sample data. Display **slide F**. Explain that the data are for rock samples taken from six locations on the map. Give the class a minute to look at the data, and then discuss the related question as shown in the table below.

Some students might not recognize that K-40 is a radioactive element. Present **slide G** to highlight both K-40 and U-238 as elements on the periodic table.

Suggested prompt	Sample student response

✱ ATTENDING TO EQUITY

Supporting emergent multilingual students: When developing new vocabulary, one strategy that may benefit emergent multilingual learners is to make connections to cognate words when possible. The word *alluvial* comes from the Latin words *ad* (against) and *lavere* (wash), because alluvial sediment was deposited by water washing against the land. *Lavere* has cognates in other romance languages such as French (*laver*), Spanish (*lavar*), and Portuguese (*lavar*). Encourage students who speak multiple languages to bring those valuable resources to bear in decoding academic words like alluvial.

What patterns do you notice in the data across these volcanic rock samples?	Each site has either K-40 or U-238, but never both. Most of the rock in the region has radioactive elements. The concentration of radioactive elements seems to be different in all the sites.

Connect with Lesson 7. Present **slide H**. Connect with students' previously developed ideas and elicit new ideas about what could account for the differences in composition, as shown in the table below.

Suggested prompt	Sample student response
We know that radioactive decay is happening in the mantle under the surface, and that when the hot magma reaches the surface, it can cool to form solid rocks. So, why would there be different amounts of radioactive parent elements in different rock samples?	Maybe there was more radioactive material in that part of the mantle at the time that it reached the surface. Maybe radioactive material is not uniformly distributed in the mantle. We saw that there must be hotter and cooler spots in the mantle, which implies that there are spots of material that are more and less radioactive, too.

The goal of this discussion is to draw connections between processes in the mantle and the presence of surface features at Afar. If students struggle to do this, you can ask the following questions:

- *If the amount of radioactive material decreases over time due to radioactive decay, how would the age of a rock that contains more radioactive material compare to the age of a rock with very little radioactive material in it?*
- *If the matter that makes up these rock samples comes from the magma in the mantle, what could the presence of rocks with varying amounts of radioactive material tell us about what has been happening in this area?*

Collect the *Rock Sample Site Map* at the end of this activity.

4 · DISCUSS RELATED PHENOMENA AND INTRODUCE RELATED TOOLS AND PROCESS

6 min

MATERIALS: science notebook, *Rock Transformation Process* (optional)

Connect to related phenomena. Present **slide I**. Say, *To figure out how much of these radioactive elements are in these volcanic rocks, scientists study the individual crystals that make up the rocks. Before we see how they do that, let's think about our own related experiences with rocks.*

Take a quick poll on the slide's question:

- *How many of you have found solid rocks with what look like tiny crystals of different colors and sizes in them?*

Most students will raise their hands. Follow up by saying, *Solid rocks with small crystals in them are typically rocks that have been either partially melted or fully melted in the past, before cooling back down. That cooling causes the crystals to form.*

ALTERNATE ACTIVITY	**Differentiation opportunity:** For students who are interested, you can encourage them to bring in a sample of rocks they may have collected that have such crystals in them or you can encourage students to take photos of any rocks they find around where they live or around the school that show evidence of this.

Read about formation of crystals containing radioactive elements. Present **slide J**. Say, *I have a reading that will help us understand the patterns we saw in the presence of radioactive materials across the rock samples from Afar*. Ask students to write a summary of the main ideas from **slides K, L,** and **M** that can help explain these patterns.

ALTERNATE ACTIVITY	Instead of having students read the text on **slides K-M**, you can distribute the *Rock Transformation Process* reading, which contains the same information.

Discuss the main ideas from the reading. Present **slide N**. Use the prompt to start a brief discussion:

- *How does the information in this reading help to explain some of the patterns we identified across the volcanic rock samples collected from Afar?*

Invite a few students to share their written summaries. Listen for the following ideas:

- Crystals are formed at different temperatures. They only contain one type of radioactive element.
- This helps explain why rock samples contain either K-40 or U-238.

Orient to the use of a spectrometer. Display **slide O**. Say, *Scientists can analyze crystals with a spectrometer to determine how much of each of these radioactive elements is in any given crystal.*

The slide shows the known relationships between three parent elements that undergo radioactive decay and the daughter elements they turn into over time. Present **slide P** to help students understand the transformations of K-40, U-235, and U-235. Before moving on, make sure they grasp the idea that matter changes through radioactive decay.

Say, *Now that we understand that radioactive elements decay, let's make predictions about the trends we might see if we could measure the amount of a radioactive element in a rock crystal over time.*

ALTERNATE ACTIVITY	**Differentiation opportunity:** If students have completed OpenSciEd chemistry courses, then they have prior experience with thinking about how spectrometers can be used to identify the elements in a sample, in their work in *OpenSciEd Unit C.3: How could we find and use the resources we need to live beyond Earth? (Space Survival Unit)*.

5 · MAKE PREDICTIONS AND CONNECT TO OUR ANCHORING PHENOMENON

6 min

MATERIALS: *Predicting Composition Trends*

Make predictions. Display **slide Q**. Distribute the *Predicting Composition Trends* handout. Give students 4 minutes to individually record predictions in their handout about what we would see if we could measure the amount of a radioactive element present in a rock crystal over time.

Draw an *x-axis* and *y-axis* on the board, and invite a volunteer to share their predictions. Then, ask students to raise their hands if they made a different prediction. Invite those who raised their hands to draw their predictions on the board as well.

ASSESSMENT OPPORTUNITY	**What to look for/listen for in the moment:** ● A graph that shows a trend (linear or nonlinear) with a solid line of decreasing y-values as x-values increase for the percentage of parent element found in a crystal over time, and a dotted line of increasing y-values as x-values increase for the percentage of daughter element found in a crystal. (SEP: 5.2; CCC: 1.4, DCI: PS1.C.2) **What to do:** ● Collect the *Predicting Composition Trends* handout at the end of the period. ● Reach out to math colleagues to find out how they are scaffolding graphing for their high school

students.

- If students are struggling, ask clarifying questions about why they are making specific decisions. This helps them articulate their reasoning, a metacognitive exercise that can be powerful in helping them figure out what to do to achieve a purpose rather than simply follow directions.
- An alternative approach to modifying instruction in support of students engaging in math and computational thinking is to ask them to describe in words the mathematical relationship they are trying to represent. This parallels similar cognitive processes while making their thinking visible. It allows you to identify areas where they might be struggling, and provide targeted support and guidance.

Building toward: 8.A.1 Sketch and describe graphs for percent of parent and daughter elements versus time; use a spreadsheet to graph and compare patterns across different crystal sizes and different parent elements and compare these to patterns predicted by an exponential decay law. (SEP: 5.2; CCC: 1.4; DCI: PS1.C.2)

Connect to the Afar region. Display **slide R**. Give students 2 minutes to turn and talk about the questions on the slide. Then discuss a variation of those as a class, as shown in the table below.

Suggested prompt	Sample student response
We made predictions about the changes in the amount of parent and daughter elements in the sample. How could we use the ratio of parent and daughter elements in rock samples to measure the rate at which various processes happened at Afar in the past?	We see that they measured these elements already in the rocks at Afar, so if we can come up with some way to connect amount to rate, it could tell us how long this has been happening, and how it compares to other areas on Earth.
How could we use this ratio to make predictions about the rate at which things might happen in the future?	If we know the rate that things happened in the past, we could use it to predict how often or how quickly similar things will happen in the future.

6 · PLAN AN INVESTIGATION

8 min

MATERIALS: group copy of radioactive decay data collection spreadsheet from https://docs.google.com/spreadsheets/d/1-7OYiN8LLC7JHzeSvRCMUc66T78H5lNx3uVqWc2e68Y/edit?usp=sharing, https://youtu.be/r6C3VnDUaq8?si=q5A3b4M3tXha5b5O, https://youtu.be/vfJkpqKkUqI (optional)

Introduce the idea that a mathematical model exists. Present **slide S**. Read the text aloud:

- *Scientists have come up with a general mathematical model that predicts how long ago a crystal formed based on how much of each radioactive parent and daughter element is in it.*

Say, *Let's see whether we can develop a similar model to figure out the rates that various processes have been occurring at Afar, by collecting some data for a simulation of radioactive decay.*

Orient to the simulation. Play the video at https://youtu.be/r6C3VnDUaq8?si=q5A3b4M3tXha5b5O . Then discuss the question on **slide S** as a class, as shown in the table below.

Suggested prompt	Sample student response
What data would we need to collect from this simulation to help us develop such a mathematical model?	We would need to collect data on the amount of radioactive elements in the crystals at different points in time. We would need to record amounts of both the parent and daughter elements.

Introduce the radioactive decay data collection spreadsheet. Present **slide T**. Tell students we have a spreadsheet for recording data from the simulation. Point out the column headings in the image on the slide. Explain that each group will spin off a copy of the spreadsheet to share so each member can contribute a row of data. Emphasize that before doing so, the group needs to make decisions about what variables to keep constant and what to change for the first condition they want to test.

ALTERNATE ACTIVITY	You can use this optional video to further orient students in using the spreadsheet to plan their first condition to collect data: https://youtu.be/vfJkpqKkUqI

Plan investigation condition 1. Display **slide U**. Reiterate that the groups now need to plan the first experiment to collect data on. Share the related link for students to spin off a copy of the spreadsheet: https://docs.google.com/spreadsheets/d/1-7OYiN8LLC7JHzeSvRCMUc66T78H5lNx3uVqWc2e68Y/edit?usp=sharing . Give groups 5 minutes to plan their first investigation.

As students plan, remind them that group members can start filling in the rows on their spreadsheets as they obtain the corresponding simulation results. This way of dividing the data collection ensures that the group can run multiple simulation trials at the same time.

ALTERNATE ACTIVITY	**Extension opportunity:** This is suggested as an optional extension opportunity for students who have demonstrated either prior fluency or a high interest in the science practice of *planning and conducting investigations*. It can function as a differentiation opportunity. Instead of providing the ready-made spreadsheet, encourage students to develop their own spreadsheet. This approach prompts them to consider how to record, analyze, and evaluate their data.

7 · COLLECT DATA FOR THE FIRST CONDITION

10 min

MATERIALS: https://openscied-static.s3.amazonaws.com/HTML+Files/Radioactive+Element+Decay.html, group copy of data collection spreadsheet

Carry out the investigation for condition 1. Display **slide V**. Share the simulation link with the class: https://openscied-static.s3.amazonaws.com/HTML+Files/Radioactive+Element+Decay.html . Monitor students as they collect and record data on their first condition. As they finish, explain that we will have time in the next class to collect data on additional conditions.

End of day 1

8 · NAVIGATE

6 min

MATERIALS: https://openscied-static.s3.amazonaws.com/HTML+Files/Radioactive+Element+Decay.html, group copy of data collection spreadsheet

Review data and discuss trial numbers. Present **slide W**. Distribute a computer to each student and have them access the data they recorded last time. Say, *Last time, we were investigating how much time it takes radioactive elements within a rock sample to decay.* Instruct them to review their data for condition 1 and consider the slide's prompt:

- *How did you know whether you had completed enough trials for a condition?* ✱

After a couple of minutes, ask students to share out. Listen for the following ideas:

- We just did it three times.
- After a few trials, the data shows results within the same range.

Collect additional data for the first condition. Present **slide X**. Use the slide prompt to let students decide whether to collect more data based on their current results. Give them 4 minutes maximum to collect more data if needed.

✱ SUPPORTING STUDENTS IN ENGAGING IN PLANNING AND CARRYING OUT INVESTIGATIONS

In Lesson 2, students had the opportunity to consider whether they had collected enough data when measuring the force combinations acting on an object. This prompt engages them in the same practice. Scan the room to decide whether students seem confident about how to answer this type of question. Knowing when they have collected enough data is key for engaging in other practices, such as developing arguments and counterarguments based on data and evidence.

If you see fit, display a sample spreadsheet that shows a limited number of trials, and conduct a few more tests using the simulation in front of the class to show that new values are either higher or lower than the ones currently collected, which suggests the need for more trials.

9 · COLLECT DATA FOR ADDITIONAL CONDITIONS

10 min

MATERIALS: https://openscied-static.s3.amazonaws.com/HTML+Files/Radioactive+Element+Decay.html, group copy of data collection spreadsheet

Collect data for a second condition. Present **slide Y**. Have groups consider the slide's prompt:

- *What other conditions do you want to test? Use a different tab for each condition you test, indicating the parent element and crystal width tested.*

Give students a few minutes to decide which conditions to test with the simulation. Then, present **slide Z**. Use the prompts to orient students to the task:

- *Carry out your data collection for all your conditions and trials.*
- *You can have multiple members start collecting and recording data for different rows and tabs in your spreadsheet.*

Demonstrate how to record additional data. Show the class where to find the additional tabs to collect data for more conditions. The last part of https://youtu.be/vfJkpqKkUqI shows how to find these.

10 · ANALYZE THE DATA

8 min

MATERIALS: *Analyzing Decay Trends*, science notebook

Analyze and interpret data individually. Display **slide AA**. Distribute the *Analyzing Decay Trends* handout. Give students about 4 minutes to individually record their analysis of their graphs for the first two questions on the handout:

- *How do the patterns across your graphs compare?*
- *How do these patterns compare to your predictions?*

Analyze and interpret data in groups. Display **slide BB**. Have students work in groups to analyze their graphs to approximate the times (on average) when 50% and 25% of the parent element was left.

Space is provided on *Analyzing Decay Trends* to record averages for up to 6 conditions. Some groups may only complete a subset of 2-3 conditions, which is fine. This should take about 4 minutes.

ASSESSMENT OPPORTUNITY	**What to look for/listen for in the moment:** A summary of the following: • The patterns in the trends of the data and how they compare to the predictions. • An estimated time determined for at least one parent element that reached 25% in approximately twice the time it took to reach 50%. (SEP: 5.2; CCC: 1.4) • How quickly or slowly various radioactive elements change into daughter elements. (SEP: 5.2; CCC: 1.4; DCI: PS1.C.2) **What to do:** It can be helpful to first ask students to describe the shape of the graphs before asking them to interpret those patterns. If they are struggling, tell them to not make any inferences, and simply point out patterns. Ask them to consider other times they have seen patterns like these, and what those patterns meant. Then ask them to start making inferences about the data. **Building toward: 8.A.2** Sketch and describe graphs for percent of parent and daughter elements versus time; use a spreadsheet to graph and compare patterns across different crystal sizes and different parent elements and compare these to patterns predicted by an exponential decay law. (SEP: 5.2; CCC: 1.4; DCI: PS1.C.2)

11 · COMPARE RESULTS

7 min

MATERIALS: *Analyzing Decay Trends*, science notebook

Compare results. Display **slide CC**. Explain that you will divide the class into thirds in a moment, and within these Jigsaw groups, students should have a discussion to determine an answer to the question on the slide, circling the claim that they decide best supports the data after comparing results:

- *Does crystal size affect the time at which there is a certain fraction (e.g., ½ or ¼) of the parent material left?*

Divide students into new Jigsaw groups. Ask for a show of hands of students who have values recorded for K-40. Assuming that more than one-fourth of the class responds, ask one-fourth of the class, comprising students whose hands were raised, to stand in one corner of the room, taking their *Analyzing Decay Trends* handout with them. Do this again, but for U-238, asking one-third of the remaining students whose hands were raised to go to a different corner of the room. Do this again, but for U-235, asking half of the remaining students whose hands were raised to go to a different corner of the room. Finally, ask the second half to join any group that they have data for. Give Jigsaw groups the remaining time to discuss the question above in their corners of the room.

12 · ARGUE FROM EVIDENCE

3 min

MATERIALS: *Analyzing Decay Trends*, science notebook

Argue from evidence. Display **slide DD**. Discuss the question as a class:

- *Does crystal size affect the time at which there is a certain fraction (e.g., ½ or ¼) of the parent material left? Which of these two claims shown on the slide did the data support?*
    - *No, regardless of the crystal size, the time is similar.*
    - *Yes, the larger the crystal size, the longer the time.*

Listen for students to say that the crystal size does not matter, because the variation in times is small and the values are similar.

Motivate further analysis of the data. Present **slide EE**. Use the table on the slide as a reminder that last time, we looked at data for rock samples collected at various locations in Afar, showing that these had different amounts of radioactive materials. Then have students turn and talk with the prompt:

- *Our analysis has helped us determine how long it takes radioactive elements to decay. How can our findings help us reconstruct the past or predict the future of Afar?*

Give partners a couple of minutes before inviting them to share out. Listen for the following ideas:

- If we know how much radioactive element is left in a rock sample, we can have an idea of how old it is.
- Knowing how old rocks are can give us an idea of how long this process has been going on.

Suggest we continue analyzing our data to see whether it can help us determine the age of the rocks.

13 · USE MATHEMATICAL THINKING TO ANALYZE RADIOACTIVE DECAY GRAPHS

10 min

MATERIALS: *Analyzing Decay Trends*, *Age of Rocks*, science notebook, calculator, *Rock Sample Site Map*, https://youtu.be/Y-GP_AedXBQ?si=kbwYEQAitgwrxnRN, https://youtu.be/H9CPgtaorzE?si=iFOyrWZSbnGGotu1, chart paper (optional), chart paper markers (optional)

Analyze and interpret data. Display **slide FF**. Have students report out the related values and add these to a chart on the board or on chart paper as reference. The values shown for time in mya should be within about 20% of the following (e.g., 50% of K-40 should remain at 1250 +/- 250 mya).

Parent element	% parent element	Time in mya
K-40	50%	~1250
	25%	~2500
U-235	50%	~700
	25%	~1400
U-238	50%	~4500
	25%	~9000

Direct students to turn and talk for a couple of minutes about the slide's second prompt:

- *What patterns do you notice between the time for 50% and the time for 25%?*

Discuss the question as a class. Listen for the following ideas:

- The time is about twice as long for 25% as it was for 50%.
- This pattern is true for each element, though the times to get to 50% are totally different.

Identify the half-lives. Say, *Scientists have found this pattern as well, and it's an important part of the mathematical model to predict how any element decays over time. Every radioactive isotope takes a certain amount of time to decay to 50% of its initial amount, no matter how much there* *was to start with. Scientists also noticed that the time to get from 100% to 50% is the same as it takes to get from 50% to 25%. They call this time the element's half-life.* Circle the half-life on the class half-life table for each of the elements and label it as the half-life for that element.

Demonstrate this on a graph. Say, *Let's see what half-life means on a graph.* To demonstrate this, either interactively use **slide GG** to repeatedly copy, paste, move, and shrink (by 50%) the dotted box shown on the graph, or show and narrate the related video of this process, https://youtu.be/Y-GP_AedXBQ?si=kbwYEQAitgwrxnRN .

14 · NAVIGATE

1 min

MATERIALS: None

Highlight limitations of our data. Present **slide HH**. Point to the data table and say, *The Afar data show us the amount of radioactive elements in rock crystals, but the data don't tell us whether this corresponds to 50% or 25% of the remaining parent element.*

Have students turn and talk with the slide's prompt:

- *What data do we need in order to determine how much percentage of the parent element is left in each sample?*

Say, *Next time, we'll explore a mathematical model to calculate this percentage.* Collect the *Analyzing Decay Trends* handout as students leave.

End of day 2

15 · USE MATHEMATICAL THINKING TO MAKE SENSE AND USE A MODEL OF RADIOACTIVE DECAY

20 min

MATERIALS: None

Remind students of the limitations of our data. Present **slide HH** again to support this discussion. Say, *Last time, we identified patterns in the radioactive decay of elements, and we thought we could use this information to calculate the age of rocks in Afar.* Ask for ideas in response to the prompt:

- *What data do we need in order to determine how much percentage of the parent element is left in each sample?*

Listen for students to suggest that we need data about the percentages of parent and daughter elements in each sample. If they struggle to answer this question, ask these followup questions:

- *What data did we use last time to calculate the age of a rock sample?*
- *Could similar data help us calculate the age of rocks in Afar?*

Say, *Let's use a mathematical model that includes data about the parent and daughter elements.*

Introduce two equivalent equations. Display **slide II**. Orient students to the variables in the left-hand equation; point out that the brown, purple, and green are provided by the simulation, and the half-life (h) in red is what we just calculated. Remind them that we recorded the ratio or the percentage of remaining parent element compared to how much was there when the rock formed, which is shown in pink in the right-hand equation and is equivalent to the ratio in the left-hand equation.

Ask what else students notice that these equations have in common. They should say there is a ½ in the parentheses and the same variables, age of rock (t) and half-life (h), in the exponent of this base.

Test what the equation predicts for a time of zero. Display **slide JJ**. Have students test what the equation yields for a t=0 for an element whose half-life is 500 mya. Give them a minute to try this on their calculators; they should say it yields 1.0. Remind them that 1.0 also means 100%, and that this should make sense because no time has passed and none of the parent atoms have decayed yet.

Test what the equation predicts for some other time values. Display **slide KK**. Have groups assign each member a row in the table to work on, determining the value for that row by calculating (with or without a calculator) what the value of P would be. This should take less than 2 minutes.

Compare predictions. Display **slide LL**. Check the reasoning that produces these values, emphasizing patterns such as:

- *0.5 is equivalent to 50% and 0.25 is equivalent to 25%, so why would the next row be 12.5%? Because that is half of the previous row.*
- *Each additional 500 mya reduces the previous amount by half again.*

Discuss how the variables can help calculate the age of rocks. Present **slide MM**. Say, *Let's see whether we can use this mathematical model to calculate additional variables.* Point to the components in the model as you use some of the following prompts:

- *Which variables from this model do we want to calculate?*
- *For which variables do we have data to substitute into the equation?*
- *Which variables do we lack evidence for?*

KEY IDEAS	**Purpose of this discussion:** Support students' engagement in mathematical modeling to identify the variables we want to calculate, the variables for which we have evidence, and the variables we lack evidence for.

Listen for these ideas:

- This model requires you to know (1) the amount of parent element that is there now, and (2) the amount of parent element that was in the crystal to start with (not directly measurable).
- We don't have data of the amount of the parent element when the crystal was formed.
- What is in the crystal is the daughter element and the remaining parent element.

Consider how to calculate the amount of parent element. Present **slide NN**. Read the text aloud:

- *Though we cannot directly measure the amount of parent element when it was formed, we can calculate it based on the amount of daughter element found now.*

Point to the components in the mathematical model presented on the slide as you use similar prompts from **slide MM** to support the use of mathematical thinking. Listen for the following ideas:

- The number of atoms of parent element that are there now, plus the number of atoms of daughter element that are there now, should equal the amount of parent element that was there when it was formed.
- We can use this in the original equation to determine the portion of the parent element remaining. With that, we can use the equation to determine the approximate age of that rock.

16 · DETERMINE THE AGES OF ROCKS IN AFAR

10 min

MATERIALS: *Age of Rocks*, *Rock Sample Site Map*

Orient to the related rock sample data. Present **slide OO**. *Say, Let's see how we can use what we figured out to determine the age of some rock samples from the Afar region that we looked at earlier*. Distribute the *Age of Rocks* handout to each student. Elicit 1-2 ideas with the prompts:

- *What information do you notice has been provided for this rock sample data?*
- *What values have we already calculated?*
- *What values do we need to calculate?*

Listen for students to suggest the following ideas:

- The table provides the ratios of parent element to daughter element.
- Column 3 provides the ratio needed for P in the equation at the bottom right of the page, which leaves only two variables in the equation to solve for.
- One variable is time (t) and one is half-life (h).

- We already know the half-life of these elements.
- We would need to calculate the age of rock.

Have students fill in the half-life for K-40 on the top left of the table on their handout and the half-life for U-239 on the top right, based on what the class recorded from the investigations.

Demonstrate how to use a spreadsheet and the equation to find how old a rock sample is. Play https://youtu.be/H9CPgtaorzE?si=iFOyrWZSbnGGotu1 to show how to do this.

Determine rock ages. Display **slide PP**. Assign students to groups of 7. Have them assign each member a different rock sample (A-G) to determine that rock's age, using the reported value for the portion of parent element remaining (Pr) and the related graph the group made to estimate the age of each rock sample. Each student should practice creating a spreadsheet for this and entering the time, half-life, and exponential decay equation. This should take about 5 minutes.

ASSESSMENT OPPORTUNITY

What to look for/listen for in the moment:

- Use the mathematical model of radioactive decay to calculate the age of their assigned group of rock samples. (SEP: 4.1; DCI: PS1.C.2)
    - **A** is 0.12-0.33 mya, **B** is 0.49-4.0 mya, **C** is 1.9-3.2 mya, **D** is 4.5-8.2 mya, **E** is 23-25 mya, **F** is 29-31 mya, **G** is 583-659 mya.

What to do: Encourage students to use a spreadsheet for their calculations, and give them a chance to revise their responses if you notice a calculation error. The ranges listed above may shift about 25% if the simulation results provided data that led students to derive a slightly different half-life.

To ensure that the calculated ages of rocks are closer to the expected values, it is important to adhere to the following criteria:

- **Time measurement unit:** The unit of time being measured is millions of years. Make sure that when students input half-life values into their calculations, they are in millions of years. Using any other unit will produce inaccurate results.
- **Significant figures:** All values of the ratio of K-40 to K-40 now include 5 significant figures. Ask students to pay careful attention to the first 5 significant numbers when performing calculations in their spreadsheet.

Building toward: 8.B.1 Analyze data using a spreadsheet and an exponential decay law to find the age of various rock samples using relationships (half-lives) discovered in prior investigations; interpret the patterns across the ages of these samples and the sites where these are located to reconstruct the geologic history of Afar over the last 700 million years. (SEP: 4.1; CCC: 1.4; DCI: PS1.C.2)

Compare results. Display **slide QQ**. Give group members about 3 minutes to share and record the ages they calculated and add everyone's results to the corresponding data table shown on the slide. As they do this, distribute 3 copies of the *Rock Sample Site Map* (in sheet protectors) to each group.

17 · ANALYZE AND INTERPRET DATA

8 min

MATERIALS: *Age of Rocks*, science notebook, *Rock Sample Site Map*

Analyze and interpret data. Display **slide RR**. Cue students to work with a partner, using the *Rock Sample Site Map* and the rock ages calculated in their *Age of Rocks* handout, to discuss these prompts for 4 minutes:

- *What patterns do you notice in the locations of older versus younger volcanic rocks?*
- *Use evidence to support your ideas.*

Then have them report what they notice about the data in the map and table. Patterns may include:

- The oldest rock is 100s of millions of years old (~600 mya), which is much older than the rest.
- The oldest rock is located along the western and eastern edge of Afar.
- The next oldest rock is around 20-30 million years old, and formed along the west edges of Afar and a little bit on the eastern edge.
- Very little happened after that until about 5-10 million years ago, and then there was a lot of recent rock formation (a few million years and less) in between the two edges of Afar.
- The youngest rock is between older rock, like a sandwich.

ASSESSMENT OPPORTUNITY

What to look for/listen for in the moment:

- Using evidence from the group data recorded on the *Age of Rocks* handout and the map in the *Rock Sample Site Map* to interpret the geologic history of Afar. (SEP: 4.1; CCC: 1.5; DCI: PS1.C.2)

What to do: Ask students to explain why they think there was no volcanic activity between 600 million and 30 million years ago, and what this tells us about what was happening to the land between the two oldest parts of Afar in the last 30 million years.

Building toward: 8.B.2 Analyze data using a spreadsheet and an exponential decay law to find the age of various rock samples using relationships (half-lives) discovered in prior investigations; interpret the patterns across the ages of these samples and the sites where these are located to reconstruct the geologic history of Afar over the last 700 million years. (SEP: 4.1; CCC: 1.5; DCI: PS1.C.2)

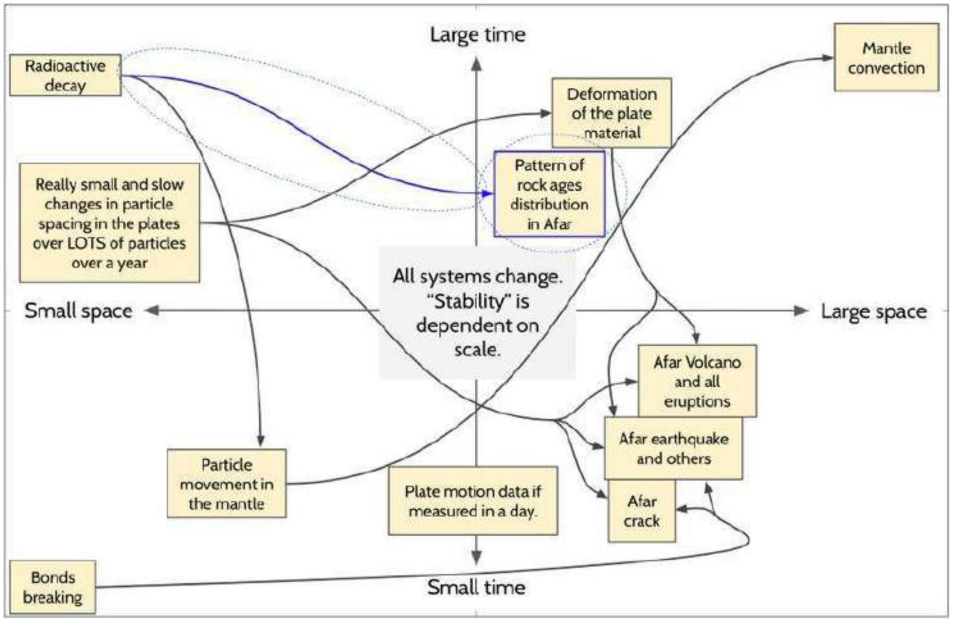
18 · UPDATE THE SCALE CHART POSTER

4 min

MATERIALS: Scale Chart poster

Revise the Scale Chart poster. Present **slide SS**. Emphasize that we should now be able to connect some of the phenomena and patterns explored in this lesson. Use the slide's prompts to elicit ideas:

- *What phenomena or patterns should we include?*
- *What new connections can we draw?*

Students might choose to move radioactive decay into large time (a half-life is very long!) or in small time (instantaneous decays). Either is fine, and if there is disagreement, you can put it in both places, labeling one "radioactive decay (half-life)" and the other "instantaneous radioactive decay". A connection is made between radioactive decay and half-life; a dotted line represents a different type of connection than previously shown.	

19 · NAVIGATE

3 min

MATERIALS: *Rock Sample Site Map*, *Age of Rocks*, science notebook

Consider the age of rocks at the global scale. Display **slide TT**. Give students 1 minute to consider the questions on their own. Then share ideas as a class, as shown in the table below. Encourage students to refer to the *Rock Sample Site Map* and *Age of Rocks* handouts during this discussion.

Suggested prompt	Sample student response
How do you think the age of rocks found in other parts of the world would compare to those found at Afar?	(Accept all responses.)

How could such comparisons help us better understand what is happening at Afar and what might happen there in the future?	Knowing when rock was formed in different parts of the world could help us figure out how long the processes going on Afar might keep going on. If the rock in Afar is much younger than the rest of the region, that would suggest it is a relatively recent phenomenon. We could compare Afar with places that have much older rocks. That could give us clues as to what could happen to Afar in its far future.
So, do you think that looking at more data will help us find patterns?	The more data we have, the more patterns we can find to help us determine where Afar fits into those patterns.

Navigate into the next lesson by saying, *It sounds like more data can help us to find patterns. Let's plan to investigate your idea of looking into how the age of rocks in Afar compare to those from other places to test our predictions in the next class period.*

Additional Lesson 8 Teacher Guidance

SUPPORTING STUDENTS IN MAKING CONNECTIONS IN MATH	**CCSS.MATH.CONTENT.HSA.SSE.A.1.B** Interpret the structure of expressions. Interpret complicated expressions by viewing one or more of their parts as a single entity. As students use mathematical thinking to compare patterns from the results of their investigations to those in an equation of exponential decay, they also use this equation to determine the age of rocks from Afar.

SUPPORTING STUDENTS IN MAKING CONNECTIONS IN ELA	**CCSS.ELA-LITERACY.SL.11-12.1.A** Come to discussions prepared, having read and researched material under study; explicitly draw on that preparation by referring to evidence from texts and other research on the topic or issue to stimulate a thoughtful, well-reasoned exchange of ideas.

Make sure all students have access to the copy of the spreadsheet shared within each group. Give them some time to make sense of their data in their small groups before working in their new Jigsaw groups. This allows them to come prepared to have a richer discussion and participation with their peers.