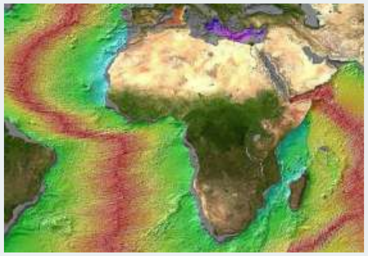
# Lesson 9: How does the rock in Afar compare to the rock around the world, and what does this tell us about the history and future of the region?

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

**This Lesson**

Investigation

2 days



Adapted from: NOAA, Elliot Lim

We look at data on the crustal ages of rocks around the world in both oceans and continents, and notice several patterns, including that the farther the rock is from some plate boundaries in the ocean, the older it is. We use manipulatives to model what might be happening at these boundaries and capture our ideas in an initial consensus model. We notice many gaps in our understanding and decide to look more closely at the rocks. We determine that the density of basalt (oceanic crust) is greater than the density of granite (continental crust), and we wonder about how that affects forces and energy transfer. Finally, we add questions to the Driving Question Board about plate boundaries and types of crust.

**Next Lesson** *We are wondering what is happening at plate boundaries. We will investigate how plates interact at divergent and convergent plate boundaries, and how these interactions result in different surface features.*

**BUILDING TOWARD NGSS**

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

**What students will do**

**9.A** Ask questions that arise from careful observations of patterns across multiple empirical sources to refine our model of how new oceanic crust is formed at plate boundaries. (SEP: 1.1, 1.2; CCC: 1.5; DCI: ESS1.C.1)

**What students will figure out**

- Continental crust is, on average, significantly older and less dense than oceanic crust.
- As you move outward from some plate boundaries in the middle of the ocean that are spreading away from each other, the basalt rocks get older, suggesting that the material originated at the boundary and was pushed outward over large temporal and spatial scales.
- The rock in Afar is young basalt, suggesting that a similar process may be occurring there.

## Lesson 9 • Learning Plan Snapshot

| Part | Duration | | Summary | Slide | Materials |
|---|---|---|---|---|---|
| 1 | 2 min | | **NAVIGATE**<br>Turn and talk about the age of Afar rock. | A | |
| 2 | 10 min | | **LOOK AT CRUSTAL AGE DATA**<br>Examine data on the age of crustal rocks with a partner. | B-D | *Ages of Crustal Rocks* |
| 3 | 20 min | | **DISCUSS INITIAL IDEAS IN A SCIENTISTS CIRCLE**<br>Make a public record of what we noticed and wondered. Take a closer look at the mid-ocean lines, relate them to tectonic plates, and use a manipulative model to reproduce the patterns around these lines. | E-G | chart paper, chart paper markers, copy paper, large book |
| 4 | 10 min | | **BUILD UNDERSTANDING IN A SCIENTISTS CIRCLE**<br>Construct an initial consensus model. Build ideas about matter cycling, forces, and energy transfer. | H-J | Initial Class Consensus Model: New Crust poster, chart paper markers |
| 5 | 3 min | | **NAVIGATE**<br>Consider what to explore next to better understand how the process of new rock forming at plate boundaries will affect Afar. | K | |
| | | | | | *End of day 1* |
| 6 | 2 min | | **NAVIGATE**<br>Turn and talk about what we can learn from rocks. | L | |
| 7 | 20 min | | **PLAN AND CARRY OUT A ROCK DENSITY INVESTIGATION**<br>Make initial observations of granite and basalt rock samples. Plan and carry out an investigation of rock density. | M-O | Rock Sample Density Lab |
| 8 | 10 min | | **DISCUSS FINDINGS AND KEEP TRACK OF OUR QUESTIONS**<br>Share our findings and discuss implications. Ask questions about plate boundaries. Add to Progress Trackers. | P-U | *Progress Tracker* |
| 9 | 5 min | | **REVISIT THE SCALE CHART POSTER**<br>Add the creation of new crust to the Scale Chart poster. | V | Scale Chart poster, 3x5 sticky notes, chart paper markers, permanent marker |

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| 10 | 5 min | | **ADD TO THE DRIVING QUESTION BOARD**<br>Revisit the Driving Question Board to add new questions about plate boundaries and crustal types. | W | 3x3 sticky notes, permanent marker |
| 11 | 3 min | | **NAVIGATE**<br>Take a closer look at plate boundaries. Complete an exit ticket. | X | loose-leaf paper, Driving Question Board |

*End of day 2*

## Lesson 9 • Materials List

| | per student | per group | per class |
|---|---|---|---|
| Rock Sample Density Lab materials | • *Measuring Rock Densities* | • granite rock sample<br>• basalt rock sample<br>• digital scale<br>• graduated cylinder<br>• 500-ml glass beaker<br>• plastic bin<br>• petroleum jelly<br>• water | |
| Lesson materials | • science notebook<br>• *Progress Tracker*<br>• 3x3 sticky notes<br>• permanent marker<br>• loose-leaf paper | • *Ages of Crustal Rocks* | • chart paper<br>• chart paper markers<br>• copy paper<br>• large book<br>• Initial Class Consensus Model: New Crust poster<br>• Scale Chart poster<br>• 3x5 sticky notes<br>• permanent marker<br>• Driving Question Board |

## Materials preparation (45 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.

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

Make copies of the handouts for this lesson:

- *Measuring Rock Densities* - 1 per student
- *Composition of Continental and Oceanic Rocks* - 1 per student (optional extension opportunity)
- *Ages of Crustal Rocks* - in color, 1 per partner pair (put in sheet protectors for reuse across classes)

Prepare chart paper for the poster in this lesson:

- Initial Class Consensus Model: New Crust

**Day 2: *Rock Sample Density Lab***
Prior to the lesson, determine what approach your materials can support for measuring volume of an irregular solid via water displacement. See the *Density Measurements Guidance* reference for options. Watch https://youtu.be/L14LIB9RhNo?si=OKkILWyhXojhWR6P for guidance on how to measure the density of the rocks for this investigation.

- **Group size:** 4-5 students.
- **Setup:** For each group, prepare a granite rock sample, basalt rock sample, digital scale, graduated cylinder, 500-ml glass beaker, plastic bin, petroleum jelly, and water.
- **Safety:** Students should wear indirectly vented chemical splash goggles during the investigation.
- **Disposal:** All materials are reusable.
- **Storage:** Dry the rock samples before using them with another group.

## Lesson 9 • 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):

- **ESS1.C.1:** Continental rocks, which can be older than 4 billion years, are generally much older than the rocks of the ocean floor, which are less than 200 million years old. (HS-ESS1-5)

Students encounter and/or co-construct ideas around several terms during this lesson, and may decide to add the following words to their Personal Glossaries: *plate boundary, continental crust, oceanic crust*. **Do not** ask students to define or keep track of any words until after the class has developed a shared understanding of their meaning.

### Where We Are NOT Going

Students explore divergent plate boundaries in this lesson but do not compare these to other types of boundaries, so there is no need to attach the vocabulary of *divergence* to the phenomenon yet. In Lesson 10, they will investigate other types of boundaries and thus will need to start labeling the different kinds of interactions between plates. They will have the opportunity to add *convergent* and *divergent boundaries* to their Personal Glossaries in Lesson 10.

# LEARNING PLAN for LESSON 9

## 1 · NAVIGATE

2 min

MATERIALS: None

**Review the age of Afar rock to motivate a comparison.** Say, *In the last lesson, we figured out that we can date rock using radioactivity. By this method, the youngest rock in the Afar region is less than a million years old. But we weren't sure what this meant, and were wondering how it compared to rock in other places.*

Present **slide A.** Pose the prompts on the slide as a Turn and Talk:

- *What does it tell us if the rock in the Afar region is the same age as most of the rock everywhere else?*
- *What if the rock in the Afar region is younger than everywhere else?*

You do not need to elicit student ideas right now, simply allow students to share with their partner.

## 2 · LOOK AT CRUSTAL AGE DATA

10 min

MATERIALS: science notebook, *Ages of Crustal Rocks*

**Examine data with a partner.** Instruct students to find a partner to work with. Present **slide B**. Distribute *Ages of Crustal Rocks* to student pairs. Alternatively, you can project **slides C** and **D** and have students come up close to the screen to look more closely. Ask students to analyze this data, keeping track of patterns they notice and questions they have in their science notebooks or on loose-leaf paper that they can add to their notebooks.

## 3 · DISCUSS INITIAL IDEAS IN A SCIENTISTS CIRCLE

20 min

MATERIALS: chart paper, chart paper markers, copy paper, large book

**Record what students noticed and wondered.** Ask students to share out. Document their noticings and wonderings on a piece of chart paper. Examples are shown in the table below.

| Notice | Wonder |
| --- | --- |

✱ **ATTENDING TO EQUITY**

**Universal Design for Learning:** Some students may not be able to see the thin, colored strips of the oceanic crust as they are

| | |
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| • Young rock comes in lines that are in the middle of the ocean, but old rock patterns are less clear.<br>• There is a rainbow pattern that starts red (young stuff) and then kind of fades into older rock, on a continuous gradient from the middle outward.<br>• The rainbow pattern makes a mirror image.<br>• Mostly in the oceans, the oldest crust is less than 200,000,000 years old, but on the continents, there is crust that is billions of years old.<br>• In the Afar region, the lines in the ocean seem to maybe continue into the lines of younger rock on the continent. | • What's going on that makes the ocean crust so different from the continents?<br>• Why is the rock in the Afar region so new?<br>• Why do some oceans, like the Atlantic, have a pattern radiating from the center?<br>• What is happening to create these patterns?<br>• How is the youngest rock on Earth formed? |

**Motivate a closer look at the mid-ocean lines.** Present **slide E**. Say, *We know the rock in Afar is young, and it looks like it's connected to one of these ocean lines of new rock. We should look at these places in the ocean where we see these lines of young rock. We also noticed a gradient pattern.* Have students turn and talk for a minute about the slide's prompt:

- *What might be happening to create these patterns?*

Ask them to share out. Listen for ideas about:

- different plates meeting
- breaks in the plates or crust
- magma seeping up
- volcanic venting
- new rock forming

**Establish an alignment with tectonic plates.** If students brought up the idea of tectonic plates, use this to motivate looking at a plate map by saying, *You mentioned the lines between plates. I have a map of tectonic plates that we can compare to our map of rock ages.* Alternatively, you can say, *These lines remind me of the maps from the start of this unit, which showed tectonic plate lines.*

Present **slide F**. Look at the map of tectonic plates, and pose the question on the slide:

- *What do you notice about the relationship between these lines in the ocean and the tectonic plates?*

Listen for students to point out that the boundaries (the lines between plates) match up to the lines of the youngest rock we see in the ocean. Say, *We think these lines of young ocean rock are aligned with the boundaries between the plates. So, can we call these lines plate boundaries?* If they do not agree, ask them to come up with something else to call the lines for now.

added to the paper. You can create a larger *representation* by using two desks pushed together instead of a book, and large chart paper instead of copy paper. Have students hold onto the paper with both hands and slowly pull outward. Pause every 8"-12" and create bold, contrasting stripes in a colorblind-friendly palette. You can also pre-make 8"-12" strips of different colors of chart paper to quickly tape to the chart paper as it emerges from between the desks, instead of coloring directly on the paper.

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| **ADDITIONAL GUIDANCE** | Research suggests that many students develop persistent, contextualized mental models for tectonic plates that are not aligned with current scientific understanding. They often believe that the plates are located somewhere underground, rather than being inclusive of Earth's surface. Additionally, they may visualize plates as moving chunks with large spaces in between, like rafts or subterranean bumper cars. Language that describes plates as "moving toward each other" or "moving away from each other" reinforces this inaccurate model.<br><br>A more accurate mental model is that of a cracked eggshell. The plates are essentially continuous, like an eggshell before it breaks, but there are zones (plate boundaries) where new crust is being created or destroyed. These constructive and destructive processes define divergent and convergent boundaries, respectively. We do not define *divergence* or *convergence* in this lesson, but it is important to discuss plates and boundaries in a way that helps students build accurate mental models. For example, you can describe rocks in the ocean floor as "spreading in opposite directions" rather than "moving away from each other."<br><br>Gobert, J. D. (2005). *The effects of different learning tasks on model-building in plate tectonics: diagramming versus explaining*. Journal of Geoscience Education, 53(4), 444–455. |

**Reproduce the patterns around the mid-ocean lines.** Present **slide G**. Say, *We think these red lines might represent places where magma is moving upward to form new rock. We also noticed this interesting rainbow gradient pattern on each side of the red lines. What does the gradient show us?* Guide students to reiterate that on each side, the rocks get older at increasing distance from the red line of new rock in the middle of the ocean floor.

Say, *Let's use a model to figure out what's causing that pattern in the age of the ocean crust.* Co-construct a model with the class, following the instructions below, and use it to determine the movement of tectonic plates that has created the age gradient in rocks on the ocean floor. ✱

Hold a large textbook oriented so the spine points toward the floor. Point out that this forms a wedge shape similar to the cross sections of Earth's interior that we saw in the mantle tomography. Say, We can use this book to represent a slice of Earth's mantle beneath the surface. Place a sticky note or a piece of scrap paper with tape as a "mantle" label on the book.


Fold a piece of copy paper (legal-size or letter-size) in half, with the fold bisecting the long side. Insert the folded paper into the book so it is sandwiched between pages in the middle, with the edge sticking out 2-3 cm beyond the book pages.

Say, Let's use this paper to represent matter flowing upward. I heard you say this matter is magma that comes through a break in the plates to form new rock. Let's use a marker to color the paper where it comes out, to show it is crystalizing into new rock. What color should we use? Use the color chosen by the majority. Students will likely suggest red, but any color is fine at this point.

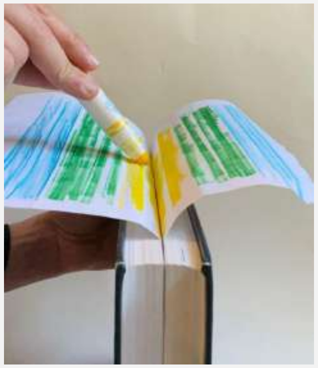
Invite a student to add color in the space where the folded copy paper is emerging from the book. This works best if the chart paper marker tip is inserted vertically into the fold, so it touches both sides of the folded paper simultaneously.

Say, We said this matter was moving upward. Let's add that movement to our model. Ask one or two students to gently pull the copy paper out of the book while you hold the book closed and the student with the marker continues to color back and forth along the crack where the paper is emerging.

After a moment, stop to display what the paper looks like so far. You can take it out of the book and unfold it, or leave it in. Ask students what they notice. Highlight responses that get at the symmetrical nature of the marker pattern on the paper. Ask why the marker ink ended up on both sides of the paper. Discuss how the marker colored both sides simultaneously because they initially came out of the book in the same place, before separating.

Point to the image on slide G and say, Let's look back at this pattern. What other colors do we need to represent the range of ages we see in oceanic crust rocks? Students should note rocks coded in yellow, green, and blue. Other colors in the rainbow are also acceptable. Put a different volunteer in charge of each marker color.

Reset the model with a new piece of copy paper. Ask how we can use the markers so our final product ends up looking like this section of the map, with a red line in the middle and the rainbow gradient progressing outward toward both edges. Allow multiple attempts if necessary, using a new piece of copy paper each time.



**ADDITIONAL GUIDANCE**

Students may initially struggle to get the order of colors to match the map. If so, look at the paper together, and ask why the colors are in the “wrong” order.

To accurately re-create the pattern in the ocean crust, red should be the last marker used as the paper is pulled all the way out of the book. Students should start with a color near the end of the rainbow (e.g., blue) and proceed to color the paper in backward-rainbow order as it is pulled out.

It is easiest for the class to see what is happening if the students pulling on the paper spread the edge of the sheet out to the side, rather than straight upward. This is also a more accurate representation of what happens to the matter on Earth’s surface; it spreads out to the sides, rather than continuing to build upward.

This model also presents an opportunity to reinforce the idea that plates are adjacent at a boundary, and there is not an increasing space between them. Note that the distance between the sides of the copy paper at the point where it emerges from the book is not changing.

**Label the finished model to correspond to Earth components.** Remove the paper from the book and open it fully in a similar orientation to the visible section of the ocean floor age map. Say, *Scientists make models to help figure things out. Let's annotate our model to show what it tells us about Earth.* Use sticky notes or write directly on the paper with a black marker.


| Suggested prompts | Sample student responses | What to label |
|---|---|---|
| *Which part of the paper got colored most recently?* | The middle.<br><br>The red part. | *"New rock" in the red section at the center of the paper.* |
| *What would this represent?* | It represents the youngest, newest rock. | |
| *Which part of the paper got colored first?* | The outside edges.<br><br>The (first color). | *"Old rock" on both edges of the paper. Make sure the label is written on the same color on both sides.* |
| *What would this represent?* | It represents the older rock that was formed earlier. | |
| *How did the paper have to move to create this pattern?* | Outward.<br><br>In opposite directions.<br><br>Upward. | *Draw two arrows going in opposite directions. Both arrows should start in the central red section. One arrowhead should point left and the other should point right. Label the arrows "movement".* |
| *What does this tell us is happening to the rocks on the ocean floor? Think about processes as well as movement.* | New rock is forming in the crack.<br><br>Old rock is being carried/pushed away to each side. | *Add any labels or descriptions that are useful.* |

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|---|---|---|
| | The rocks that used to be in the middle are getting split up. | |

## 4 · BUILD UNDERSTANDING IN A SCIENTISTS CIRCLE

10 min

MATERIALS: Initial Class Consensus Model: New Crust poster, chart paper markers

**Start an initial consensus model.** Present **slide H**. Bring the class's attention to the Initial Class Consensus Model: New Crust poster. Ask what scale we should model at. Listen for students to suggest a chunk of oceanic plate, or even the whole Atlantic Ocean, which should also work. Go with the class's suggestion (within reason). Set up the model as a cross section with the surface and interior visible.

**Build ideas about matter cycling.** Present **slide I**. Discuss the prompts as shown in the table below.

| Suggested prompts | Sample student responses | What to draw |
|---|---|---|
| *What did the model tell us about what was happening to the matter in the system?* | The matter was coming out of Earth. | *Ask students how to represent this, and sketch matter emerging from Earth's interior.* |
| *Where was the matter coming from, exactly?* | The mantle.<br><br>The crust. (You can remind students who say "the crust" that the radioactive elements in the crust are the same as those in the mantle material, so it could be the mantle.) | *Label beneath Earth's surface. Use question marks to indicate disagreement or uncertainty.* |
| *What evidence do we have for this from previous lessons?* | (Allow students to cite any relevant data or evidence from previous lessons.) | |

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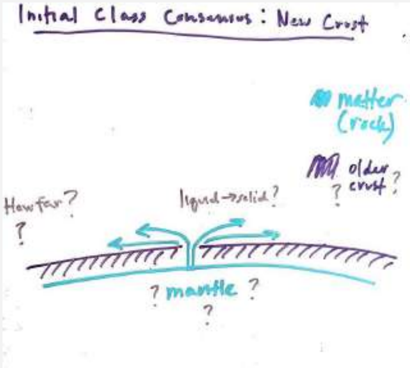
| *What state was the matter in?* | Liquid.<br><br>Solid. | *If students aren't sure, write "liquid? solid?" to indicate uncertainty.* |
| *What evidence do we have for this from previous lessons?* | (Allow students to cite any relevant data or evidence from previous lessons.) | |
| *What would we see if we could "rewind" this model backward? Would the whole crust get sucked back into this line?* | Probably not, because there are a lot of cracks.<br><br>The crust would get sucked back in, but if something didn't get pushed out at some point, Earth would get bigger.<br><br>No, because if we ran time forward and all the crust came out, then Earth's interior would be empty eventually. | *Indicate uncertainty with short phrases and question marks.* |

Wherever there was controversy or confusion on the model, add question marks and phrases indicating *why*. You might also have a question mark to indicate that we are not sure where the matter is coming from, or whether continental crust would have emerged in the same way if we could rewind time back far enough.




Say, *It sounds like we have some ideas, but also a lot of questions. We think the lines may be aligned with tectonic plate boundaries. New crust is forming at the boundary between these plates. So, that could be a place where material is coming up from the mantle. This is maybe a place where there's a break in the crust, or in the plate (crust plus magma), or both.*

**Build ideas about forces and energy transfer.** Present **slide J**. Pose the question for discussion, as shown below.

| Suggested prompt | Sample student response |
|---|---|

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|---|---|
| *What are the unbalanced forces in the system that could be responsible for the motion of the matter?* | Mantle convection. (We got this from Lessons 6 and 7.)<br><br>Buoyant force.<br><br>Gravity. |

Add the forces that students suggest to the model, again indicating controversy or uncertainty with question marks and phrases.

| Suggested prompt | Sample student response |
|---|---|
| *These pushing forces must transfer energy somewhere. Where is the energy going?* | Maybe it goes into the motion of the plates? |

Again, add question marks to the model to indicate that we aren't sure how the energy transfers.

## 5 · NAVIGATE

3 min

MATERIALS: science notebook

**Think about where to go next.** Present **slide K**. Pose the questions on the slide as a Stop and Jot:

- *How might the young rock we see in the oceans, and in the Afar region, be different from older continental rock?*
- *How could that help us make progress on our questions about the Afar region?*

## End of day 1

## 6 · NAVIGATE

2 min

MATERIALS: None

**Turn and talk about what we can learn from rocks.** Say, *We had a lot of ideas last time about how the differences in continental and oceanic rock might affect the dynamics of the Afar region.* Encourage students to look back at their Stop and Jot to refresh their memories.

Present **slide L**. Have students turn and talk about the prompt on the slide:

- *What can we learn from samples of oceanic and continental crust?*
- *What could this tell us about the Afar region?*

If needed, remind the class that both types of rock have been found in and around the Afar region. Elicit student ideas after a minute.

## 7 · PLAN AND CARRY OUT A ROCK DENSITY INVESTIGATION

20 min

MATERIALS: Rock Sample Density Lab

**Make initial observations of rock samples.** Present **slide M**. Say, *Let's look at these two types of crust (actual rock samples).* Explain that granite is generally found on continents and in continental crust. The younger basalt is generally found in oceanic crust. The new rock in Afar is basalt, like the new rock forming in the ocean, but there is a lot of granite in the surrounding regions. Because of this, these sample rocks are representative of the types of rocks found in the crust in Afar.

Organize the class into groups of 4-5. Direct each group to pass their samples around, holding the rocks in their hands. Point out which one is granite (continental) and basalt (oceanic). Have students share their observations. If they mention color, ask what could give rocks different colors. Listen for them to recall that crystals in rock like this are made of different elements. Highlight any inferences that the different colors must mean the rocks have different composition, but it is not necessary to push students to reach this conclusion if they don't bring it up.

Remind the class that we are interested in the forces at play in Afar. Ask the slide's second question:

- *What could we test or observe that could help us understand how each might interact with other parts of the crust or rigid mantle?*

Listen for students to suggest density. Say, *We could measure the density of these rocks.*

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| **ADDITIONAL GUIDANCE** | Students might also suggest rigidity, temperature, or composition. If they suggest temperature, this would be easy to measure in the classroom. Tell students rigidity and composition require equipment that we don't have, but encourage them to look it up later and report back.<br><br>Highlight density as something that affects both convection and seismic velocities, so it is definitely worth investigating. |

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| | Watch https://youtu.be/L14LIB9RhNo?si=OKkILWyhXojhWR6P for additional guidance on how to measure the density of the rocks for this investigation. |

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| **ALTERNATE ACTIVITY** | **Extension opportunity:** The standards do not require students to investigate the composition of various types of rock and how that affects their density. For those who are eager to learn more, consider offering the optional extension reading, *Composition of Continental and Oceanic Rocks*. You can also have them research the composition of other types of rocks in Earth's crust, and come to class prepared to share this information with their peers. |

**Plan an investigation of rock density.** Present **slide N**. Point out that the rock in the photo isn't easily measured by a ruler or other device meant to measure straight or flat sides.

Say, *How can we measure the density of these rocks? Remember that density is mass per volume. So, to calculate density, we need to determine the mass and volume of these rocks. We can get the mass with a scale. But how do we get the volume of an irregular shape?*

Listen for students to suggest that we can put the rock in water and measure the volume of water displaced. But if they don't come up with this idea quickly, don't play guess-what's-in-my-head. Say, *One way to get the volume of an irregular object is to measure the volume of water that it displaces.*

Share the available tools for measuring volume this way (see *Density Measurements Guidance* for guidance). Ask students to describe how we could use the tools to accurately measure the volume of water displaced by a rock. As a class, develop a plan for using these tools to calculate the water displacement.

**Conduct the investigation.** Present **slide O**. Distribute the *Measuring Rock Densities* handout to each student. Distribute lab materials to each group, or have students share and retrieve materials as necessary.

Instruct groups to carry out the investigation, measuring the mass of each rock sample with the digital scale. Remind them to record mass measurements to at least tenths of grams, and volume to the nearest milliliter. It may be helpful to have them recall that 1 mL of volume is the same as 1 cubic centimeter; therefore, each displaced milliliter of water is equivalent to a measurement of 1 $cm^3$ of solid rock. As students work, circulate to ensure that they are recording the *displaced* water volume.

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| **ADDITIONAL GUIDANCE** | Students use the density formula, density = mass/volume, for each rock sample. If their measurements and calculations are accurate, they should find a density for granite in the range of 2.6-2.7 g/cm$^3$ and a density for basalt in the range of 2.9-3.0 g/cm$^3$. The more important conclusion they should reach is that granite is less dense than basalt, and thus, oceanic crust is denser than continental crust. |

## 8 · DISCUSS FINDINGS AND KEEP TRACK OF OUR QUESTIONS

10 min

MATERIALS: science notebook, *Progress Tracker*

**Share findings and discuss implications.** Gather the class in a Scientists Circle. Present **slide P**. Use the prompts for a quick debrief:

- *Which rock was more dense?*
- *How did you figure that out?*

Listen for students to agree that the basalt was more dense, because it had a higher g/cm$^3$ according to their measurements.

**Ask questions about plate boundaries.** Present **slide Q**. Pose the two questions:

- *Why would dense, new rock be forming where these two plates are in contact?*
- *Could this be happening at every plate boundary (where two plates are in contact)?*

Students may respond that new rock must be coming from the mantle. They may also identify that in some locations where new crust is forming, the older crust has to go somewhere, so it might be getting moved toward other boundaries. If these ideas do not come up, use further prompts on **slides R-T** to elicit them, specifically the creation of new rock from the mantle.

Present **slide R**. Ask students to turn and talk for about 2 minutes about the prompt:

- *How might the different densities of these rocks affect what is happening at those boundaries?*

Have students share out. Accept all ideas, and ask questions to help students clarify their thinking, such as:

- *I heard you say _____; is that what you meant?*
- *Could someone rephrase that idea?*
- *What other processes work in the way you just described?*

Present **slide S**. Ask, *What do we know about the crust in Afar?* Students should recall that the new crust in the Afar region is basalt. They may make the connection that this is the same type of rock as in the crust in the ocean, not the crust usually found on continents. If they do not, consider bringing up **slide B** to remind them that the rock in the Afar region is relatively new, then direct them back to our investigation and the rock types to consider what type of rock is present in the Afar region.

Ask the slide's second question:

- *What might that mean about what's happening in the Afar region, based on our model?*

Students should have ideas about how processes similar to what is happening in the lines along the ocean floor might be happening in Afar. If they are stuck, point them to our new consensus model.

Present **slide T**. Have students stop and jot about the question:

- *If the crust in the Afar region is basalt, does that mean a new ocean is forming there?*

After a few moments, ask students to share their ideas. They may say that the Afar region's basalt suggests that new oceanic plate material is emerging there. They may also say that a new ocean could be forming in this location. Propose that we revisit the Scale Chart poster to add this new process, but first, students should take some time to update their Progress Trackers.

**Add to Progress Trackers.** Project **slide U**. Give students a couple of minutes to add to their trackers. Make sure they can see the poster of the class consensus model developed earlier.

Students may add ideas related to creation at the ridges, over geologic timescales, of new crust containing basalt, which is more dense than the granite commonly found on continental crust. They may cite change over time as a crosscutting concept that helped them, because they considered small changes over large time periods in creation of new crust at plate boundaries that are spreading apart, as with the Afar region or the Mid-Atlantic Ridge. They may also cite thinking across different scales, because they zoomed out to the world view after analyzing the more local view of a particular boundary where two plates were spreading apart.

At this point, students may also choose to add the following words to their Personal Glossaries: *plate boundary, continental crust,* and *oceanic crust*.

## 9 · REVISIT THE SCALE CHART POSTER

5 min

MATERIALS: Scale Chart poster, 3x5 sticky notes, chart paper markers, permanent marker

**Add the new phenomenon to the Scale Chart poster.** While students are still in the Scientists Circle, shift their attention to the Scale Chart poster. Present **slide V**. Point out that we have just paused to reflect on our learning, and in that process, reminded ourselves that we had explored a new phenomenon occurring over both time and space. Say, *We're trying to explain what happened in Afar at multiple scales, and our Scale Chart is helping us make those connections. What new phenomenon did we explore in this lesson that we can add to the chart?*

Students should explain that we have learned about the creation of new crust at ridges. They may describe this as seafloor spreading or use other terms that make sense to them at the moment. In the example chart below, this sticky note is labeled "new plate material creation".

Ask where this phenomenon would be located on the Scale Chart poster. Students should determine that this change happens very slowly and over a large spatial scale. They should suggest placing it in the upper right of the chart, above mantle convection (the positive, positive quadrant).

However, if students argue that this change can happen slowly but is observable at smaller timescales in millimeter distances, negotiate a new place for the sticky note. Place the sticky where it makes sense from the class's temporal and spatial perspective.

**Connect new crust creation to other processes.** Step back and ask students whether this phenomenon is caused by or connected to any other processes on the chart. They should identify that it is driven by mantle convection, which is driven by the smaller-scale process of parcels moving because of particle movement. Draw arrows between these processes to show how they are related, if these arrows do not exist yet. See the example image here, with new items outlined in blue.

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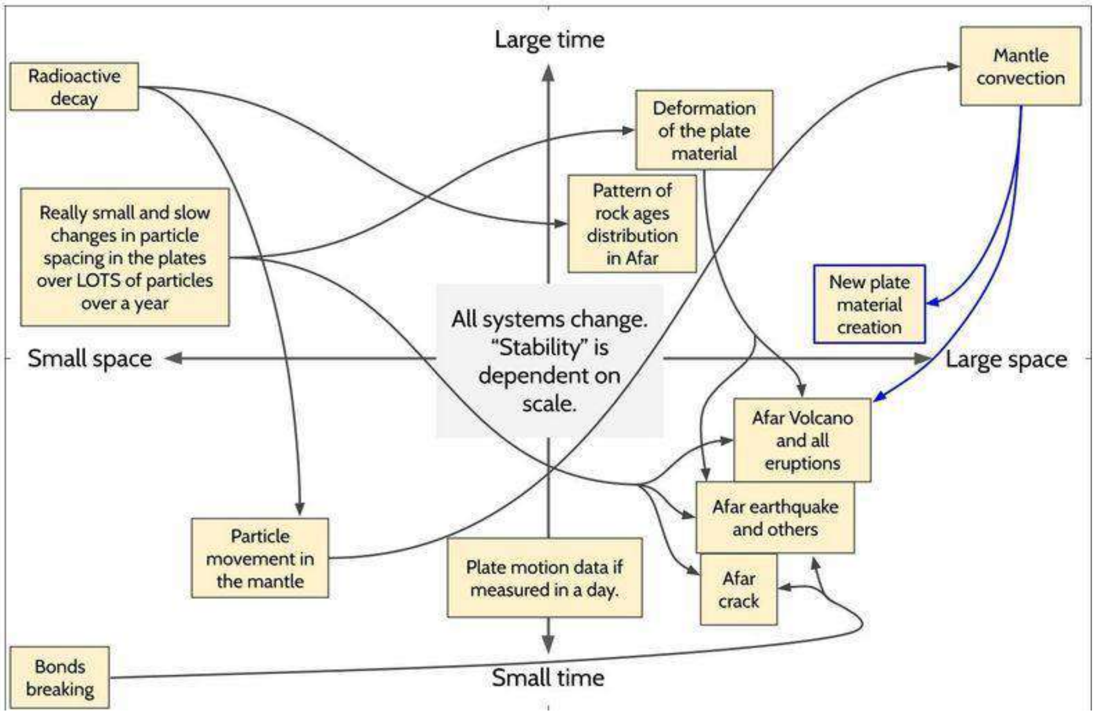
| **New plate material creation** was added under mantle convection on the large time, large space quadrant. Because students may be thinking about the scale of this change over a single year or centuries, the placement of this sticky note can be wherever students argue is best on the time axis.<br><br>**Connections were made** between **mantle convection** and **new plate material** as well as the **Afar volcano**. |  |

## 10 · ADD TO THE DRIVING QUESTION BOARD

5 min

MATERIALS: 3x3 sticky notes, permanent marker

**Add new questions to the DQB.** Present **slide W**. Say, *We've thought about how new crust is created at places where plates are spreading apart, but what does that make you wonder about now? What new questions do you have about plate boundaries, crust, and forces in the Afar region?*

Distribute sticky notes and markers to students and direct them to add their new questions about plate boundaries and continental versus oceanic crust to the DQB.

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| **ASSESSMENT OPPORTUNITY** | **What to look for/listen for:**<br>● Assess whether students are asking questions intended to refine our model by looking for alignment with the question marks on the Initial Class Consensus Model: New Crust poster. (SEP: 1.1, 1.2)<br>● Assess student understanding of the DCI by looking for questions about plate boundaries, oceanic versus continental crust, and the ages of rocks in the Afar region and elsewhere that require empirical evidence to answer. (CCC: 1.5; DCI: ESS1.C.1)<br><br>**What to do:** Encourage students to draw on their observations of patterns across multiple empirical sources by pressing them to link their questions to a source of data from the lesson; for example, ask, *What empirical evidence from today's lesson led you to wonder that?* (SEP: 1.1; CCC: 1.5)<br><br>**Building toward: 9.A** Ask questions to refine our model of how new oceanic crust is formed at plate boundaries that arise from careful observations of patterns across multiple empirical sources. (SEP: 1.1, 1.2; CCC: 1.5; DCI: ESS1.C.1) |

## 11 · NAVIGATE

3 min

MATERIALS: loose-leaf paper, Driving Question Board

**Motivate a closer look at plate boundaries.** Present **slide X**. Elevate any new DQB questions about the two types of crust we have seen in the Afar region and the impacts of the creation of new crust.

Remind students, *We learned about a type of plate boundary that's in the middle of oceans, where new oceanic crust is forming and two plates of oceanic crust are spreading out in opposite directions. We also figured out that the density of the crust on the continents is less than the density of the crust in the ocean. So, what happens in the places where those two types of crust meet, like at these boundaries?* Point to a convergent boundary on the map where subduction is occurring, such as the western edge of South America, and elicit student responses. Accept all ideas, and point to places on the DQB where we still have questions and controversy.

Say, *We still have a lot of questions about what happens at the places where plates meet, and in particular, about what happens when these two types of crust meet up. Next time, let's look at these boundaries between plates and find out more about what is happening to the material there.*

**Administer an exit ticket.** Have students respond on loose-leaf paper to the slide's prompt as an exit ticket:

- *What do you think might be happening at the places where these two types of crust meet up? Why do you think that?*

Collect the exit ticket as students exit the classroom, and read through these as a formative assessment before the next lesson.

# Additional Lesson 9 Teacher Guidance

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| **SUPPORTING STUDENTS IN MAKING CONNECTIONS IN ELA** | CCSS.ELA-LITERACY.RST.9-10.1 Cite specific textual evidence to support analysis of science and technical texts, attending to the precise details of explanations or descriptions.<br><br>Students who would like to learn more about crustal composition have the opportunity to read about the chemical composition of granite and basalt. If students engage in this opportunity, they are also given the opportunity to research the topic and share what they have learned with the class. |