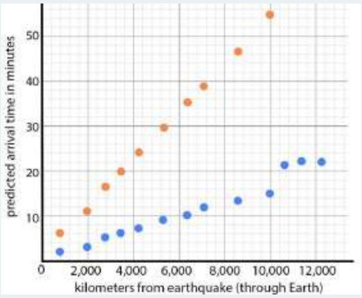
Lesson 5: How do we investigate the connection between matter in Earth's interior and surface features above?

Previous Lesson *We evaluated two models for understanding and explaining earthquakes, elastic deformation, and breaking of solid matter. We used a computer simulation to investigate how external forces on a solid affect matter changes and energy transfers at the particle level. We revised our M-E-F and Scale Chart posters to account for the roles of fields on large-scale phenomena, and used these ideas to explain volcanic eruptions in an Electronic Exit Ticket.*

This Lesson

Investigation, Putting Pieces Together

3 days



We wonder what could be happening in Earth's interior to cause unbalanced forces. We learn that energy transfers differently through different types of matter, and that scientists use this to collect indirect evidence about Earth's interior. We analyze seismic wave data and notice wave speed anomalies that suggest Earth's interior is not entirely solid. We analyze a model of Earth's layers and use a simulation to test our predictions about seismic energy transfers at plate boundaries. We zoom in to a local scale to investigate the connection between mantle matter properties and surface features at locations across the globe. We revise our model of Earth's layers to include a heterogeneous mantle and add to our Progress Trackers.

Next Lesson *We will develop a predictive model of the mantle movement. We will analyze a video of a tank containing a mixture of liquid and plastic pellets simulating the matter in the mantle to figure out what happens to the matter when heat is added. We will observe convection in the tank and develop a model to represent it.*

BUILDING TOWARD NGSS	What students will do
HS-PS1-8, HS-ESS1-5, HS-ESS2-1, HS-ESS2-3	**5.A** Analyze mathematical representations of indirect data to reveal anomalies in the pattern of arrival times for seismic waves to support a claim about the relationship between wave speed and the medium through which the wave is passing in Earth's interior. (SEP: 4.1, 5.2; CCC: 1.4, 3.2; DCI: PS4.A.1, ESS2.A.2)
	5.B Analyze seismic velocity anomaly data at multiple scales and evaluate the impact of this data on our working model of Earth's interior to provide evidence for a causal link between local matter variation in Earth's mantle and surface features, such as mountains, volcanoes, and cracks. (SEP: 4.1, 4.5; CCC: 1.1, 1.2; DCI: ESS2.A.2, PS4.A.4)

What students will figure out

- The speed of a wave through matter depends on the matter through which it is passing.
- Seismic velocity data provide evidence that Earth is composed of layers.
- Earth has a solid inner core, a liquid outer core, a mantle, and a crust.
- Differences in matter in the mantle cause unbalanced forces in different locations, which is why some regions have different kinds of surface features than others.

Lesson 5 • Learning Plan Snapshot

Part	Duration		Summary	Slide	Materials
1	5 min		**NAVIGATE** Review explanations from Lesson 4 to consider what causes most earthquakes.	A-C	Initial Class Consensus Model (from Lesson 1)
2	15 min		**READ ABOUT INVESTIGATING EARTH'S INTERIOR** Read *How Do Scientists Explore Earth's Interior?* in partners using a close reading protocol. Answer the questions and be ready to discuss as a class.	D	*How Do Scientists Explore Earth's Interior?*
3	5 min		**BUILD UNDERSTANDING ABOUT SEISMOLOGY** Conduct a Building Understandings Discussion structured by the questions in the reading. Establish that energy travels in seismic waves and that the waves' speed is affected by the medium they are passing through.	E-F	*How Do Scientists Explore Earth's Interior?*, Scale Chart poster
4	5 min		**BUILD UNDERSTANDING ABOUT P-WAVES AND S-WAVES** Continue the Building Understandings Discussion. Establish how seismic waves move through matter, and notice patterns in seismic data.	G-I	*How Do Scientists Explore Earth's Interior?*, M-E-F poster
5	5 min		**TEST OUR IDEAS AND MAKE INFERENCES** Analyze and interpret graphs of seismic arrival times to reveal anomalies that suggest a heterogeneous Earth.	J-L	*How Do Scientists Explore Earth's Interior?*
6	10 min		**NAVIGATE** Discuss a model of Earth's layers in partners. Complete an exit ticket about the layers.	M-N	*How Do Scientists Explore Earth's Interior?*, *Earth's Interior Model*, loose-leaf paper
					End of day 1
7	5 min		**NAVIGATE** Review what we figured out about P-waves and S-waves in Earth's liquid outer core. Reflect on a crosscutting idea.	O	
8	10 min		**TEST OUR IDEAS WITH A SIMULATION**	P-Q	device with access to http://ds.iris.edu/seismon/swaves/index.php?lat=34.2&lon=-

		Observe seismic waves in a simulation passing through Earth, with S-waves dissipating and P-waves slowing down. Make sense of the energy transfer, in particular that energy from S-waves must be absorbed and reflected at the mantle-core boundary, in a Building Understandings Discussion.		118.5&depth=17&mag=6.7&title=Northridge%201994&date=1994-01-17T12:30Z&w_terrain=false&wiki=https%3A%2F%2Fearthquake.usgs.gov%2Fearthquakes%2Fstates%2Fevents%2F1994_01_17.php
9	15 min	**READ ABOUT EARTH'S MANTLE** Read about Earth's mantle and answer Making Sense questions. Consider a closer look at the mantle.	R-S	*Earth's Interior Model*, *The Mantle and the Moho*
10	10 min	**USE A DIGITAL TOOL TO COMPARE THE MANTLE BENEATH AFAR TO OUR REGION** Use the SubMachine web tool to generate models of mantle cross sections beneath the Afar region and our region. Record observations of seismic wave anomalies on a local scale.	T-U	*Investigating Cross Sections of the Mantle*, colored pencils, device with access to https://www.earth.ox.ac.uk/~smachine/cgi/index.php?page=cross_section
11	5 min	**UPDATE THE PERSONAL GLOSSARY** Add new words to Personal Glossaries.	V	*How Do Scientists Explore Earth's Interior?*, *The Mantle and the Moho*
				End of day 2
12	8 min	**NAVIGATE AND RETURN TO THE DRIVING QUESTION BOARD** Consider which questions on the DQB might be addressed by investigating properties of the mantle on a local scale.	W	
13	13 min	**INVESTIGATE ADDITIONAL MANTLE CROSS SECTIONS** Use SubMachine to investigate cross sections of Earth's mantle in pairs. Investigate three locations and record any observed patterns on the handout.	X	*Investigating Cross Sections of the Mantle*, device with access to https://www.earth.ox.ac.uk/~smachine/cgi/index.php?page=cross_section, *Longitude and Latitude Coordinates for Mantle Cross Sections*, colored pencils
14	13 min	**BUILD UNDERSTANDING ABOUT THE MANTLE** Identify patterns in the types of anomalies beneath various categories of surface features in a Building Understandings Discussion. Revise our model of Earth's mantle to include local-scale heterogeneities.	Y-AA	*Investigating Cross Sections of the Mantle*, *Earth's Interior Model*

15	11 min		**NAVIGATE AND UPDATE THE DRIVING QUESTION BOARD AND PROGRESS TRACKER** Revisit the Scale Chart poster, return to the DQB, and add to the Progress Tracker. Consider different temperatures in the mantle as an exit ticket.	BB-DD	*Progress Tracker*, sheet of loose-leaf paper, Scale Chart poster, Driving Question Board, chart paper markers

End of day 3

Lesson 5 • Materials List

	per student	per group	per class
Lesson materials	• *How Do Scientists Explore Earth's Interior?* • science notebook • *Earth's Interior Model* • loose-leaf paper • *The Mantle and the Moho* • *Investigating Cross Sections of the Mantle* • colored pencils • *Progress Tracker* • sheet of loose-leaf paper	• device with access to https://www.earth.ox.ac.uk/~smachine/cgi/index.php?page=cross_section • *Longitude and Latitude Coordinates for Mantle Cross Sections* • colored pencils	• Initial Class Consensus Model (from Lesson 1) • Scale Chart poster • M-E-F poster • device with access to http://ds.iris.edu/seismon/swaves/index.php?lat=34.2&lon=-118.5&depth=17&mag=6.7&title=Northridge%201994&date=1994-01-17T12:30Z&w_terrain=false&wiki=https%3A%2F%2Fearthquake.usgs.gov%2Fearthquakes%2Fstates%2Fevents%2F1994_01_17.php • device with access to https://www.earth.ox.ac.uk/~smachine/cgi/index.php?page=cross_section • Driving Question Board • chart paper markers

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:

- *How Do Scientists Explore Earth's Interior?* - 1 per student

- *Earth's Interior Model* - 1 per student
- *The Mantle and the Moho* - 1 per student
- *Investigating Cross Sections of the Mantle* - 1 per student
- *Longitude and Latitude Coordinates for Mantle Cross Sections* - 1 per student pair

Before using SubMachine with students, make sure you know how to generate cross sections. View https://youtu.be/mcJJ6fyBwCk?si=AlTxOY6cfiK-RUh4 for further guidance.

For the investigation using SubMachine on day 2, be prepared with the coordinates of your location.
Follow these steps to get the coordinates of a location:

1. Open Google Maps: https://www.google.com/maps
2. Enter the search term of the place or area you are exploring and press "Search".
3. Right-click the name of the place or area on the map, which opens a pop-up window. At the top of the pop-up window are two numbers that correspond to the latitude and longitude of that location.

Introduce the coordinates in SubMachine:

1. Open the SubMachine tool website https://www.earth.ox.ac.uk/~smachine/cgi/index.php?page=cross_section in a different tab.
2. Enter the first value obtained in Google Maps in the Latitude 1 and Latitude 2 fields.
3. For longitude, subtract 10 from the second value obtained in Google Maps and enter that in Longitude 1. Add 10 to the second value obtained in Google Maps and enter that in Longitude 2.

Lesson 5 • 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 ideas (DCIs):

- **PS4.A.1: Wave Properties.** ~~The wavelength and frequency of a wave are related to one another by~~ the speed of travel of the wave~~, which~~ depends on ~~the type of wave and~~ the medium through which it is passing. (HS-PS4-1)
- **PS4.A.4: Wave Properties.** Geologists use seismic waves and their reflection at interfaces between layers to probe structures deep in the planet. (secondary to HS-ESS2-3)
- **ESS2.A.2: Earth Materials and Systems.** Evidence from deep probes and seismic waves~~, reconstructions of historical changes in Earth's surface and its magnetic field,~~ and an understanding of physical and chemical processes lead to a model of Earth with a hot but solid inner core, a liquid outer core, a solid mantle and crust. (HS-ESS2-3)

For the first Wave Properties DCI, the ideas struck out about the type of wave will be developed in *OpenSciEd Unit P.5: How do we use radiation in our lives and is it safe for humans? (Microwave Unit)*. For the Earth Materials and Systems DCI, the ideas struck out about changes to Earth's surface will be covered later in the unit as we look for clues about what happened at Afar in the past and what will happen in the future.

This lesson addresses ideas that are fundamental to the performance expectation HS-ESS2-1:

- Develop a model to illustrate how Earth's internal and surface processes operate at different spatial and temporal scales to form continental and ocean-floor features.

These ideas are not necessarily well articulated in DCIs. They include mantle heterogeneity at multiple scales as well as the connection between surface features and activity in Earth's interior. In Lesson 6, students will make the connection between heterogeneity and convection, building toward the following DCI:

- **ESS.3: Plate Tectonics and Large-Scale System Interactions.** Plate movements are responsible for most continental ~~and ocean-floor~~ features ~~and for the distribution of most rocks and minerals within Earth's crust~~. (HS-ESS2-1)

ESS2.B.3 is only partially covered. Students consider how the things we have figured out about the mantle might explain plate motions we observed in earlier lessons. They will continue to grapple with this idea in future lessons, and layer on ideas about friction and mid-ocean ridges. For this reason, it is not claimed in this lesson, even though we are building toward it.

This lesson is designed to support students toward the Next Generation Science Standards (NGSS) Nature of Science Understanding titled **Scientific Knowledge Is Based on Empirical Evidence** (Appendix H). The relevant understanding element is:

- Science includes the process of coordinating patterns of evidence with current theory.

Students encounter and/or co-construct ideas around several terms, and may decide to add the following words to their Personal Glossaries during this lesson: *seismic waves, Moho, anomaly, heterogeneous,* and *homogeneous*. **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 notice that Earth is heterogeneous, but they do not use evidence to fully construct a model of the interior. Instead, they are introduced to a model, and they need to decide whether it matches the evidence they have.

LEARNING PLAN for LESSON 5

1 · NAVIGATE

5 min

MATERIALS: Initial Class Consensus Model (from Lesson 1)

Navigate by reviewing what causes most earthquakes. Present **slide A**. Pose the questions on the slide:

- *What did we figure out about what causes most earthquakes?*
- *How does this explanation also help us understand volcanic eruptions?*

Encourage students to describe some of the interactions they saw when they worked with the foam. Listen for ideas about the edges or boundaries of plates (or pieces of foam). Students may say that earthquakes happen at plate boundaries, or when two chunks rub together or collide.

Revoice these ideas in M-E-F language by saying, *I hear you telling me we found a connection between two plates meeting, a plate boundary, and earthquakes or volcanoes. The force interactions at these boundaries transfer the energy that we then experience as earthquakes or, as in the Electronic Exit Ticket, volcanic activity.*

Problematize Afar not being at a plate boundary. Present **slide B**. Say, *But we noticed in Lesson 1 that the events in East Africa that we thought were connected to the Afar region didn't appear to be along an established plate boundary, right?*

Give students a moment to consider this gap in our current model. Then point to the class consensus model and pose the question on the slide:

- *Looking back at our consensus model, what ideas did we have that could explain where the forces come from to cause earthquakes, volcanic eruption, and breaking in the Afar region?*

Listen for ideas about magma, lava, the mantle, or anything else beneath Earth's crust. If these do not surface quickly, ask, *Could there be something underneath the crust that might be applying forces?* Listen for students to agree that it would be worth looking into.

Talk about how to investigate beneath Earth's surface. Present **slide C**. Have students turn and talk for a minute about the prompt:

- *What data could we use to investigate the matter below Earth's surface to explain where the forces might be coming from to cause earthquakes, volcanic eruption, and breaking where there are no clear plate boundaries?*

Elicit 2-3 ideas. Listen for students to suggest data taken from digging into Earth's crust or retrieving samples, from lava that comes out of volcanoes, seismic data, X-rays, or sonograms. Accept all ideas, but highlight ideas about seismic waves (if they come up) and obtaining samples by drilling/digging.

Say, *It's very tricky to get data about Earth's interior. In fact, we have more direct evidence for what makes up the surface of Mars, millions of miles away, than for what's a few miles beneath our feet! Let's read more about why it's so hard to gather data about Earth's interior, and what kind of evidence we can collect.*

2 · READ ABOUT INVESTIGATING EARTH'S INTERIOR

15 min

MATERIALS: *How Do Scientists Explore Earth's Interior?*

Do a close reading in partners. Present **slide D**. Distribute the *How Do Scientists Explore Earth's Interior?* handout to each student and direct their attention to the close reading protocol. Read the instructions aloud and allow time for clarifying questions:

1. *Read once for understanding. Underline words or ideas that are new or confusing.*
2. *Share your ideas with a partner. Discuss the questions we have as a class with your partner before reading again.*
3. *Read a second time. As you read, highlight information that might help us answer our questions.*
4. *Respond to the Making Sense questions with a partner. Be ready to discuss with the class.*

Give students 15 minutes to read the handout and respond to the questions in partners. If they do not have time to record their responses, tell them it is more important to discuss their ideas with their partner and be ready to share with the class. These questions are not intended to be assessed.

3 · BUILD UNDERSTANDING ABOUT SEISMOLOGY

5 min

MATERIALS: *How Do Scientists Explore Earth's Interior?*, Scale Chart poster

Discuss Earth's scale and the handout's first question. Present **slide E**. Ask a student to read the excerpt from the reading at the top of the slide, and ask another student to translate by explaining it in different words. They might say something like, "Earth is too big for us to observe with our eyes or collect samples from the inside, so we have to figure out what's inside of it in different ways."

Pose the slide's prompt, directing students to Making Sense Q1:

- *What other systems have we learned about that cannot be studied directly, and why?* ✱

✱ SUPPORTING STUDENTS IN DEVELOPING AND USING SCALE, PROPORTION, AND QUANTITY

At this moment, students consider connections across disciplines by discussing other systems we have learned about. Help

See the assessment callout below for expected responses.

ASSESSMENT OPPORTUNITY	**What to look for/listen for:** ● Students should list examples of systems at various scales, such as the solar system, the electrical grid, tectonic motion, or an atom. ● Students should recognize and explain that scale affects our ability to collect empirical evidence. If something is too large, too small, or on too long a timescale, it is very difficult to observe directly. (CCC: 3.2) **What to do:** Provide examples if students are having trouble making this connection. Ask them to look across these systems, then ask, *What makes them so hard to observe?* Once the idea of too big and/or too small is on the table, give them a second chance to come up with examples of systems or phenomena. **Building toward: 5.A.1** Analyze mathematical representations of indirect data to reveal anomalies in the pattern of arrival times for seismic waves to support a claim about the relationship between wave speed and the medium through which the wave is passing in Earth's interior. (SEP: 4.1, 5.2; CCC: 1.4, 3.2; DCI: PS4.A.1, ESS2.A.2)

Discuss seismic waves and Making Sense Q2. Present **slide F**. Ask a student to read the excerpt at the top of the slide, and ask another student to translate as before. They might say something like, "The vibrations that come from an earthquake travel at different speeds, and scientists use that information to figure out the kind of matter the vibrations are passing through." If they struggle to articulate something complete, do not worry right now; we will spend time making sense of this later.

Then pose the slide's prompt, directing students to Making Sense Q2:

- *What evidence have we seen that vibrations can travel through solid matter?*

They may say that the particles in the matter in the simulation from earlier lessons exhibited vibrations when external forces were applied and removed. They also saw the springs and foam vibrate back and forth when they changed the net force applied to the system.

them see that scale affects how we collect data about a system. Examples they might come up with include the solar system, the electrical grid, tectonic motion, or an atom. If the opportunity arises, note that some systems are also difficult to study because of their temporal scale, and point to the Scale Chart poster from earlier in the unit. Examples might be natural selection and adaptation, climate change, or the life cycle of the sun.

4 · BUILD UNDERSTANDING ABOUT P-WAVES AND S-WAVES

5 min

MATERIALS: *How Do Scientists Explore Earth's Interior?*, M-E-F poster

Use an animation to build understanding. Present **slide G**. Say, *The reading described two kinds of seismic waves. I found an animation of P-waves that we can observe and make sense of.* Move through the slides' prompts with the class, as shown in the table below.

Suggested prompt	Sample student response
What do we know about P-waves that can help explain what is going on here?	They are basically sound waves, so they compress the matter, and then they expand again, which pushes on the particles around them, making them compress, and transferring energy.
If lines in the animation represent bonds between particles, where are the particles, and how are they moving?	They are at the intersections of the bonds. They are moving back and forth. ✱
What is actually traveling through the solid if it is not the particles themselves? ✱	Energy is moving through the solid.

KEY IDEAS

Listen for the following key ideas before moving on:

- Matter might vibrate or move back and forth in a wave, but it does not travel from one place to another.
- In a wave, energy transfers through the motion of matter.

Discuss P-waves, S-waves, and Making Sense Q3. Present **slide H**. Ask a student to read the excerpt at the top of the slide. Then pose the prompt, pointing students to Q3:

- *Which type of wave should reach the seismic measurement stations first?*

Students should say the P-waves should reach the stations before the S-waves. ✱

Identify and interpret patterns in the graph of arrival times. Present **slide I**. Remind students that when we see a new graph or other kind of data representation, it can be helpful to annotate it by first identifying patterns, without making any guesses about what those patterns mean. Then we can start to interpret them. Elicit observations of patterns using the slide's first prompt:

- *What patterns can you identify on the graph?*

✱ SUPPORTING STUDENTS IN DEVELOPING AND USING ENERGY AND MATTER

Students might say that motion, compression, or vibration is moving through the solid. Point to the M-E-F poster developed earlier in this unit to prime them to think about matter-energy relationships. Use probing questions to help them clarify their thinking, and layer the appropriate scientific vocabulary onto their ideas if necessary. Questions you might ask include:

- *When matter changes its motion, what is transferring through it, according to our M-E-F triangle?*
- *When you say "vibration," what do you mean? Is a vibration something that moves, or is it evidence of something else that is moving or transferring?*

✱ ATTENDING TO EQUITY

Universal Design for Learning: Watch for students to move their hands back and forth, even if they are not articulating back-and-forth motion in words, and highlight this by saying, *It looks like you're moving your hands back and forth like this.* Allowing students to *express* their ideas using multiple modalities (such as gesturing) supports their ownership of their learning by giving them choice, access, and control in navigating their understanding around science ideas. It also

Students may say the lines go up. Listen for someone to point out that the orange line stops and the blue line goes wonky after 10,000 km. Do not press if these ideas do not come up, as you can elicit ideas about anomalies on the next slide. Then pose the second prompt:

- *What does each of the patterns that you identified mean?*

Listen for students to explain that the lines go up because as the waves travel farther and farther, it takes longer and longer for them to arrive. They may or may not have an explanation for the anomalies right now. If a student suggests that these anomalies are due to differences in the state of the matter that the waves must pass through, say, *That's a really interesting idea. Let's keep it in mind as a strong hypothesis, and see whether we can reason through some additional evidence to support it.*

supports students who are emergent multilingual learners.

✱ SUPPORTING STUDENTS IN DEVELOPING AND USING SYSTEMS AND SYSTEM MODELS

To support students in using ratio reasoning to understand data and make predictions, a logic they will apply over this course, follow up by asking, *For this station that looks like it's twice as far away as this one, how much longer should it take the S-waves to arrive?* If you have time, give students a chance to discuss this with partners and make predictions. They should say that it should take twice as long. Sketch a line graph to illustrate that as the ratio of the distances increases, so does the distance between the data points of the arrival times of P-waves and S-waves.

5 · TEST OUR IDEAS AND MAKE INFERENCES

5 min

MATERIALS: *How Do Scientists Explore Earth's Interior?*

Motivate applying computational reasoning to test our ideas. Present **slide J**. Pose the first question:

- *Where do the data appear to be different from what we would expect (an anomaly)?*

Pause for a moment to make sure students have noticed the new word (anomaly) and can infer a definition from the question (where the data are different from what we expect). Consider recording this at the front of the room, or giving students a chance to record it in their Personal Glossaries. They will have a more formal chance to add to their glossaries at the end of the lesson.

Determine that there is a place on the graph where there is a break in the P-wave data, and the S-wave data disappears. If you are projecting on a whiteboard or interactive board, draw a line up the 10,000 km mark on the *x-axis*. Pose the slide's second question:

- *What could we do to test whether the data matches what we expect?*

✱ SUPPORTING STUDENTS IN ENGAGING IN ANALYZING AND INTERPRETING DATA

Follow up on outliers by asking which data point was tested. Demonstrate the math at the front of the classroom, and help students see that a slight deviation from the expected number is normal, as long as it is

Accept all reasonable ideas, but listen for students to suggest using the numbers in the reading. Say, *Let's see whether these data points are anywhere near the numbers we'd expect to get if the waves travel at the speeds given in the reading.*

Test data points to quantify the anomaly. Present **slide K**. Say, *One way we can test whether this is really an anomaly is by checking the speed that each wave was traveling. Remember, speed is just a measure of how far something goes in a certain amount of time, expressed as distance over time, like miles per hour or kilometers per second.*

Model the calculation first with the dot at 2,000 km. The P-wave appears to arrive at about 3 minutes, and the S-wave appears to arrive at about 11 minutes.
2,000 km/(3*60 seconds) = 11.1 km/s
2,000 km/(11*60 seconds) = 3 km/s

Have students check the reading to confirm that these speeds are roughly accurate. Then explain that we are going to test additional data points. Split the class down the middle, tell one half to choose another data point from Part 1 of the graph, and tell the other half to choose an anomalous data point from Part 2. Give students time to work out the math, and then ask them to share their findings with a show of hands, as shown in the table below. ✱

Suggested prompt	Student response
Let's take a show of hands. For those who tested a data point that matched our expectations, how many got speeds that were very close to the numbers in the reading?	(Look for students to raise their hands.)
For those who tested an anomalous data point in Part 2, how many got speeds that matched the numbers in the reading?	(Look for students to not raise their hands.)

Say, *It looks like, in general, the numbers matched up for the first half of this graph, but not for the second half. This appears to support our claim that something weird is going on with these dots over here.*

Make inferences about Earth's structure. Present **slide L**. Pose the question:

- *What can we infer from each part of the graph about the states of matter that make up Earth's structure?* ✱

KEY IDEAS	Listen for the following key ideas before moving on:

within 10%. If there is time, do the calculation to show that at about 12,000 km, the speed would be 13.3 km/s, which is 2 km/s away from the known speed of P-waves in a solid (11 km/s), a difference of almost 20%. On the other hand, the values in Part 1 should be within 10% (11 km/s).

✱ SUPPORTING STUDENTS IN THREE-DIMENSIONAL LEARNING

This is an opportunity to help students see that "...the speed of travel of [a] wave... depends on the...medium through which it is passing." This is part of the DCI element associated with the performance expectation HS-PS4-1: "Use mathematical representations to support a claim regarding relationships among the frequency, wavelength, and speed of waves traveling in various media." This performance expectation and the associated DCI are addressed primarily in [material:pr], when students derive the relationship between frequency, wavelength, and wave speed. But the important idea that wave speed is affected by the medium is established first in this unit.

- S-waves only travel through solids, so they are probably hitting a liquid or even a gas.
- P-waves move slower through liquids and gases, so when they slow down, they are probably hitting a liquid or even a gas.

Use probing questions to help students clarify their thinking as they make connections between the patterns they identified and the reality of seismic waves moving through matter. Examples include:

- *Which pattern are you explaining right now? Can you point to the pattern on the slide?*
- *What about this pattern right here? What does that tell us about the speed of the seismic wave for waves that pass all the way through Earth's center?*
- *What information can we draw from the reading that could help us explain that pattern? Take a moment to look back at the section on seismic waves.*
- *I hear you say that the waves must be moving through a liquid (or a gas). Can you point to some evidence that P-waves slow down in a liquid (or a gas)?*

Use talk moves to get students responding to one another's ideas. Examples include:

- *Can someone restate that idea in different words?*
- *I hear you say that _______. Does anybody have a different idea?*
- *Great idea. Can someone else point to evidence that supports that idea?*

ASSESSMENT OPPORTUNITY

What to look for/listen for:

- Students should recognize that the data points representing observed arrival times depart significantly from the expected times at this point, with arrivals later than expected for P-waves and none at all for S-waves. (SEP: 4.1; CCC: 1.4)
- Through discussion, the class should make a connection between this pattern and the reading, which explains that wave speeds are affected by the media through which they pass. (DCI: PS4.A.1)
- Students should make and defend the claim that in Part 2 of the graph, the pattern of speed anomalies indicates that the seismic waves have encountered matter that is not a solid. S-waves do not travel through liquid or gas, which is why they disappear. P-waves slow down in a liquid or a gas, which is why they arrive later than expected. (SEP: 5.2; CCC: 1.4)

What to do: If students recognize the anomaly but struggle to interpret it, give them more time to read. Have them specifically look for information that could explain why P-waves might travel more slowly and S-waves might not travel at all. Have them record these questions at the top of their handout to refer back to. Then bring the class back together and try again.

Building toward: 5.A.2 Analyze mathematical representations of indirect data to reveal anomalies in the pattern of arrival times for seismic waves to support a claim about the relationship between wave speed and the medium through which the wave is passing in Earth's interior. (SEP: 4.1, 5.2; CCC: 1.4, 3.2; DCI: PS4.A.1, ESS2.A.2)

6 · NAVIGATE

10 min

MATERIALS: science notebook, *How Do Scientists Explore Earth's Interior?*, *Earth's Interior Model*, loose-leaf paper

Discuss a model of Earth's layers in partners. Present **slide M**. Distribute the *Earth's Interior Model* handout to each student. Instruct them to work in partners to make sense of the model using the questions on the slide. These questions also set them up for the exit ticket.

Assign an exit ticket. Present **slide N**. Read the prompts aloud:

- *Which layers cause P-waves to slow down?*
- *The speed of P-waves through liquid iron is ~9 km/s. Use this to support your claim with evidence and reasoning.*

Have students respond on loose-leaf paper. Draw attention to their *How Do Scientists Explore Earth's Interior?* handout as a resource. Assign the exit ticket and move around the classroom to support students who might be intimidated by doing calculations. ✱ Collect the exit ticket at the end of class to review and provide math support if necessary.

ASSESSMENT OPPORTUNITY

What to look for/listen for:

- Students should make the claim that the liquid outer core causes P-waves to slow down and S-waves to disappear. (DCI: ESS2.A.2)
- Students might choose to use the speed provided on the slide (~9 km/s) to test at least one anomalous data point from the graph in the *How Do Scientists Explore Earth's Interior?* handout. For example, to test the dot at about 12,200 km, they can divide the x-value (12,200 km) by the y-value

✱ SUPPORTING STUDENTS IN THREE-DIMENSIONAL LEARNING

This is an opportunity to make explicit that the process we are practicing, by coordinating patterns in the evidence with a current model, is one that scientists often use to build theory. This lesson supports students toward the Next Generation Science Standards (NGSS) Nature of Science Understanding titled **Scientific Knowledge Is Based on Empirical Evidence** (Appendix H). The relevant understanding element reads:

- Science includes the process of coordinating patterns of evidence with current theory.

(22 minutes = 1,320 seconds) to get 9.2 km/sec. Then they compare that number to the speed on the slide and find it is roughly equal; it should be a little off, because the waves are not passing exclusively through liquid iron. They can use this to support their claim that the liquid core causes the slow-down pattern in the P-wave data. (SEP: 4.1, 5.2; DCI: PS4.A.1)

- Alternatively, students may choose to support their explanation without doing the calculations but still applying mathematical reasoning. For example, they might argue that because 9 km/s is slower than 11 km/s, it makes sense that the P-waves arrive later than expected. They might also point out that these data points move in an odd pattern, going up and then back down. This implies that at some point, the waves are no longer moving through as much liquid iron and may be moving through a more solid inner core, reducing the lag. (SEP: 4.1, 5.2; DCI: PS4.A.1)

What to do:

- If you think your students will be intimidated by this math, consider letting them discuss and work out the math in pairs before responding.
- Consider encouraging students to work through mathematical reasoning without doing the math.
- Move around the classroom and provide support for students who have trouble organizing the resources available. Point to the graph on the handout and ask them to choose a dot corresponding to a P-wave moving slower than expected. Then ask them how they could figure out that wave's speed from the information on the graph. They should recognize that speed is distance over time, or the x-value over the y-value.

Building toward: 5.A.3 Analyze mathematical representations of indirect data to reveal anomalies in the pattern of arrival times for seismic waves to support a claim about the relationship between wave speed and the medium through which the wave is passing in Earth's interior. (SEP: 4.1, 5.2; CCC: 1.4, 3.2; DCI: PS4.A.1, ESS2.A.2)

End of day 1

7 · NAVIGATE

5 min

MATERIALS: None

Reorient to P-waves and S-waves in the outer core. Present **slide O**. Say, *Last time, we figured out that Earth's interior is heterogeneous (that is, not all the same).* Have students turn and talk about the slide's prompts:

- *How does the energy in P-waves transfer through the solid mantle versus through the liquid outer core?*
- *How does the energy in S-waves transfer through the solid mantle versus through the liquid outer core?*
- *How did graphing and math support your reasoning?*

Highlight ideas about how P-waves slow down in the liquid outer core and S-waves stop, dissipate, or reflect. Do not play guess-what's-in-my-head. If students are still not ready to make inferences about the speed of waves through matter, or why S-waves might disappear when passing through the core, they will have a chance to make observations in a simulation.

Reflect on a crosscutting idea. Elicit 2-3 ideas about the third question on the slide to enable students to see how indirect empirical evidence and mathematical representations helped them identify patterns and anomalies in seismic velocities to support their reasoning.

ASSESSMENT OPPORTUNITY	**What to look for/listen for in the moment:** ● Use this as a quick check-in to make it explicit that by organizing the data as a graph, we could see patterns that might not have been clear, and that by applying mathematical reasoning, we could quantify how anomalous certain patterns were and highlight patterns that helped us figure out what might be going on deep inside our planet. (CCC: 1.4) **What to do:** Revoice students' ideas about how the graphing and math helped us figure things out. Then make the idea explicit by saying, *Scientists rely on mathematical representations like graphs and equations to identify patterns. Without these tools, we might not be able to pick out interesting patterns in a bunch of numbers.* **Building toward: 5.A.4** Analyze mathematical representations of indirect data to reveal anomalies in the pattern of arrival times for seismic waves to support a claim about the relationship between wave speed and the medium through which the wave is passing in Earth's interior. (SEP: 4.1, 5.2; CCC: 1.4, 3.2; DCI: PS4.A.1, PS4.A.4, ESS2.A.2)

8 · TEST OUR IDEAS WITH A SIMULATION

10 min

MATERIALS: device with access to http://ds.iris.edu/seismon/swaves/index.php?lat=34.2&lon=-118.5&depth=17&mag=6.7&title=Northridge%201994&date=1994-01-17T12:30Z&w_terrain=false&wiki=https%3A%2F%2Fearthquake.usgs.gov%2Fearthquakes%2Fstates%2Fevents%2F1994_01_17.php

Observe a simulation of seismic waves. Present **slide P**. Say, *Let's look at a simulation to test our ideas about what might be happening with these waves to produce these anomalies*. Project http://ds.iris.edu/seismon/swaves/index.php?lat=34.2&lon=-118.5&depth=17&mag=6.7&title=Northridge%201994&date=1994-01-17T12:30Z&w_terrain=false&wiki=https%3A%2F%2Fearthquake.usgs.gov%2Fearthquakes%2Fstates%2Fevents%2F1994_01_17.php . Make sure to select the "shadow zone" settings, and then press play. ✱

ALTERNATE ACTIVITY	This can be done as a class, but if there is time, you can also have students observe the simulation in small groups.

Have students turn and talk about the question at the bottom of the slide:

- *What do you notice about the P-waves and S-waves when they pass through Earth's liquid core?*

Elicit ideas. Listen for students to notice that the S-waves do not pass through the core and the P-waves slow down. Remind them that seismic waves spread out in every direction from one point rather than traveling in a straight line, to help them understand that this visualization lets us see where the front of all the P-waves and S-waves is at any given moment. ✱

Make sense of the simulation's energy transfer. Present **slide Q**. Pose the first question to start a Building Understandings Discussion:

- *Does the simulation support our model for what happens to the energy transferring in P-waves and S-waves when they pass through Earth's liquid outer core?*

Listen for consensus that the simulation generally supports our model. Pose the second question:

- *What can we infer about where the energy transfers when S-waves arrive at Earth's liquid outer core?*

Students might suggest that it gets absorbed or reflected, or talk about transferring thermal energy in the surrounding matter. Remind them that energy cannot disappear; it must transfer elsewhere.

✱ ATTENDING TO EQUITY

The simulation has the option to choose from a wide variety of historical earthquakes. The default is the 1994 Northridge Earthquake in Southern California. If your area has a history of large earthquakes, click "Load new quake" and look for one that is interesting and relevant. Connecting phenomena to place supports students in seeing connections between science content and their own lives.

9 · READ ABOUT EARTH'S MANTLE

15 min

MATERIALS: science notebook, *Earth's Interior Model*, *The Mantle and the Moho*

Motivate the reading. Present **slide R**. Have students take out their *Earth's Interior Model* handout. Problematize a homogeneous mantle by asking whether the model explains why the forces are stronger in the Afar region than in regions like ours. They should say no, not really.

Point out that the speed of seismic waves told us about changes in Earth's matter. Ask, *Could we use the same kind of evidence to figure out what's happening under the crust at a local scale?*

Read about the mantle and the Moho. Present **slide S**. Ask, *Do these questions represent what we're wondering about?*

- *What might be different about the mantle rock under the Afar region?*
- *How do you think the mantle rock under the Afar region might compare to the mantle rock under the region where we live?*

Suggest that we read about the mantle to help answer our questions. Distribute *The Mantle and the Moho* to each student. Then ask, *What else do you hope we'll figure out from the reading?* Accept all ideas.

Give students about 10 minutes to read the handout and answer the Making Sense questions (the same as on **slide S**). If they do not get to those, that is fine. The questions are meant to navigate into the SubMachine investigation.

Motivate using the SubMachine tool. Use the last question on the slide to motivate a closer look at the mantle under Afar and comparison to the mantle under our region. Briefly ask for 1-2 responses to the previous question:

- *What might be different about the mantle rock under the Afar region?*

Then say, *I have a digital tool we can use to investigate the mantle in both places to answer that question.*

10 · USE A DIGITAL TOOL TO COMPARE THE MANTLE BENEATH AFAR TO OUR REGION

10 min

MATERIALS: *Investigating Cross Sections of the Mantle*, colored pencils, device with access to https://www.earth.ox.ac.uk/~smachine/cgi/index.php?page=cross_section

Introduce SubMachine. Say, *This tool lets us generate a model of seismic wave anomalies over a much smaller scale and in greater detail, at any location within Earth's mantle. We can use it to "see" under the surface and find out whether the speed of energy transfer through the mantle in that specific part of the world is above average, below average, or close to average.*

Continue by saying, *This image shows one such model.* Present **slide T**. Distribute the *Investigating Cross Sections of the Mantle* handout and colored pencils to each student. Project the tool at https://www.earth.ox.ac.uk/~smachine/cgi/index.php?page=cross_section . Use the slide to help them make connections between the various representations depicted in SubMachine.

As the class discusses the prompts, annotate the diagram on the slide and have students annotate the image on their handout (Question 1) with the following labels:

- negative velocity anomaly
- positive velocity anomaly
- crust
- mantle
- Earth’s surface
- Earth’s interior

Pose the slide’s first prompt:

- *What do you notice about the images shown by this tool?*

Students should mention colors, the red-blue color scale labeled “seismic velocity anomaly,” the map, the cross section, and the location dots and lines. Continue by saying, *Let’s focus on these colors first. What do the different colors represent?* They should suggest that the colors show seismic velocity anomalies. Invite students to look back at the meaning given for the word *anomaly* on **slide J**.

Say, *We know that an anomaly is when we see data that are different from what we expect. In this case, we expected seismic waves would travel at a certain speed through the mantle, based on the assumption that the mantle’s material is the same at any depth; however, the value we obtained was different. The colors show how different the actual seismic velocity is from the expected value.*

Point out that these colors also represent a relationship in temperature between the sections of mantle. Ask students to turn and talk to a partner about Question 2 on their handouts. Then elicit ideas about what these colors correspond to.

Guide students to determine that the seismic velocity anomalies correspond to temperature anomalies. The color scale is designed to make that apparent. Have students label the positive and negative seismic velocities in the boxes that indicate temperatures on page 1 of the handout.

Identify geographical correspondence between images. Point to the images on the slide. Say, *Let’s look at the location on Earth that these images represent. How are the images related to each other? Do they have any features in common?*

Students should mention the dots following a curved line. Make sure they understand the connection between the dots and the cross section. The lines connect the black and green dots to corresponding locations on the planet, showing that the cross section’s upper edge corresponds to the surface. The cross section represents locations or a planar section of Earth’s interior that is not visible on the map.

Label the crust, mantle, surface, and interior on both the map and the cross section.

Explore Afar with SubMachine. Present s**lide U**. Say, *We're trying to explain what happened to the crust in Afar, and what's going on beneath the surface might be important. Let's generate a model of Earth's interior beneath that region. What surface features did we observe that might be evidence for unbalanced forces in the mantle?*

Listen for students to mention things they observed in the anchor, such as cracks, volcanic eruption, and broken rocks in the Afar region. Tell them these ideas and observations from the anchor can be recorded in the "Surface observations" column of Question 3 in *Investigating Cross Sections of the Mantle*.

Use the following inputs in the tool to generate a cross section beneath the Afar region:

- latitude - 1: 10
- latitude - 2: 10
- longitude - 1: 30
- longitude - 2: 50

Ask students to record their observations of the seismic velocity anomalies by coloring or shading in the cross section diagram, and describing what they see in the final column of Question 3. At minimum, look for them to notice a large, extreme negative seismic velocity anomaly in the upper part of the mantle (the asthenosphere) beneath Afar.

Compare the Afar cross section to our location. Ask, *How do you think the mantle beneath where we live might compare to the mantle in Afar?* Accept all responses. Students may suggest that the anomalies would be smaller or nonexistent, because our region is not cracking in the same way Afar is; or, they may suggest a large positive seismic velocity anomaly in contrast to Afar's negative anomaly. Ask them to explain their thinking, but do not evaluate the accuracy of their predictions.

Use the predetermined coordinate ranges for your location to generate a SubMachine model. Have students record observations and ideas individually. Discuss what looks different or similar between the mantle below your location and the mantle below Afar, as shown in the table below. During the discussion, prompt students to record their answers to Question 4 if they have not already done so.

Suggested prompt	Sample student response
What differences do you notice in the mantle models for these two locations?	They have different colors/a different mix of colors. The blobs of color are different sizes.

	The seismic velocity anomalies are stronger in some places than in others.
What is unique about the mantle under Afar compared to where we are?	The mantle at Afar has a bigger red part. The mantle at Afar has a large high-temperature zone. The mantle at Afar has a larger negative seismic velocity anomaly.

11 · UPDATE THE PERSONAL GLOSSARY

5 min

MATERIALS: science notebook, *How Do Scientists Explore Earth's Interior?*, *The Mantle and the Moho*

Identify terms for Personal Glossaries. Present **slide V**. Ask students to look back with a partner at what they underlined in the readings, or to think about any other new words used in this lesson. Suggestions you can make include *heterogeneous, anomaly, homogeneous, Moho*, and *mantle*.

End of day 2

12 · NAVIGATE AND RETURN TO THE DRIVING QUESTION BOARD

8 min

MATERIALS: None

Navigate and return to the DQB. Present slide **W**. Pose the slide's first question:

- *How did observing seismic waves on a local scale help us understand more about the matter in Earth's mantle?*

Listen for ideas about how seismic waves travel at varying speeds, indicating a change in matter. Then pose the second question:

- *What questions on the DQB might we be able to make progress on by changing from a global scale to a more local scale to investigate the mantle?*

Highlight questions that get at smaller-scale variations in Earth's properties or behavior, such as surface features or earthquakes. Move these to a new spot to revisit at the end of the lesson.

13 · INVESTIGATE ADDITIONAL MANTLE CROSS SECTIONS

13 min

MATERIALS: science notebook, *Investigating Cross Sections of the Mantle*, device with access to https://www.earth.ox.ac.uk/~smachine/cgi/index.php?page=cross_section, *Longitude and Latitude Coordinates for Mantle Cross Sections*, colored pencils

Investigate mantle cross sections. Present **slide X**. Have students take out their *Investigating Cross Sections of the Mantle* handout and find a partner to work with. They are to investigate at least three more locations using a map program and a provided list of coordinates, and then respond to the questions on the handout.

Distribute an internet-connected device, *Longitude and Latitude Coordinates for Mantle Cross Sections*, and colored pencils to each pair. The reference gives instructions for how to use SubMachine to generate models of Earth's mantle at specific locations. Direct students to https://www.earth.ox.ac.uk/~smachine/cgi/index.php?page=cross_section . As they work to complete the chart for Question 6 on the handout, walk around to help with technical and conceptual questions.

After investigating three locations, student pairs should respond to Question 7, describing any patterns they see in their own observations.

ADDITIONAL GUIDANCE	The purpose of this investigation is to illuminate potential connections between processes in Earth's interior and features on Earth's surface. Most continental and ocean-floor features on the surface are created by the motion of tectonic plates. Seismic velocity anomalies in the mantle correspond to locations where the properties of mantle material cause tectonic activity. At this point, it is not necessary to connect specific surface features or events to characteristic mantle properties or plate boundary types. The broad pattern students should see is that when there is a more significant mantle anomaly, either in size or magnitude, there is more likely to be a geologically significant surface feature on the crust above. Locations with surface features such as volcanoes, mountains, ridges, rifts, and so forth have red or blue (more anomalous) mantle models. Locations that are relatively "featureless" (e.g., flat, not earthquake-prone) have more neutral-colored mantle models. The reference list includes three categories of earthquake case locations. The first four (Hawaii, Japan, Chile, and Denver) have visible volcanic and/or mountainous features caused by various types of tectonic activity. The second group of four (Atlantic Ocean, Libya, Russia, and Antarctica) does not have prominent tectonic

features. The third group is all the case studies from Lesson 1. It will be beneficial to investigate all these locations across the class, and for all students to see a variety of location types. You may decide to assign locations to different pairs, or allow them to choose their own if the class is large.

When students view the surface using Google Maps or Google Earth, consider encouraging them to zoom in or out to view the region at various geographic distance scales to help them see and identify various surface features.

14 · BUILD UNDERSTANDING ABOUT THE MANTLE

13 min

MATERIALS: science notebook, *Investigating Cross Sections of the Mantle*, *Earth's Interior Model*

Lead a Building Understandings Discussion. Present **slide Y**. Say, *Over the last two classes, we've modeled mantle properties beneath many surface locations. Let's talk about the new ideas that have come from these smaller-scale models.* Discuss the slide's prompts as shown in the table below. Tell students they should write down all the patterns the class identifies in the Question 8 box on their handout.

Suggested prompt	Sample student response
What mantle patterns did you notice beneath volcanoes?	Red sections near the surface. Negative velocity anomalies. Hotter temperatures. Except it was blue and cooler under the volcano in Japan, Mt. Fuji.
What mantle patterns did you notice beneath locations with earthquakes, or the case study locations?	They tend to have stronger anomalies/darker colors. It doesn't seem like the color is consistent. Sometimes it's very red (hotter), sometimes it's very blue (colder).

✱ STRATEGIES FOR THIS BUILDING UNDERSTANDINGS DISCUSSION

As students respond, push for them to talk about the rock's temperature. For example, say, *I heard you say there was a lot of red rock. What does that mean in terms of temperature?* If they struggle to identify patterns, ask them to focus on the colors in the mantle models closer to the surface (at the top of the cross section). Remind them to record the patterns identified by the class on their handout in the Question 8 box.

What mantle patterns did you notice beneath mountains?	Blue sections near the surface, especially for mountains that aren't active volcanoes. Positive velocity anomalies. Cooler mantle temperatures.
What mantle patterns did you notice beneath other surface features, or in other locations?	Beneath things like deserts, oceans, and rivers, the mantle did not have strong colors near the surface. There didn't tend to be seismic velocity anomalies or temperature anomalies in these places.

Revise our model to include local differences in the mantle's matter. Give students 5 minutes to respond to Questions 9-10 on the handout, if they have not already, before they share their ideas.

Present **slide Z**. Pose the first two questions:

- *What have we figured out that can help explain the plate motions we observed?*
- *How should we revise our Earth's Interior Model to reflect our new understandings about the mantle?*

Highlight ideas about smaller-scale differences in the mantle. Listen for recognition that mantle heterogeneity can help explain differences in forces, features, or behavior of the crust. Support speculation about cause-and-effect relationships between properties of matter in Earth's interior and phenomena observed on the surface. Remind students that our existing model shows a homogeneous mantle of solid rock (magnesium iron silicate), which does not account for the local differences we observed in the tomography data.

Present **slide AA**. Have students get out their *Earth's Interior Model* handout. Give them about 5 minutes to revise their models on their own, following the directions on the slide:

- *Add labels, symbols, drawings, and/or annotations to your model of Earth's interior to reflect our new understandings about the mantle and its matter.*

ASSESSMENT OPPORTUNITY	**What to look for/listen for in the moment:** • Look for all students to add images or words to their global model to indicate that the mantle layer is not all the same; rather, it varies on a relatively local scale. (SEP: 4.5; CCC: 1.2; DCI: ESS2.A.2,

PS4.A.4)

- Some students might include information about temperature or seismic wave velocities. They may add surface features corresponding to heterogeneity in the mantle below (e.g., volcanoes above a warmer mantle location). They might also show that these differences create different unbalanced forces in different locations, which is why some regions have different kinds of surface features than others. (DCI: ESS2.A.2, PS4.A.4)

What to do: If students do not know where to begin, have them look back at the handout *Investigating Cross Sections of the Mantle*, Questions 7-10. Help them explain to you how the cross sections they created show a small slice of the mantle in the model. Ask whether those cross sections are represented in their models, and help them brainstorm how to fill that gap.

Building toward: 5.B.1 Analyze seismic velocity anomaly data at multiple scales and evaluate the impact of this data on our working model of Earth's interior to provide evidence for a causal link between local matter variation in Earth's mantle and surface features, such as mountains, volcanoes, and cracks. (SEP: 4.1, 4.5; CCC: 1.1, 1.2; DCI: ESS2.A.2, PS4.A.4)

15 · NAVIGATE AND UPDATE THE DRIVING QUESTION BOARD AND PROGRESS TRACKER

11 min

MATERIALS: science notebook, *Progress Tracker*, sheet of loose-leaf paper, Scale Chart poster, Driving Question Board, chart paper markers

Foreshadow convection by focusing on scale and change. Present **slide BB**. Pose the first question:

- *How does the scale of these mantle anomalies compare to the scale of the anomalies we used to figure out Earth's layers?*

Call students' attention to the Scale Chart poster. Have them compare the scale of the velocity anomalies that told us about Earth's layers to those that told us about mantle matter differences. Then ask them to consider the timescale. They should realize that although we know these anomalies occur on both global and local scales, we don't know where they would go temporally on the chart.

Say, *We don't know where to put these on the y-axis, because we don't know on what timescales these anomalies exist. Are they forever? Do they change over time? And if so, on what timescales?* Use this to motivate the second question on the slide:

- *Could these anomalies change over time?*

Elicit student responses. Accept all ideas, and suggest that we keep this question in mind.

Return to the DQB. Remind the class of the DQB questions we identified earlier. Ask, *Which of these questions can we answer, or do we have ideas about?* As students identify the questions that we have answered, put a checkmark on that sticky note and move it to the side. Leave any unanswered questions on the DQB.

Update the Progress Tracker. Give students a few minutes to record their ideas in their Progress Trackers. They may record something like: "The mantle has different temperatures in different places, which means the matter is different. This could create different unbalanced forces in different locations, which is why some regions have different kinds of surface features than others."

ASSESSMENT OPPORTUNITY

What to look for/listen for in the moment:

- Look/listen for students to start answering DQB questions about specific surface features (such as volcanoes) and events (such as earthquakes) by describing seismic anomalies in the mantle at a regional scale that were added to our working model of Earth's interior. (SEP: 4.5; CCC: 1.1; DCI: ESS2.A.2, PS4.A.4)
- Look for students to describe in their Progress Trackers how scaling down from a global to a regional grain size allowed us to see the patterns of differences in mantle matter that were important for understanding surface features. (CCC: 1.2)
- Students still have a significant gap in the causal chain connecting surface features to mantle matter, because they have not yet connected temperature variation to convection, and thus to plate movement. This will be developed over the next several lessons. Do not look for students to be able to make that connection here.

What to do: If students do not feel ready to answer questions on the DQB because of the gap in the causal chain, do not push them. They will have the opportunity to go back to the DQB several more times in the unit.

Building toward: 5.B.2 Analyze seismic velocity anomaly data at multiple scales and evaluate the impact of this data on our working model of Earth's interior to provide evidence for a causal link between local matter variation in Earth's mantle and surface features, such as mountains, volcanoes, and cracks. (SEP: 4.1, 4.5; CCC: 1.1, 1.2; DCI: ESS2.A.2, PS4.A.4)

Navigate with an exit ticket. Pose the prompt on **slide DD** as an exit ticket:

- *What do we know about how flowing matter of different temperatures interacts that could explain how the mantle might change over time?*

You do not need to collect these exit tickets. They will be used at the start of Lesson 6 to motivate a closer look at convection.

Additional Lesson 5 Teacher Guidance

SUPPORTING STUDENTS IN MAKING CONNECTIONS IN ELA	These are the CCSS for ELA/Literacy-related ideas that are used to support sensemaking in this lesson: • **CCSS.ELA-LITERACY.11-12.RST.9** Synthesize information from a range of sources (e.g., texts, experiments, simulations) into a coherent understanding of a process, phenomenon, or concept, resolving conflicting information when possible. This standard shows up because students synthesize information from two readings, a simulation, and tomography models to develop a coherent understanding of Earth's interior and how scientists use evidence from seismic waves to investigate it. • **CCSS.ELA-LITERACY.11-12.RST.2** Determine the central ideas or conclusions of a text; summarize complex concepts, processes, or information presented in a text by paraphrasing them in simpler but still accurate terms. This standard shows up because students determine the central ideas from two readings and use the Making Sense questions and class discussions to paraphrase the important ideas.

SUPPORTING STUDENTS IN MAKING CONNECTIONS IN MATH	**CCSS.MATH.CONTENT.HS.A-CED.2** Create equations that describe numbers or relationships: Create equations in two or more variables to represent relationships between quantities; graph equations on coordinate axes with labels and scales. On day 1 of this lesson, students analyze a linear graph. They use an equation (mathematical model) to test several data points in order to identify anomalous patterns in seismic wave velocities. They respond to a reflection question during navigation into day 2 on how mathematical representations helped them identify patterns and anomalies in seismic velocities to support their reasoning.