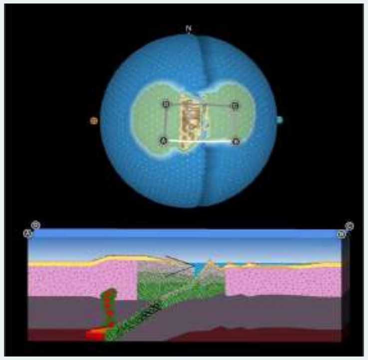
Lesson 10: What is happening at plate boundaries?

Previous Lesson *We looked at data on the crustal ages of rocks around the world and noticed several patterns. We modeled what might be going on at plate boundaries, where we observed interesting patterns, and we determined the densities of basalt versus granite. We added questions to the Driving Question Board about plate boundaries and types of crust.*

This Lesson

Investigation

2 days



Images generated using Tectonic Explorer (https://tectonic-explorer.concord.org/), developed at the Concord Consortium.

We wonder what is happening at plate boundaries. We look at plate motion based on GPS data and notice that not all plates move at the same speed. We identify three types of plate boundaries--divergent, convergent, and transform--according to the plate motion at those boundaries. We use a simulation to investigate plate interaction at convergent and divergent boundaries, and we analyze data to compare surface features on Earth and in the simulation. We read about the flow of matter between the mantle and the crust, and we use these ideas to develop a consensus model that explains how plate interactions result in the surface features we identified at the simulated boundaries. We use multiple sources of evidence to predict what Afar and Africa will look like in the future. We wonder which forces acting on plates can help us explain the patterns we identified in their motion.

Next Lesson *We will wonder how forces act on plates to cause their motion, and we will create initial models to represent our ideas. We will consider the properties of plates that might influence how forces act on them. We will plan and carry out an investigation to understand the properties that affect friction forces, and we will connect these to plate motion.*

BUILDING TOWARD NGSS	What students will do
HS-PS1-8, HS-ESS1-5, HS-ESS2-1, HS-ESS2-3	**10.A** Use a computer model that simulates the movement of tectonic plates to produce data to serve as the basis for evidence that can support an explanation of how plate interactions at plate boundaries shape the planet's surface features. (SEP: 2.6; CCC: 4.3; DCI: ESS2.B.3)

10.B Construct an explanation about the patterns in radiometric data using a consensus model of plate interactions at convergent and divergent boundaries. (SEP: 6.2; CCC: 1.5; DCI: ESS2.B.1, ESS2.B.3)

10.C Construct and revise an explanation about the future of Afar and Africa based on valid and reliable evidence obtained from a variety of sources and the assumption that plate tectonics is the unifying theory that explains the past and current movements of the rocks at Earth's surface. (SEP: 6.2; CCC: 4.4; DCI: ESS2.B.2, ESS2.B.3)

What students will figure out

- Convection in the mantle causes hot, solid rock to move from regions of higher pressure into regions of lower pressure, lowering the rock's melting temperature.
- At convergent boundaries, the high density of the oceanic crust causes it to slide beneath lower-density crust into the mantle.
- As the oceanic crust slides down at a convergent boundary, its water content is released, causing overlying rocks to melt at lower temperatures.
- The movement of plates and their interactions at plate boundaries shape the planet's surface features, such as mountains, islands, earthquakes, and volcanoes.

Lesson 10 • Learning Plan Snapshot

Part	Duration		Summary	Slide	Materials
1	2 min		**NAVIGATE** Discuss what was figured out about plate boundaries and share ideas about the expected changes on Earth's crust.	A	
2	7 min		**INTERPRET PLATE MOTION AT THE GLOBAL SCALE** Share noticings and wonderings about a map of Earth's tectonic plates to motivate investigating plate boundaries. Identify the types of plate boundaries.	B-C	*Rate and Direction of Plate Movement*, chart paper, chart paper markers, whiteboard marker
3	13 min		**EXPLORE SIMULATION OF PLATE BOUNDARIES** Learn about the simulation's functionalities through a class demonstration. Use the simulation in small groups to investigate plate boundaries.	D-F	device with access to https://tectonic-explorer.concord.org/
4	17 min		**INVESTIGATE PLATE BOUNDARIES** Work in groups to choose a convergent plate boundary and a divergent plate boundary from the *Rate and Direction of Plate Movement* reference and investigate these in the simulation.	G	*Investigating Plate Interactions*, https://tectonic-explorer.concord.org/, *Rate and Direction of Plate Movement*
5	6 min		**NAVIGATE AND READ ABOUT MAGMA** Complete a reading about magma. Orient to where we are going next.	H-I	*Magma's Origins*
					End of day 1
6	2 min		**NAVIGATE** Recall the purpose of investigating plate boundaries.	J	*Magma's Origins*
7	5 min		**DRAFT AN EXPLANATION ABOUT AFAR'S FUTURE** Make a prediction about what will happen to Afar and East Africa in the future, and construct an explanation using evidence about plate interactions (from the computer model) and magma formation (from the reading).	K	*Predicting the Future of Africa and Afar*, *Investigating Plate Interactions*, *Magma's Origins*
8	3 min		**PREPARE FOR THE SCIENTISTS CIRCLE** Organize thoughts on plate boundaries before the class discussion.	L	

9	15 min		**DEVELOP A CONSENSUS MODEL OF PLATE BOUNDARY INTERACTIONS** Have a Consensus Discussion in a Scientists Circle to build a consensus model about plate boundary interactions that can be used to make predictions about Africa and Afar.	M	*Investigating Plate Interactions*, *Predicting the Future of Africa and Afar*, Plate Interactions Consensus Model poster, chart paper markers, https://tectonic-explorer.concord.org/
10	5 min	☑	**USE THE CONSENSUS MODEL TO EXPLAIN RADIOMETRIC DATA** Use the Plate Interactions Consensus Model to explain patterns found in the radiometric data explored in Lesson 9.	N	Plate Interactions Consensus Model poster, https://tectonic-explorer.concord.org/
11	15 min	☑	**REVISE EXPLANATIONS ABOUT THE FUTURE OF AFAR** Revise our explanations of what will happen to Africa and Afar, using multiple sources of evidence to support our ideas.	O	*Investigating Plate Interactions*, *Predicting the Future of Africa and Afar*, *Progress Tracker*, *Rate and Direction of Plate Movement*, Plate Interactions Consensus Model poster

End of day 2

Lesson 10 • Materials List

	per student	per group	per class
Lesson materials	• science notebook • *Rate and Direction of Plate Movement* • *Investigating Plate Interactions* • https://tectonic-explorer.concord.org/ • *Magma's Origins* • *Predicting the Future of Africa and Afar* • *Progress Tracker*	• device with access to https://tectonic-explorer.concord.org/	• chart paper • chart paper markers • whiteboard marker • Plate Interactions Consensus Model poster • https://tectonic-explorer.concord.org/

Materials preparation (40 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' notebooks.

For day 1, make 1 copy per student of:

- *Magma's Origins*
- *Investigating Plate Interactions*
- *Rate and Direction of Plate Movement* - Follow the directions on this reference to cut out the map for students ahead of time, and have them reuse this map on day 2.

For day 2, make 1 copy per student of:

- *Predicting the Future of Africa and Afar*

For day 2, also make several copies of the following document. These data sets that we have used in the past are sources of evidence that students may want to use to support their predictions about Africa and Afar:

- *Measuring Rock Densities*

For day 2, prepare a sheet of chart paper in landscape orientation with the title “Plate Interactions Consensus Model”.

Lesson 10 • 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):

- **ESS2.B.1: Plate Tectonics and Large-Scale System Interactions.** Plate tectonics is the unifying theory that explains the past and current movements of the rocks at Earth's surface and provides a framework for understanding its geologic history. (ESS2.B Grade 8 GBE) (secondary to HS-ESS1-5)
- **ESS2.B.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. (ESS2.B Grade 8 GBE) (HS-ESS2-1)

This lesson focuses on exploring how the movement and interactions of tectonic plates are responsible for (1) the flow of matter between the plates and the mantle and (2) the planet's surface features, such as ridges, mountains, trenches, and volcanoes. Students are asked to use plate tectonics to explain the age of rocks explored in Lesson 9 and to make predictions about the future of Afar. As a result, it is important that during the first investigation with the simulation, students describe the plates' vertical and horizontal movement, the movement of matter, and the surface features that result from plate interactions. Having a clear idea about plate movement allows them to pay attention not only to the dynamic frictional forces generated through convection, but also to the role of gravitational forces in driving the plates' motion during Lesson 11.

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: *convergent boundary* and *divergent boundary*. **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

Although students will be able to connect the role of density to a central component affecting the movement of the plates, this lesson does not focus on the role of the forces explaining the patterns in the plate movement that students observe during their investigations.

Students also observe trends about the depth and magnitude of earthquakes and the boundaries where these originate. This connection is not explored here, but it represents a rich extension opportunity to intentionally use some of this unit's central ideas with the elements of the M-E-F triangle.

LEARNING PLAN for LESSON 10

1 · NAVIGATE

2 min

MATERIALS: None

Review where we are coming from. Present **slide A.** Say, *Last time, we saw that the Afar region had a lot of younger basalt rock, like you would find in oceanic crust. We also left with questions about what happens at the boundaries where plates meet. In particular, we wanted to know what is happening where oceanic and continental crusts meet up.* Pose the slide's question:

- *Why did we want to investigate what happens at plate boundaries where these two types of crust meet?*

Accept all responses. Listen for students to say that because basalt was found in Afar, we need to learn more about places where basalt and granite crust meet. Say, *Well, let's look at the places where plates meet up!*

2 · INTERPRET PLATE MOTION AT THE GLOBAL SCALE

7 min

MATERIALS: science notebook, *Rate and Direction of Plate Movement*, chart paper, chart paper markers, whiteboard marker

Present a map of rates of plate motion. Present **slide B**. Distribute the precut *Rate and Direction of Plate Movement* reference to each student. Give them a minute to look at the map, then ask, *What do the arrows on the map represent?* They should say that the arrows represent the rate of movement (velocity) and direction of the plates. Remind them that the lines represent plate boundaries, or places where two plates meet. (The colors represent information that we do not need for now.)

Give students about 3 minutes to capture noticings and wonderings about the map on a T-chart in their notebooks, as indicated on the slide. Then elicit noticings and wonderings, and spend 5 minutes making a public record of these ideas on a T-chart at the front of the room.

Expected noticings:

- Not all plates are moving at the same rate or direction.
- At some boundaries, plate material is moving apart (arrows pointing outward).
- At some boundaries, plate material is colliding (arrows pointing inward).
- The Caribbean plate and the North American plate are moving past each other (or any example of specific plate interactions).
- Plates are next to each other, so the motion of one might affect the motion of the surrounding plates.
- Some plates have arrows pointing in multiple directions.

Expected wonderings:

✱ ATTENDING TO EQUITY

Supporting emergent multilinguals: The names *convergent* and *divergent* clearly describe relative motion at a boundary. Students may or may not be familiar with these terms in general. It is worth taking a few moments to establish a common understanding of what "converge" and "diverge" mean independently of tectonic plates. You can use hand gestures to represent these motions, and make connections to more familiar words. For example, "diverge" is like "divide" and illustrates something being broken apart into smaller pieces.

- What is happening between the Nazca plate and the South American plate?
- Why does the Pacific plate move much faster than other plates?
- What happens when two plates move toward each other?
- Why are so many of the blue arrows moving apart in the ocean?

Say, *It seems like plates are moving in different directions at the boundaries. What are the possible ways that two adjacent plates are moving at the boundary between them?* Listen for these three ideas:

- Plates are moving toward each other, colliding.
- Plates are moving away from each other, spreading.
- Plates are sliding past each other, without getting closer together or farther apart.

Introduce the types of plate boundaries. Say, *Scientists have named these types of boundaries according to how the plates are moving.*

Project **slide C**. Introduce the terms *convergent plate boundary, divergent plate boundary,* and *transform plate boundary*. Write these on a whiteboard. Have students identify some of these on the map, and quickly add short definitions to be used for the rest of the lesson. Consider using familiar words, as in the *Attending to Equity* callout to the right, to create a student-friendly definition in the moment. ✱

Transform plate boundaries are so named because they connect to other plate boundaries. The word "transform" does not refer to a direction of motion, but to the transformation (change) of relative plate motion or the site of plate motion. Students do not need to know this etymology, but it may help them understand the overall convention of naming boundaries based on patterns of movement.

Divergent and convergent plate boundaries are the focus of this lesson. They relate to the motion and properties of mantle material more directly than transform boundaries do.

3 · EXPLORE SIMULATION OF PLATE BOUNDARIES

13 min

MATERIALS: device with access to https://tectonic-explorer.concord.org/

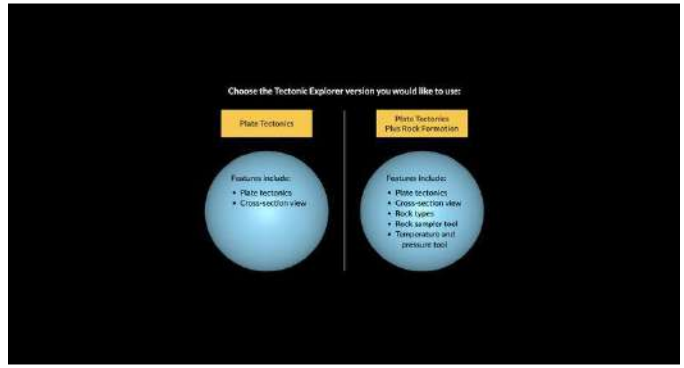
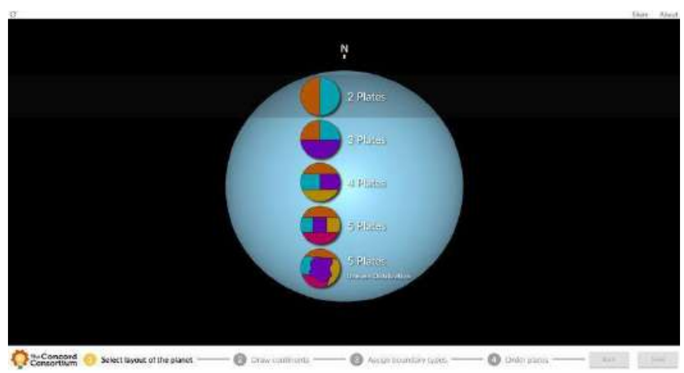
Motivate the need to investigate plate boundaries. Present **slide D**. Say, *Now that we have words to describe these types of boundaries, let's think about what happens there.* Pose the slide's first question:

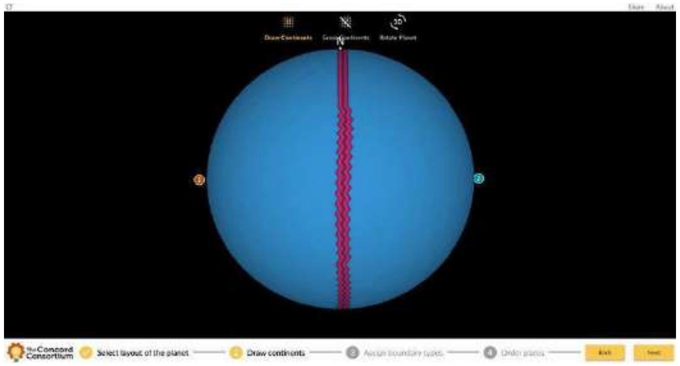
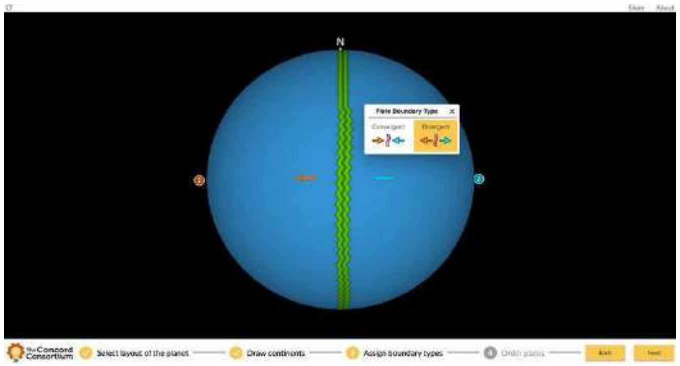
- *What changes do you expect would happen on Earth's surface near plate boundaries over time?*

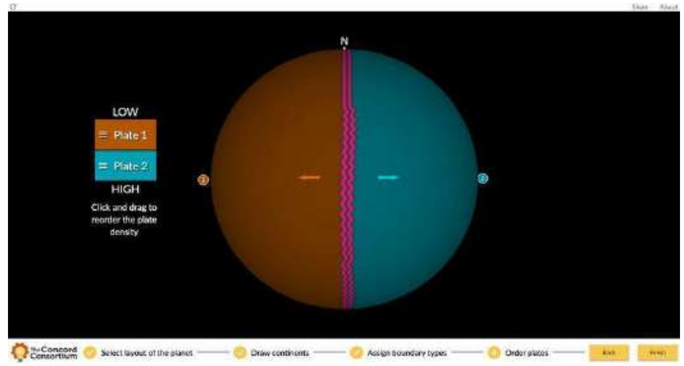
Accept all responses. Continue by saying, *We should investigate these possible changes! However, it's difficult to test predictions about phenomena that take place over millions of years. What tools have we used in the past to investigate phenomena that are very slow?* Listen for students to suggest a simulation or computer model. Say, *I have just the right simulation to investigate our predictions!*

Demonstrate the simulation with a plate boundary example. Present **slide E**. Say, *We'll use the simulation together to explore the variables we can investigate to answer some of our questions.* Organize the class into small groups of 2-3 students, and distribute computers or devices to the groups so they can explore the simulation simultaneously.

Project https://tectonic-explorer.concord.org/ and make sure all students can easily see the screen. Share the link so they can open the simulation on their devices. See the demonstration prompts in the table below.

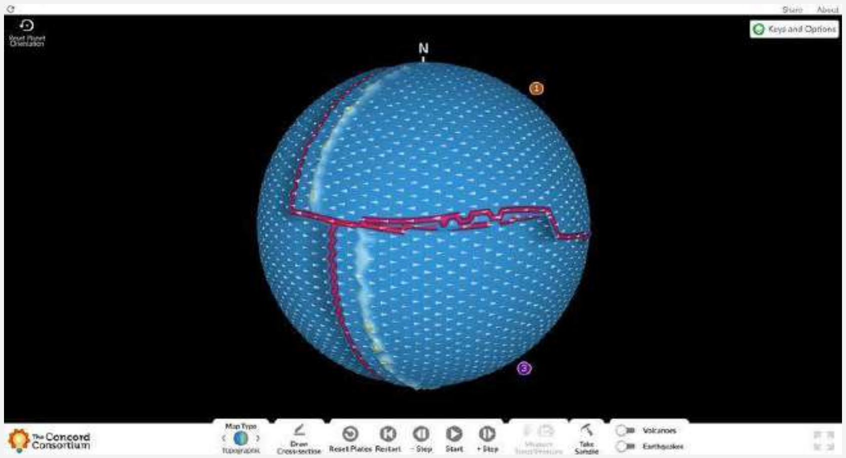
Begin by selecting “Plate Tectonics Plus Rock Formation”.	 Images generated using Tectonic Explorer (https://tectonic-explorer.concord.org/), developed at the Concord Consortium.
Then select the “2 Plates” option.	 Images generated using Tectonic Explorer (https://tectonic-explorer.concord.org/), developed at the Concord Consortium.

Tell students not to draw a continent. Remind them that there is a solid, rocky crust beneath the ocean waters they see on the globe. Using the oceanic plates for this demonstration simplifies the analysis and allows them to focus on the global changes they observe. Click “Next”.	 Images generated using Tectonic Explorer (https://tectonic-explorer.concord.org/), developed at the Concord Consortium.
Ask students to select the divergent boundary. Tell them that although there are some places with different patterns of movement (transform plate boundaries), our focus is on divergent and convergent boundaries.	 Images generated using Tectonic Explorer (https://tectonic-explorer.concord.org/), developed at the Concord Consortium.

Tell students not to change the density of the plates for this demonstration. Just make sure they are aware that Plate 1 is less dense than Plate 2.	 Images generated using Tectonic Explorer (https://tectonic-explorer.concord.org/), developed at the Concord Consortium.

When you click “Finish”, the simulation starts running automatically. Pause it, and ask students to do the same. Tell them to use the lowest “Model Speed” to allow more time to make sense of the rapid and multiple changes. To change the speed, click on the “Options” tab in the top right corner and move the bar to the desired speed.

Unclick the “Metamorphism” and “Show Sediments” options, and click on the “Force Arrows” and “Plate Boundaries” options. This allows students to observe changes at the global scale while thinking about the forces causing them. Show them how to rotate the planet by clicking on the dark area around it and dragging the cursor to the desired orientation.



Images generated using Tectonic Explorer (https://tectonic-explorer.concord.org/), developed at the Concord Consortium.

Let the model run for a few seconds, enough for students to get puzzled about what is happening at the boundary. Pause it and ask what they see. It is productive if they feel confused by these elements:

- The white arrows moving in opposite directions. Clarify that these represent velocity arrows.
- The ambiguous surface features shown at the boundary in the simulation.

Identify patterns at the global scale. Present **slide F**. Say, *Now, use the simulation with these settings, and notice any interesting changes at the global scale. Let it run for a longer time. You can always click the "Restart" button to move the plates back to their initial positions.*

After 3 minutes, invite groups to share what they noticed. Listen for the following observations:

- Sometimes one of the plates breaks into two smaller plates.
- It's hard to see what is happening on the surface of the planet.
- Although plates are moving away from each other, they are moving toward each other on the opposite side of the planet.

ALTERNATE ACTIVITY	Because this is a 3D representation with multiple interactions happening all at once, some students may struggle to connect the changes happening on different parts of the planet. If you notice expressions of confusion, you can help them use their hands to make sense of the plates' motion and the forces acting on them.

Say, *I hear you saying that the plates are moving away from each other at this boundary, but what is happening on the other side?* Have students put their hands together as if grabbing a sphere. Each hand represents a plate, and the thumbs represent the plates at the divergent boundary. The size of the planet is represented by the spherical space between the hands.

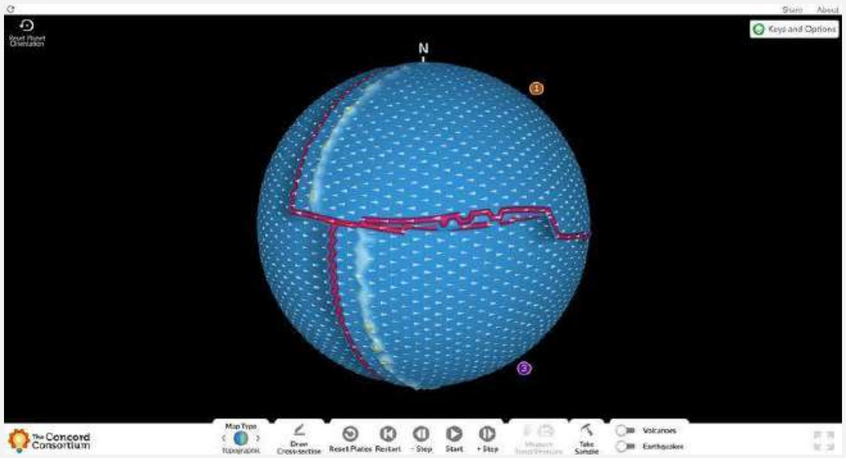
Ask students to represent the oceanic plates moving away from each other. They should move their thumbs apart.

Follow up by asking, *Where do you feel a force when your thumbs move apart?* Students should say they felt more pressure on the tips of their fingers. Say, *Interesting--when plates are moving, the forces change and something happens on the opposite boundary. But wait a second, what would happen to the size of the planet if the plates (the thumbs) keep moving apart?* They should say that Earth would get larger.

Then ask, *Is Earth growing in size in the simulation or in real life?* They should say no. Continue, *What would we need to do with the rest of our fingers to avoid increasing the size of the planet?* Listen for them to suggest overlapping or crossing their fingers.

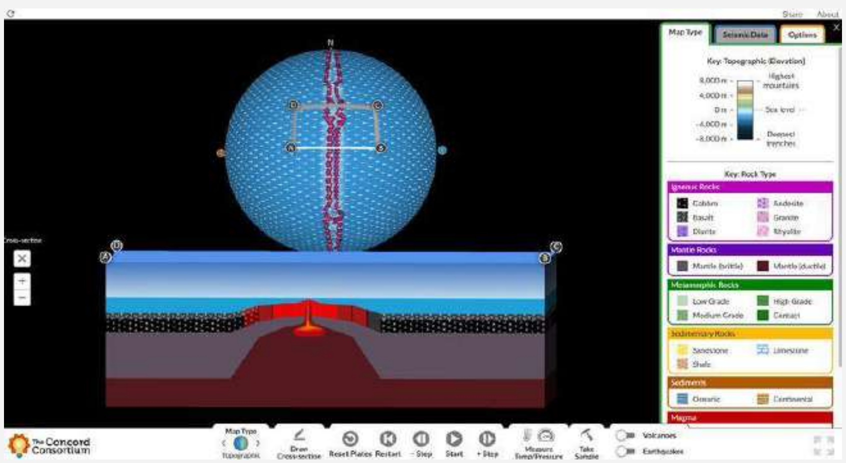
Say, *Those are great suggestions. Where on the planet in the simulation do we want to see what is actually happening?* Students should suggest looking at the opposite side. Rotate the camera and press the "Start" button again. Let it run for a few seconds to demonstrate that it is hard to see changes at the surface level.

Discuss the formation of a new plate. If students did not notice that a plate can break into two different plates, run the simulation again until this happens. Pause the simulation and discuss what could have triggered this event. Point out that the velocity vectors are pointing at different directions on each of the resulting plates, and discuss how this movement in opposite directions (as shown by the velocity vectors) can result in the formation of two plates.



Images generated using Tectonic Explorer (https://tectonic-explorer.concord.org/), developed at the Concord Consortium.

Motivate the need to look at cross sections. Ask, *If we cannot see clear changes on the surface, where else could we look to explore how these plates are interacting with each other?* Listen for students to suggest using a cross section in that region. Show them how to generate one by clicking on the "Draw Cross-Section" button at the bottom. Use the "Map Type" tab in the top right to show the keys to these representations.



Images generated using Tectonic Explorer (https://tectonic-explorer.concord.org/), developed at the Concord Consortium.

Then say, *Let's restart the simulation to see what's happening here from the beginning.* Click on "Restart". Warn students that they should only click the "Reset Plates" button to test a new plate boundary, as they will need to define all the variables again.

Discuss what is represented in the simulation:

- The brittle and ductile sections of the mantle. To help students understand the meaning of these, recall that in Lesson 3 we described how materials with a higher elastic limit than others can sustain larger deformation when forces act on them. Here, the ductile mantle has a higher elastic limit than the brittle mantle, so it can sustain higher forces before breaking.
- The basalt rock from the oceanic crust.

Finally, show that the simulation also lets us visualize volcanoes and earthquakes. Say, *When we first read about Afar, we saw that people felt a strong earthquake, and then the giant crack formed close to a volcano. This simulation allows us to visualize volcanoes and earthquakes, so maybe we can find more evidence about how those could be related to the land stretching and breaking.* Activate the visualizations of volcanoes and earthquakes by clicking on the switches at the bottom right.

Click on the "Seismic Data" tab and ask how the depth and magnitude of the earthquake are represented. Students should notice that the depth is represented by the color, and the magnitude is represented by the diameter of the circles.

4 · INVESTIGATE PLATE BOUNDARIES

17 min

MATERIALS: *Investigating Plate Interactions*, https://tectonic-explorer.concord.org/, *Rate and Direction of Plate Movement*

Distribute materials and give instructions for the investigation. Present **slide G**. Say, *Now that we have a better idea about how to use this simulation, let's investigate how plates interact at different boundary types.* Distribute the *Investigating Plate Interactions* handout to each student. Explain that although this is group work, everyone needs to record their findings for an individual task later on. Give the class the rest of the period to complete the handout.

As students conduct their investigations, circulate through the classroom and ask what is happening with the plates (matter) in the system, and how the plates interact with other matter in the system. ✱ If they do not finish the investigations, give them additional time at the beginning of the next class. Collect the handouts before students leave (they will need these for the next class). ✱

ASSESSMENT	**What to look for/listen for in the moment:** Using the *Investigating Plate Interactions Key*, look for students to:

✱ SUPPORTING STUDENTS IN DEVELOPING AND USING SYSTEMS AND SYSTEM MODELS

In this unit, students consider many parts of the Earth system, both interior and exterior. This computer model allows them to describe the matter flow between Earth's interior and exterior. By changing the simulation's speed, students can model the flow of matter and energy within the Earth

OPPORTUNITY

- Rows 2 and 3: Use a model to generate data to serve as the basis for evidence that can support an explanation. In row 3 specifically, look for a description of the plates' vertical and horizontal motion. This evidence will be central for the investigation in Lesson 11. (SEP: 2.6)
- Row 4: Use ideas about density to explain how plate interactions at plate boundaries shape the planet's surface features. (DCI: ESS2.B.3)
- Row 5: Use the simulation to describe the interactions between these components of the system's matter: moving plates, mantle material, magma, and surface features. (CCC: 4.3)

What to do: Walk through the classroom as groups complete their investigations, asking them to briefly describe to you the changes they see at plate boundaries.

Listen for the following observations of convergent boundaries:

- The denser plate is moving underneath the other one.
- The sinking plate is melting, creating magma.
- The magma flows upward when the subducting zone reaches a certain depth.
- The magma forms continental crust over the less-dense plate.
- Mountains form where the continental crustal matter is being crumpled.
- Volcanoes form where the magma is erupting.

Listen for the following observations of divergent boundaries:

- Magma is coming from the mantle into the point of divergence.
- Magma is turning into oceanic crust.
- The oceanic crust is spreading out to each side.
- The boundary moves over time.
- Magma reaches the crust at a higher point of elevation, and over time, it moves downward.
- Volcanoes form where the magma is erupting.

Building toward: 10.A Use a computer model that simulates the movement of tectonic plates to produce data to serve as the basis for evidence that can support an explanation of how plate interactions at plate boundaries shape the planet's surface features. (SEP: 2.6; CCC: 4.3; DCI: ESS2.B.3)

About 6 minutes before the class ends, move on to the next activity.

system at different timescales. You can support them in recognizing their use of this crosscutting concept by using systems language in your verbal prompts. For example:

- *What components (parts) of the system are interacting at this boundary?*
- *What interactions between system parts are occurring at this boundary?*
- *Do these interactions involve transfer of matter or energy? Can you describe how that works?*
- *Over what timescales do these transfers of matter or energy take place?*

✱ SUPPORTING STUDENTS IN ENGAGING IN DEVELOPING AND USING MODELS

While SEP 2.6 is being assessed, students are also using the model to investigate the relationships between components of the system by observing the relationships between plate density, plate movement, magmatism, and formation of surface features. This can also be used as an assessment moment for SEP 2.3: "Develop, revise, and/or use a model based on evidence to illustrate and/or predict the relationships between systems or between components of a system." Listen for students to make connections between components, such as:

- The horizontal inward movement of plates at a convergent boundary and the subduction (downward movement) of the denser plate, which is being forced below the less-dense plate.
- The subduction of the denser plate and the formation of magma from the melting rock.
- The rising magma at convergent boundaries and the formation of surface features from continental crust.

5 · NAVIGATE AND READ ABOUT MAGMA

6 min

MATERIALS: *Magma's Origins*

Motivate the reading. Present **slide H**. Motivate a closer look at magma, as shown in the table below.

Suggested prompt	Sample student response
We have been investigating convergent and divergent plate boundaries. Before we discuss the differences we found, let's quickly share what they actually have in common.	Plates are moving. There are volcanoes and earthquakes. There is magma moving in both plate boundaries.
Interesting. Was there magma everywhere?	No, only in some locations, at the place of divergence, and deep where the denser plate was moving inside the mantle at convergent boundaries.
What do we know about magma?	Magma is really hot.

	It is molten rock.
Was the motion of magma in the mantle characteristic of the motion of matter in the mantle when we investigated convection?	No, matter circulates in the mantle.

Then say, *It seems magma is different from the rest of the matter in the mantle, but it's present at both types of plate boundaries. I have a reading that will help us understand how magma is formed, and why it moves through the mantle in the patterns that we found.*

Read about magma. Present **slide I**. Distribute the *Magma's Origins* reading to each student, and explain that we will use ideas from this reading to build a model in our next class. Give them time to read the passage. Prompt them to use their preferred method of notetaking and marking key information in the reading to help them figure out what is happening in Afar.

ALTERNATE ACTIVITY	If students prefer to read independently outside of class, *Magma's Origins* could be assigned as home learning.

End of day 1

6 · NAVIGATE

2 min

MATERIALS: science notebook, *Magma's Origins*

Orient to where we left off. Present **slide J**. Say, *Last time, we read about the formation of magma. Why did we want to learn more about that?* Accept all responses, highlighting ideas about how magma's properties and movement are different from other mantle and crust material.

Continue by saying, *We used a simulation to investigate what was happening at plate boundaries. Why was that investigation important for helping us figure out what's going on in Afar?* Accept all responses.

7 · DRAFT AN EXPLANATION ABOUT AFAR'S FUTURE

5 min

MATERIALS: science notebook, *Predicting the Future of Africa and Afar*, *Investigating Plate Interactions*, *Magma's Origins*

Draft an explanation for what will happen in Afar. Say, *You all had some ideas about what might happen to Afar in the future. We wondered whether it was going to become an ocean, or maybe heal up, or break into two plates. Now that we've taken a closer look at magma formation and plate interactions, what do you think will happen to Afar in the future?*

Present **slide K**. Return the *Investigating Plate Interactions* handout and distribute the handout *Predicting the Future of Africa and Afar* to each student. Give them 5 minutes to complete the front side (Questions 1 and 2). Encourage them to refer to *Investigating Plate Interactions* for evidence of plate interactions from the simulation, and to the *Magma's Origins* reading for evidence about magma formation.

Motivate development of a consensus model. Say, *It can be hard to make a prediction about what's going to happen in Africa when there are so many pieces of the system interacting and multiple sources of evidence. Let's sort through our evidence and create a model with all our ideas about the way plates interact. That can help us improve our predictions about the future of Africa and Afar.*

8 · PREPARE FOR THE SCIENTISTS CIRCLE

3 min

MATERIALS: None

Prepare for the Scientists Circle. Present **slide L**. Say, *Developing a consensus model requires contribution from all of us. The more ideas we have on the table, the more we can make sense of this system together, and the more useful our model is. Let's go back to your groups and discuss the main ideas that can help us explain the points on the slide:* ✱

- *the movement of the plates at convergent and divergent boundaries*
- *the relationship between the movement of the plates and the observed changes in the crust at each boundary*
- *the movement of matter we observed between the mantle and the plates at each boundary*

Prior to the Scientists Circle, circulate while groups discuss to listen for key ideas about plate movement and surface features at each major boundary type.

✱ ATTENDING TO EQUITY

Recruit a student who participates less frequently in whole-class conversations to share an idea from their group conversation. You can quietly let that student know about your intent in advance so they can think through their response ahead of time or let you know if they don't feel comfortable sharing. For example, you might say, *When we move to the Scientists Circle, I'd like you to share your group's idea about how the magma is forming at a convergent boundary. Would you be willing to go public with this really productive idea?*

9 · DEVELOP A CONSENSUS MODEL OF PLATE BOUNDARY INTERACTIONS

15 min

MATERIALS: science notebook, *Investigating Plate Interactions*, *Predicting the Future of Africa and Afar*, Plate Interactions Consensus Model poster, chart paper markers, https://tectonic-explorer.concord.org/

Lead a Consensus Discussion about plate boundary interactions. Present **slide M**. Convene a Scientists Circle, asking students to bring their handouts with them and to sit next to the members of their group in the circle. Have https://tectonic-explorer.concord.org/ ready in case it is needed during this discussion.

Display the chart paper titled "Plate Interactions Consensus Model" to develop the model with the class. See the finalized version of this model below for an idea of how to use the space on the poster.

Discuss divergent boundaries of oceanic plates. Begin the discussion with a divergent boundary, as shown in the table below.

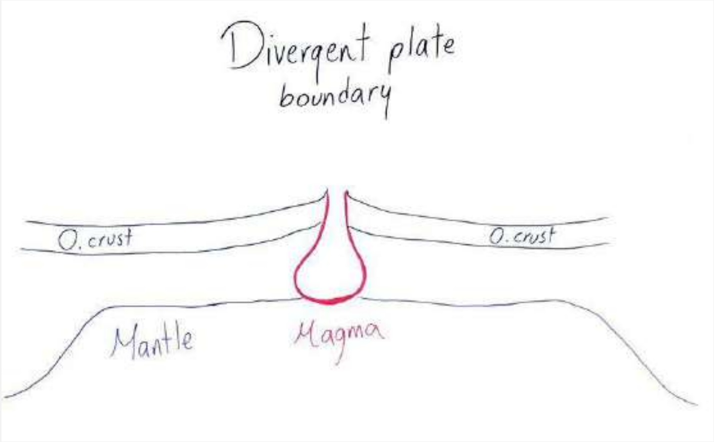
ADDITIONAL GUIDANCE	Project https://tectonic-explorer.concord.org/ and use it to demonstrate particular points where the class disagrees or an idea seems unclear. Having a student who feels confident about using the simulation for these demonstrations will help you focus on leading the Consensus Discussion while building the model. Make sure to invite this student to take part in the discussion.

KEY IDEAS	**Purpose of this discussion:** To press the class toward a common model of plate tectonics. This will serve not only as the basis for making predictions about Africa and Afar, but also for considering the forces that might be acting on the plates that can help us explain the differences in their velocity. As a result, it is important for the model to include the following key ideas: ● the main elements of the system (type of crust, mantle, surface features, magma) ● the direction of movement of these elements ● the interactions between the plates and the mantle ● the surface features present at each plate boundary (ridges at divergent boundaries and trenches at convergent boundaries, in addition to volcanoes and mountains) Additional prompts that can help you build this consensus model include: ● *How are these explanations similar? How are they different?* ● *Both groups seem to be using the same term but in a different way. Could someone explain the difference?* ● *How can we modify what we have, to account for the evidence that we agree is important to consider?* ● *What modifications would you make to clarify confusion or address the discontent that this group feels?*

- *Is more evidence or clarification needed before we can come to an agreement? What is that?*

Suggested prompt	Sample student response
Let's look at each other's divergent boundary models. What elements did we all include?	The two plates. Magma between both plates. The mantle. Volcanoes. Earthquakes.
Plates have either continental crust or oceanic crust. What type of crust do we see in divergent boundaries?	Oceanic crust.

Draw these elements on the poster, leaving out the volcanoes and earthquakes for now. Continue, including new elements and interactions that emerge during the discussion.



Add arrows for the motion of various components as they are discussed, as shown in the table below.

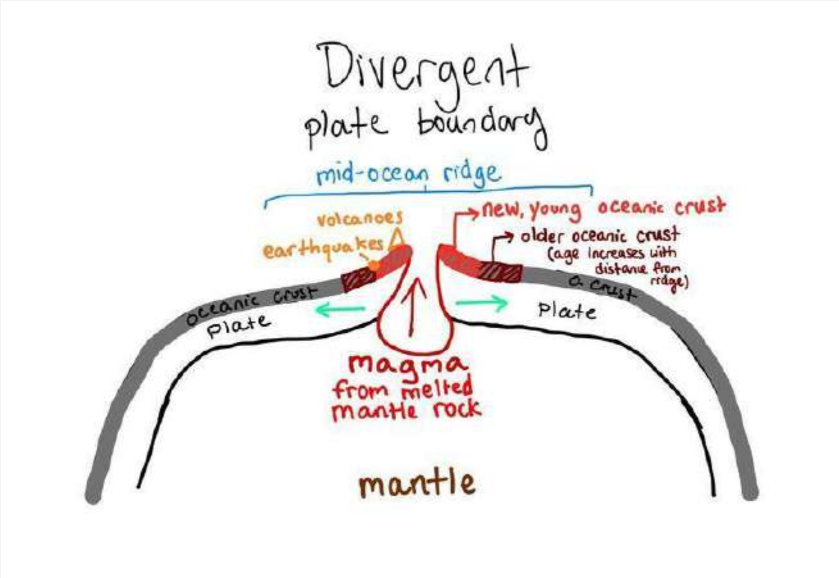
Suggested prompt	Sample student response
Let's now focus on the motion at this divergent plate boundary. How is the plate material moving at this boundary?	The plates are moving in opposite directions. Plate material is moving away from the boundary. The plate material is spreading out/apart.
What about magma?	Magma is moving upward from the mantle.
Is the movement of the plates and the movement of magma related, or do they move independently of each other?	They are not independent of each other. As magma moves upward, it pushes the plates.
What evidence do we have to support this idea?	The red material, magma, accumulates on top and slowly pushes the rest of the darker material away.
So, what happens with the magma that reaches the crust over time?	It becomes oceanic crust (igneous rock/basalt). It forms volcanoes.

Use the prompts in the following table to draw and label the mid-ocean ridge at the location of the newest ocean crust, with earthquake and volcanic activity.

Suggested prompt	Sample student response
What do you notice about the shape, or feature, of the crust at this location?	It is pushed upward. The location where the new rock is forming is at a higher elevation.

	It's like a line of small mountains under water.
Yes, this ocean floor feature is called a ridge. In the simulation, we saw different colors in the oceanic crust on each side of the ridge. What do the colors represent?	The red color is the newest crust. The darker the color, the older the rock.
Great. The rock of the oceanic crust is formed from magma that comes from the mantle. Why does magma move upward?	Magma is less dense. When the rock melts, it moves upward.
But magma seems to be formed only in a particular region of the mantle. Why does it form there?	The rock is super-hot and moves upward. As it moves, there is less pressure from the overlying rock, so it melts. When it is melted, it continues moving upward.
Some of you mentioned earthquakes. The simulation gave us information about the depth and magnitude of earthquakes. Did you notice any patterns in their depth or magnitude at this plate boundary?	They were mostly shallow, close to the surface. A lot of them were low magnitude.

By now, the model should look like this:



Discuss both types of convergent boundaries. Follow the above discussion thread for modeling convergent boundaries, as shown below.

Suggested prompt	Sample student response
Let's now look at each other's convergent boundary models. What elements did we all include?	Two oceanic plates. Two continental plates. One continental and one oceanic plate. Mountains. Volcanoes. Earthquakes.

If students describe only oceanic plates, continue to the section below the next set of prompts and responses.

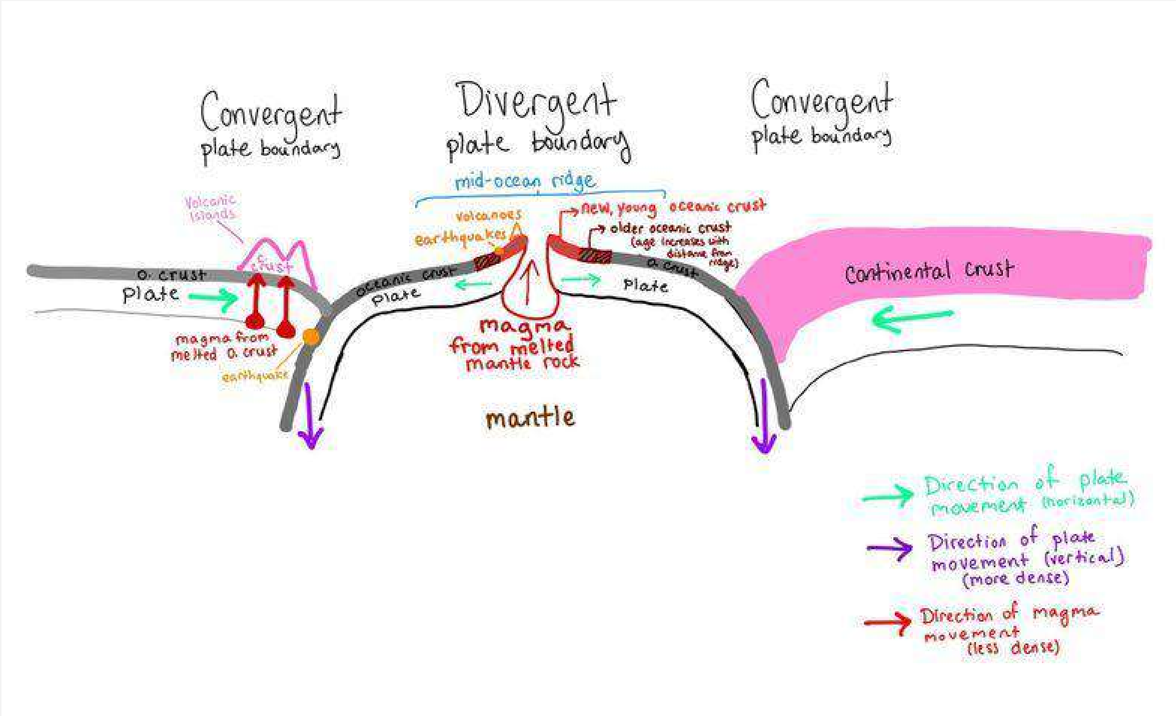
If students do bring up continental plates, say, *Because you mentioned two types of plates, I'm going to include a different type on each side of the model. How should we draw the continental crust to distinguish it from the oceanic crust?* Accept all responses, and press toward a common representation. For example, students should note that continental crust is thicker. Using a different color may also be helpful. (The example model uses pink to represent the minerals typical of continental igneous rocks.)

Draw the plates without including surface features yet (mountains, volcanoes, or earthquakes). Continue with the discussion as shown below, adding new elements that the class suggests.

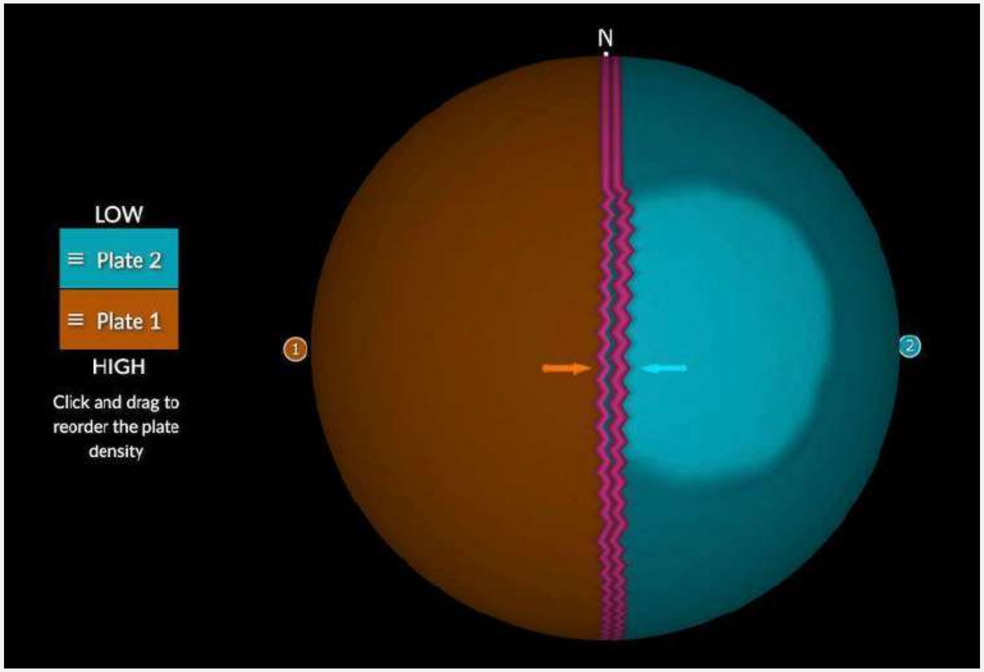
Suggested prompt	Sample student response
Let's focus on the motion at this plate boundary where two oceanic plates are converging. How are the plates moving here?	The plates are moving toward each other. One plate slides down under the mantle. One plate moves downward.
What determines which plate slides down under the mantle?	The denser plate. The plate with high density goes beneath the plate with low density.
What kinds of features, components, or events are common at a boundary where two oceanic plates are colliding?	Volcanoes. A magma pocket or magma forming. Islands. Earthquakes.
Let's begin with the magma. Where does it come from and where does it go?	It comes from the oceanic plate that is sliding down into the mantle.

	It goes upward toward the surface.
At the divergent boundary, we saw that magma was pushing the plates away from each other. What does the magma do at this convergent boundary?	It forms volcanoes. It accumulates on top of the oceanic crust and creates continental crust. It forms islands.
Some of you mentioned earthquakes. Did you notice any patterns in their depth or magnitude at this plate boundary?	A lot of them happened deeper in the mantle. There were earthquakes of all types of magnitudes.

At this point, the model should look like this:



If students describe only oceanic plates, draw that side of the model first. Then prompt them, *Remember, we were curious about what happens when continents and ocean floor meet at a plate boundary. How can we use the simulator to include that in our model?* Project and run https://tectonic-explorer.concord.org/ for the class to observe the collision of a continental plate and an oceanic plate. Be sure that the plate with the continent is less dense, as seen in the settings in the image below:



Images generated using Tectonic Explorer (https://tectonic-explorer.concord.org/), developed at the Concord Consortium.

Continue the discussion as shown below, moving to the model's other convergent boundary. Add motion arrows to the plates and magma on the site of oceanic-continental convergence.

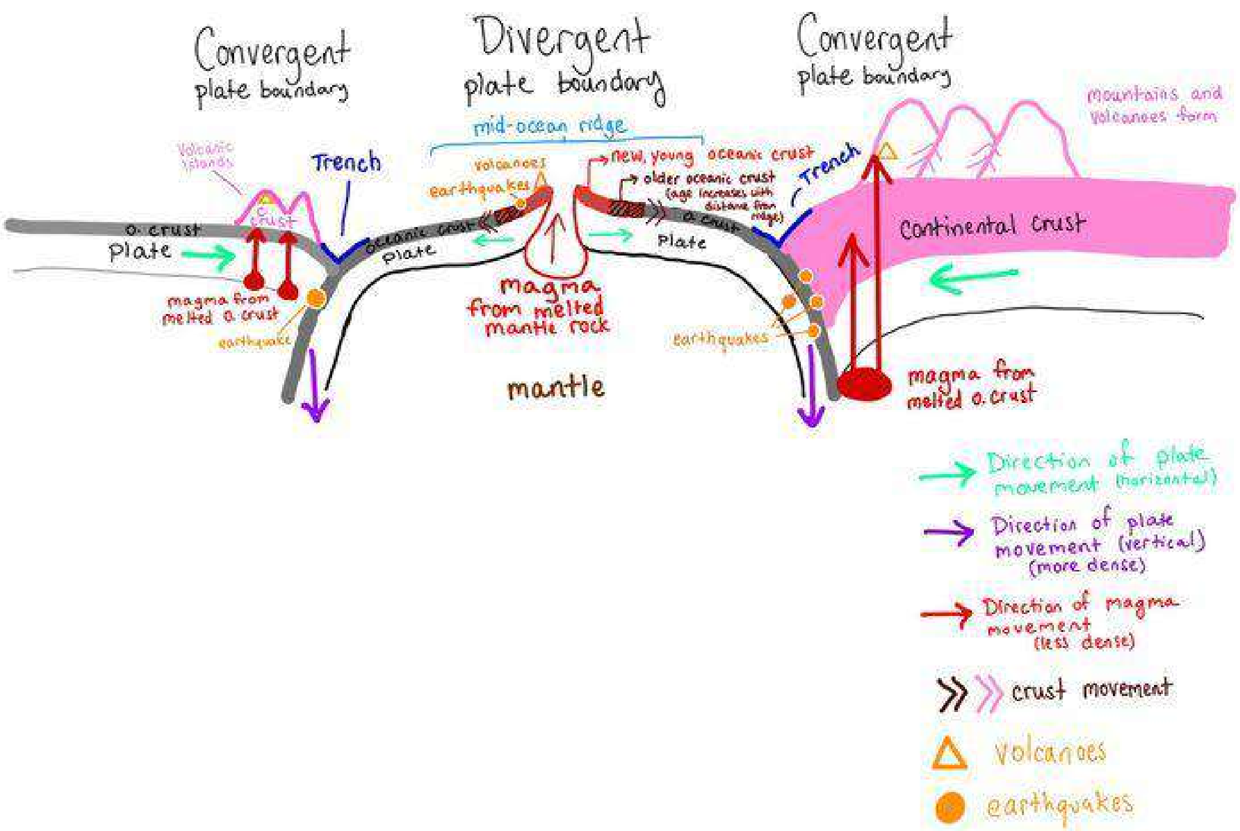
Suggested prompt	Sample student response
Let's now focus on the boundary where the continental and oceanic plates are converging. What elements did we include in our models?	Mountains. Volcanoes. Earthquakes.

The other convergent boundary we modeled did not have mountains. What makes mountains form when oceanic and continental plates converge?	Because both plates are moving toward each other, the continental crust crumples and rises while the oceanic crust slides down into the mantle.
Why does the crust get pushed upward on the continent side?	Continental crust is thicker and less dense, so it can't sink down into the mantle. It has to be pushed higher as it collides.
What evidence do we have about the differences between oceanic and continental crust?	When we measured the density of the rock samples, the granite had a lower average density than the basalt.
What about the magma? Where does it come from and where does it go?	It's the same as the other convergent boundary. It comes from the oceanic plate that is sliding down into the mantle, then it goes upward toward the surface.

Use the prompts below to label the earthquakes and trenches at convergent boundaries.

Suggested prompt	**Sample student response**
What happens when the magma reaches the surface?	It forms volcanoes and it accumulates on the crust.
And the earthquakes? Did you notice any patterns in their depth or magnitude at this plate boundary?	A lot of them happened deeper in the mantle. There were earthquakes of all types of magnitudes.
You noticed that earthquakes happen deeper at this type of boundary. What do you notice about the depth of the crust itself? We can look at the key on the elevation map for help.	The elevation gets very low on one side of a convergent boundary.
Yes, a place like this where the ocean gets very deep is called a trench. (Label trenches on both convergent boundaries.) Why do you think the elevation gets so low here?	The place where the plates converge is being dragged downward. The sinking plate is bending the other plate where they are colliding.

At the end of this discussion, your consensus model should look something like the image below. Notice that it does not include explicitly named force vectors. The focus has been on the motion of the elements included in the model, and the arrows represent movement, not forces.

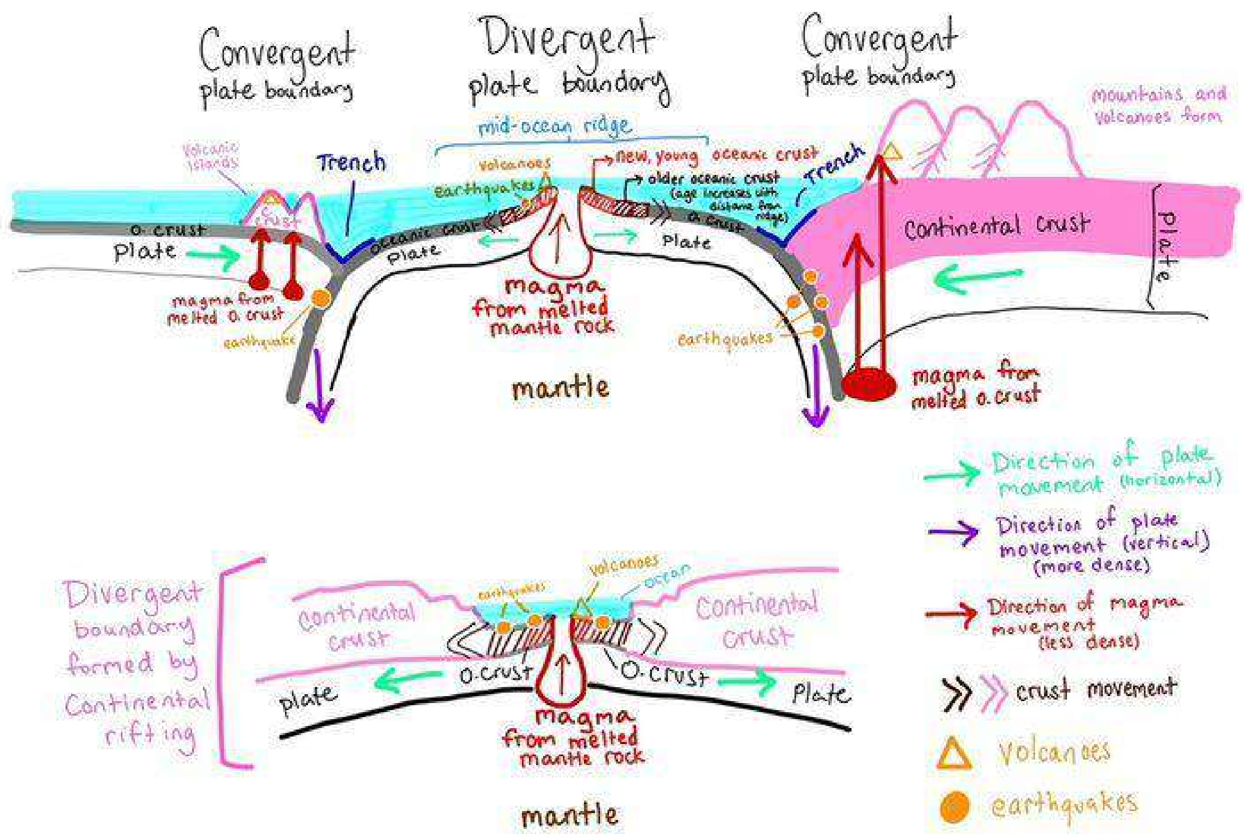


Convergent plate boundary
Divergent plate boundary
Convergent plate boundary
mid-ocean ridge
Volcanic islands
Trench
o. crust
Plate
magma from melted o. crust
earthquake
oceanic crust
Plate
volcanoes
earthquakes
new, young oceanic crust
older oceanic crust (age increases with distance from ridge)
magma from melted mantle rock
mantle
o. crust
Plate
Trench
earthquakes
mountains and volcanoes form
Continental crust
magma from melted o. crust
Direction of plate movement (horizontal)
Direction of plate movement (vertical) (more dense)
Direction of magma movement (less dense)
crust movement
volcanoes
earthquakes

Discuss a divergent boundary of two continental plates. Make sure to demonstrate this boundary by projecting https://tectonic-explorer.concord.org/ . This time, when setting up the simulation, draw a continent on the center of the planet before defining the boundary. Guide this discussion as shown below.

Suggested prompt	Sample student response
We can also use this simulation to investigate boundaries where two continental plates are moving away from each other. Why is this simulation particularly relevant for us?	Because we think this is what is happening at Afar.
When two oceanic plates moved away from each other, we saw new oceanic crust forming at the boundary. What happens when two continental plates move away from each other?	Oceanic crust is also formed in the space between the plates.
What happens to the continental crust as that happens?	It is stretched and separated. Eventually, it breaks apart.
Did we observe any surface features at this boundary that were caused by the motion of the plates?	Yes, we saw the land stretching and forming a stair-like structure. We also saw earthquakes and volcanoes around the plate boundary.
At this boundary, we have not included interactions with other boundaries on the right and the left. If the other plates on the right and the left are either diverging or converging, would that change the surface features we would see?	It matters. If the plate to the right is converging with another plate on that side, we would see mountains. If the other plate is diverging, then maybe we would not see mountains.

This is how the final consensus model might look:


Convergent plate boundary
Divergent plate boundary
Convergent plate boundary
mid-ocean ridge
Volcanic islands
crust
Trench
volcanoes
earthquakes
new, young oceanic crust
older oceanic crust (age increases with distance from ridge)
Trench
mountains and volcanoes form
o. crust
Plate
oceanic crust
Plate
Plate
o. crust
Continental crust
plate
magma from melted o. crust
earthquake
magma from melted mantle rock
earthquakes
mantle
magma from melted o. crust
Direction of plate movement (horizontal)
Direction of plate movement (vertical) (more dense)
Direction of magma movement (less dense)
crust movement
Volcanoes
earthquakes
Divergent boundary formed by Continental rifting
continental crust
earthquakes
volcanoes
ocean
Continental crust
plate
O. crust
O. crust
Plate
magma from melted mantle rock
mantle

10 · USE THE CONSENSUS MODEL TO EXPLAIN RADIOMETRIC DATA

5 min

MATERIALS: Plate Interactions Consensus Model poster, https://tectonic-explorer.concord.org/

Use the consensus model to explain radiometric data. Present **slide N**. Say, *Scientists develop models to try to explain patterns they identify in their data. Maybe we can use our model to explain patterns we identified earlier in the ages of oceanic and continental crusts. Can someone remind us what those patterns were?*

Listen for students to say we found that continental crust is much older than oceanic crust, and that with increasing distance from divergent boundaries, the oceanic crust gets older, with the youngest crust along the zone of divergence. You may choose to display the Tectonic Explorer using the "crust age" map type on the bottom menu to support the discussion of oceanic crust age patterns. Write these patterns on the board.

At this point, ask students to turn towards the members of their groups. Continue by saying, *Take a few minutes with your group to use the class consensus model to explain how the flow of matter through this system could create these patterns*. After a few minutes, invite students to share their explanations.

ASSESSMENT OPPORTUNITY

What to look for/listen for in the moment:

- Explicitly use the consensus model of plate interactions to explain the patterns in radiometric data. (SEP: 6.2; CCC: 1.5; DCI: ESS2.B.1, ESS2.B.3)
- Include the flow of magma through the system as a mechanism that influences the movement of rocks and that explains the patterns in the ages of crustal rocks. (CCC: 1.5; DCI: ESS2.B.1, ESS2.B.3)
- Include divergent and convergent plate boundary interactions to explain the differences in composition of the crust. (SEP: 6.2; DCI: ESS2.B.1, ESS2.B.3)

What to do: Invite students to come to the front of the classroom and use the consensus model to illustrate their ideas, which might look like the following:

- At divergent boundaries, magma, which comes from melted mantle, moves upward. The magma reaches the surface and becomes part of the oceanic crust. This is why oceanic crust is youngest right at the divergent boundary. The matter is flowing between Earth's interior system and Earth's surface.
- Over time, newer oceanic crust pushes older oceanic crust. This is why the age of oceanic crust increases as you move away from the divergent boundary. The matter flows in the direction from where it is created toward where it is destroyed. This flow of matter is also the movement of tectonic plates.

- Continental crust forms when magma from re-melted oceanic crust solidifies. This continental crust does not sink easily. As a result, it does not get destroyed at convergent plate boundaries. This is why continental crust persists over very long periods of time. Its matter is not transformed back into magma.

Building toward: 10.B Construct an explanation about the patterns in radiometric data using a consensus model of plate interactions at convergent and divergent boundaries. (SEP: 6.2; CCC: 1.5; DCI: ESS2.B.1, ESS2.B.3)

11 · REVISE EXPLANATIONS ABOUT THE FUTURE OF AFAR

15 min

MATERIALS: science notebook, *Investigating Plate Interactions*, *Predicting the Future of Africa and Afar*, *Progress Tracker*, *Rate and Direction of Plate Movement*, Plate Interactions Consensus Model poster

Revise explanations about the future of Afar. Have students return to their seats. Present **slide O**. Say, *Scientists also use models to make predictions about future patterns. Let's use models to explain what will happen to Afar in the future. You can change or add to the predictions and explanations you developed at the start of class. Be sure to consider the new evidence that we used to develop our consensus model.*

Give students the rest of the period to complete this task. They should revise their responses to Questions 1 and 2 on the handout *Predicting the Future of Africa and Afar*, and respond to all parts of Question 3 on the back. Collect the handout as students leave.

ASSESSMENT OPPORTUNITY

When to check for understanding: When students complete the handout *Predicting the Future of Africa and Afar*. Use the *Predicting the Future of Africa and Afar Key* to get an idea of the types of predictions and supports that students might bring to the task of making a prediction about the future of Afar and Africa.

What to look for/listen for in the moment:

- Question 1: The prediction about the future of Afar and Africa should be focused on changes to surface features. Students should not explain anything at this point. Drawings might be a good way for them to represent important surface features. (CCC: 4.4)
- Question 2: Students should use multiple sources of evidence and the consensus model to construct an explanation of how the plate interactions under Africa will cause the predicted surface changes. (SEP: 6.2; CCC: 4.4; DCI: ESS2.B.2, ESS2.B.3)

What to do: Encourage students to use various sources of evidence for their explanation. Students might want to use the following handouts to support their predictions about Africa and Afar:

- *Measuring Rock Densities*
- *Rate and Direction of Plate Movement*

Tell students that you have copies of data sets we have used in the past. Let them take a copy to their seat and return it when they are done with it.

These are some of the additional sources of evidence students might include:

- findings collected in the *Investigating Plate Interactions* handout
- *Progress Tracker*

Building toward: 10.C Construct an explanation about the future of Afar based on valid and reliable evidence obtained from a variety of sources and the assumption that plate tectonics is the unifying theory that explains the past and current movements of the rocks at Earth's surface. (SEP: 6.2; CCC: 4.4; DCI: ESS2.B.2, ESS2.B.3)

Additional Lesson 10 Teacher Guidance

SUPPORTING STUDENTS IN MAKING CONNECTIONS IN ELA	**CCSS.ELA-LITERACY.RST.11-12.9:** 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. Students synthesize information from multiple sources, including the reading about magma and the computer simulation of plate interactions, into a coherent understanding of plate tectonics as a unifying theory that explains multiple phenomena in the Earth system. This includes how interactions involving the transfer of energy and matter at plate boundaries lead to the development of distinctive surface and ocean-floor features, characteristic patterns in the ages of rock, and distinctive patterns in earthquake depth.