Modeling Convection for Plate Tectonics

Essential Question: How do Earth's plates move?

Prior knowledge needed:

1. The basic layers of Earth's interior and their properties (core, mantle and crust). Properties should include at least composition, temperature, and density.
2. The Earth has tectonic plates that move
3. Density
4. Claims-Evidence-Reasoning

Targeted grade range: Middle School

Objective: Students will use physical and digital models of the Earth's mantle and crust to describe mechanisms of heat transfer (with a specific focus on convection) and their role in plate motion.

NGSS: (Listed with each activity)

Overarching Claim: As Earth cools, heat is transferred from its interior to its exterior by the process of convection. The motion, or currents, created by convective heat transfer move the tectonic plates.

Evidence from activities:

1. The mantle is a solid (like thick plastic or asphalt) that flows over long periods of time.
   The mantle behaves elastically (will bend but regain its original shape when force is released) on short timescales, but becomes viscous on long (geologic) timescales.
2. Temperature controls the viscosity of a substance. When substances are heated, viscosity decreases and ability to flow increases.
3. There are four types of heat transfer (convection, conduction, radiation and advection). Convective heat transfer dominates within the mantle, ultimately resulting in the movement of plates.
   Convection currents create friction between the rigid lithosphere and flowing viscous asthenosphere, resulting in plate movement.
4. Convection causes upwelling of hot, less dense mantle material from Earth's interior to come in contact with the tectonic plates and moves them toward the cooler boundaries.

Reasoning:

1. The Earth's core is radiating heat into the mantle.
2. Although the mantle is a solid, the high temperature of the Earth's interior decreases the viscosity of the mantle.
3. The hotter, less viscous mantle material rises from Earth's interior towards the plates and cooler mantle material sinks away from the plates. This heat transfer process occurs via convection, which creates currents within the mantle that ultimately cause the plates to move.

Overview of Activities

Introduction

Before starting this lesson arc, students should be introduced to the Essential Question (EQ) "how do Earth's plates move?" A brainstorming session should occur to expose students' prior knowledge and ideas about plate tectonics. The teacher should also introduce the EQ graphic organizer page at this point - this is where students will collect evidence. Each activity is previewed below and detailed in subsequent pages.

Viscosity of the Mantle

In this activity, students will investigate the question "What properties control the flow rate of a substance?" in two parts. First, they will investigate the speed at which different objects flow down an incline. Second, they will look at how temperature affects the speed at which one substance (honey) flows.

Modeling Heat Transfer in a Fluid

In this activity, students will view a demonstration of convection currents in a fluid. Using food coloring, the teacher will model for students how convection currents move hot fluid to cooler areas, creating a cyclical pattern. As an optional extension, teachers may use a piece of "fun foam" to model the movement of a plate on the convection current.

Visualizing Convection in Earth's Mantle

In this activity, students will view digital simulations of convection in the Earth's mantle and compare this model with the previous demonstration to better understand the processes taking place in the Earth's mantle that ultimately lead to plate motion.

Assessment

Students will use the Claims-Evidence-Reasoning framework to answer the question "how do Earth's plates move?" by providing evidence from the three activities to support their claim. A graphic organizer will be provided to students at the start of the unit to track evidence from the activities and answer the question. Students may make claims along the way that will be modified as they collect further evidence in the activities.

Future Lessons

The activities in this lesson arc are intended to be followed by activities that support a system-level understanding of plates. Learning about how the plates move will help students to better understand the interactions plates have with one another on a local and global scale.

Activity 1 - Viscosity of the Mantle
Teacher Instructions

NGSS Performance Expectations
MS-ESS2-1. Develop a model to describe the cycling of Earth's materials and the flow of energy that drives this process.

Cross Curricular skills
- Energy and matter

Science and Engineering Practice
- Analyzing and interpreting data
- Constructing explanations

Materials
(one set of the following per group)
Part I
- cutting board
- wax paper
- adhesive tape (masking, clear, packing)
- books (or some other method to create the 45 degree incline for the cutting board)
- protractor (to measure the angle of the cutting board)
- metric ruler
- marker
- stopwatch
- Fluids t 10mL each of the following
    - water
    - oil (olive or vegetable)
    - shampoo
    - honey
    - pudding
    - (other fluids of your class's choice)
- newspaper (to catch runoff from cutting board)
- paper towels to clean up

Part II
- thermometer
- 3 samples of 10mL of honey
    - warm
    - room temperature
    - refrigerated
- cutting board
- wax paper
- adhesive tape (masking, clear, packing)
- books (or some other method to create the 45 degree incline for the cutting board)
- protractor (to measure the angle of the cutting board)
- metric ruler
- marker

- stopwatch
- newspaper (to catch runoff from cutting board)
- paper towels to clean up
- graph paper

Pre-class setup required:
Part II
- Honey will need to be refrigerated ahead of time for roughly two hours. Longer refrigeration will further increase the viscosity.

Modifications
Both Part I and II can be done as whole class demonstrations, rather than small group investigations.

Part I
- Student ideas and choices can be incorporated by completing the "flow" brainstorm and Part I Predictions a day before the activity. This will allow for teachers to elicit student thinking before determining what substances to test.
- For some classes, particularly those with younger students, it may be helpful to measure out 10mL of the substances ahead of time.

Part II
- Honey can be substituted for another substance in the presence of allergies. Maple or corn syrup would make good substitutes.
- Computer programs can be used to create the bar graph of temperature vs. time.

Teacher's Instructions
1. Ask students what they know about the word "flow." This can be done in multiple ways:
    a. Create a "padlet" page online if you have the technology access
    b. Use scrap paper to do a "jot thoughts" activity in small groups.
    c. Create a group mind-map on the board.

Part I
2. Pass out investigation sheets to students. Tell students that they will be investigating how properties of a substance affect its ability to flow.
3. Show students samples of substances they will be testing today (honey, shampoo, water, etc.) Ask them to make predictions about which substances will flow faster or slower and record those predictions on their papers.
4. Have students share their predictions, and elicit reasons for their answers. This informal formative assessment can reveal student ideas that should be further developed in the activity.
5. Following the protocol on the worksheet, have students test the rate at which the different fluids flow down the incline. Complete three trials.
    a. Tips: make sure newspaper covers the tables well enough to catch spills. It may also help to model the first fluid as a class before having small groups work on their own.
6. Guide students through revisiting their investigation question for the activity and answering it with the Ct Et R framework, which is scaffolded for the students on the worksheet. Teachers should look for students to identify certain substances (i.e., honey, shampoo) as flowing more slowly than others (i.e., water, oil). Students should provide evidence using the recorded time it took substances to flow down the incline. Their reasoning should relate to the "stickiness" or "thickness" of the substances at the most basic level.

Making Connections
7. Read the opening statement for "Making Connections" aloud to students.
8. Have student work in their small groups to sort the substances they tested into high and low viscosity.

9. Discuss student sorts and their reasoning with them - why did they put substances in the categories they did?
10. Students should then reflect on what the viscosity of the mantle might be - high or low?
11. Have students brainstorm about what factors may change the viscosity of a substance. If no one says temperature, try to arrive at this answer by asking how we could make something flow faster or how we could get the syrup out of the bottle?

Part II

12. Set up Part II by asking students to predict how changing the temperature of honey will change how fast it flows down the incline. Discuss predictions as in Part I.
13. Provide students with materials needed to complete the test. Provide students with one sample of honey at a time, starting with room temperature. Remind students to measure the temperature before placing on the incline. While students investigate the room temperature honey, heat 10mL of honey for each group by placing the honey in a glass beaker (or similar vessel) of hot water. While they investigate the heated honey, retrieve the cooled honey (in refrigerator for 2 hours) from the refrigerator and allow students to investigate the cool honey. (*Teacher note: Cooled honey may not run down the incline. Be prepared to stop students before the cool honey reaches the bottom of the incline.*)
14. Complete three trials with each temperature of honey.
15. Provide students with graph paper, a computer graphing program (like Excel), or a pre-fabricated graph template. Scaffold their graphing as needed.
16. Guide students to answer the Part II question with the C-E-R framework. Have them share their work in pairs or small groups. Monitor responses to determine if further discussion needs to occur. Students should reach the conclusion that warmer substances flow more easily, cite evidence from their table and/or graph, and include the change in viscosity as reasoning for the difference in flow rate.
17. Next, ask students to put the two investigations together and answer the question: How do the properties of a substance affect its ability to flow? They should again use the C-E-R framework to structure their response. Such as: The temperature of objects affect how an object flows. The warmer version of the substance flows faster than cooler version. This is because the warmer the object the lower the viscosity. These warmer substance have their atoms more spread out, and become less sticky than cooler objects whose atoms are closely packed.
18. Connect the activity back to the Earth's interior - while doing this it may help to refer back to a diagram or model of the layers of the Earth which include the average temperatures of each layer. How will temperature affect the viscosity of the mantle? Students should write the key evidence they have learned in the EQ graphic organize they were given the first day.

Activity 2 - Convections Currents
Modeling Heat Transfer in the Mantle

NGSS Performance Expectations
MS-ESS2-1. Develop a model to describe the cycling of Earth's materials and the flow of energy that drives this process.

Cross Curricular skills
- Patterns
- Cause and effect
- Energy and matter

Science and Engineering Practice
- Developing and using models
- Constructing explanations

Materials
Pre-demo lesson
- textbook, slideshow or other non-fiction reading that allows students to define convection, conduction, radiation and advection.

Demo
- Pyrex (or other heat-safe) dish (8x8 is ideal, but this can be modified to work with what you have available.)
- sterno can (or other heat source - candles can work, but will take longer to heat the water)
    - **Please note**: *Safety precautions should be taken when dealing with open flames and extreme heat. Please handle with care and according to instructions on packaging. Saftey goggles should be worn and loose articles of clothing should be secured. Please comply with all local fire and safety regulations. Fire extinguishers should be readily available during the activity.*
- food dye
- books or other means to prop dish up above the heat source
- craft foam piece (about 1" square) (Optional)

Modifications
- Project movement of water in dish on a document camera to allow students to see larger, or record with camera and replay for students to have repeate viewings.
- Allow students to draw pictures for the 'real life' examples rather than write them out.
- Provide students with the definitions and generate examples as a group brainstorm.

Teacher Instructions
Pre-activity
1. Introduce students to today's guiding question: "How can the transfer of heat from Earth's interior lead to the movement of tectonic plates on Earth's surface?" Ask them to think about possible answers and list those on paper.
2. Provide students with resources to define and give examples of heat transfer. This may be available in their textbook, through the Internet, etc. Students should define each of the heat transfer terms and provide an example for each term. This may be a review of concepts learned previously.
3. Review the student answers either one on one or with the class to ensure everyone has a developing understanding of the four different types of heat transfer.

Part I

1. Review viscosity from the previous activity by having the students summarize the key points from yesterday's flow activity. Address the definition of viscosity and factors that can affect viscosity. Relate this to the Earth's mantle and its ability to flow slowly over long periods of time.
2. Introduce or review the concept of models with the students. Have a student read the text on their worksheet under the title: Part I- Modeling heat transfer inside Earth.
3. Show students the set-up for the demonstration – use books or other structures to suspend a clear, heat-safe dish over a heat source (for example: a Pyrex baking dish over a sterno can) filled with about an inch and a half of room temperature water. Ask them to make a prediction about where they think the water will be hotter and why. Discuss with class.
4. Turn on the heat source.
5. Have student volunteers record the temperature in the center of the dish close to the bottom (deep) and on the sides of the dish near the surface (shallow) at 2 minute intervals for 10 minutes. It is helpful to have a student write these numbers on chart paper or a whiteboard as you go.
6. After 10 minutes, have all students gather where they can see the dish at eye level. Add 3 drops of food coloring the to the center of the dish while students observe.
7. Have students draw what they have observed on their student paper.
8. Students should write out what kind of heat transfer they observed, and what evidence supports this claim. Discuss these answers as a class. Note: some students may discuss the radiant heat coming from the heat source. This is okay to include, but students should also include the convection happening in the water.

Part II

1. Optional: Show students the piece of fun foam, and let them know this is representing the Earth's tectonic plates in our model. What do they predict will happen when it is placed in the center of the model? Ask them to write their predictions on their paper.
2. Have students gather around the model again. Place the piece of fun foam, in the center of the model. Allow the foam to move in the dish, but remove it before it hits any walls.* Ask students to draw their observations on their paper.
    a. * Removing the foam before it hits the walls will help to avoid student misconceptions concerning plate to plate interactions, e.g. subduction.
3. Discuss the observations as a class before asking students to answer the driving question – "How can the transfer of heat from Earth's interior lead to the movement of tectonic plates on Earth's surface?" - utilizing the C-E-R framework which has been scaffolded for them on their paper.

Making Connections

1. Have students write down their ideas on how this model is different than the Earth's mantle. Discuss these ideas, making sure all students recognize that the mantle is a solid and the model is liquid.
2. Have students add evidence from this activity to their EQ graphic organizer.

Activity 3 - Visualizing Convection in Earth's Interior
Teacher Instructions

NGSS Performance Expectations

MS-ESS2-1. Develop a model to describe the cycling of Earth's materials and the flow of energy that drives this process.

Cross Curricular skills

- Systems and system models
- Energy and matter

Science and Engineering Practice

- Developing and using models
- Analyzing and interpreting data
- Constructing explanations

Materials

- Visualization model Convection animation, heated from below (mpg,1.3 Mbyte) from http://user.uni-frankfurt.de/~schmelin/what-is-convection.html#Englishversion
- Student worksheet: Visualizing Convections in Earth's Mantle

Teacher Instructions

1. Lead students in a discussion review of the model they saw yesterday.
    a. Describe the modeling activity.
    b. What did it represent?
    c. What did they learn about Earth's mantle and plates?
    d. What were the challenges in modeling the Earth's mantle this way?
2. Introduce the new model to the students - it is a computer animation that represents the Earth's mantle. Look at the model once as a group. Ask students to make observations - what do they notice is happening in the model?
3. Read the questions with the students before viewing the visualization/animation another time. The student should complete the questions as they view the visualizations.
4. Students' answers should be discussed. This can be done in pairs, small group or whole class, depending on classroom culture and norms.
5. These answers can also be used to formatively assess students' understanding of convection in the mantle. By the end of this activity, students should be able to articulate the following main points:
    a. the Earth's mantle is solid but can flow over long periods of time
    b. the heat in the mantle is a major factor that allows the solid mantle to flow
    c. heat is transferred in the mantle from the hotter lower portions to the cooler upper portions by means of convection.
    d. convection in the mantle creates currents that move the plates.

Name: _____ Pd:_____
Essential Question Graphic Organizer

Essential Question: How do Earth's plates move?

As we go through these activities over the next few days, our goal is to understand how Earth's plates move. Record the activity name and any evidence we collect that helps us answer our essential question. This evidence will be used to complete the summative assessment at the end of all the activities.

Activity	Evidence
Viscosity of the Mantle Part I- Viscosity of Different Fluids	
Viscosity of the Mantle Part II- Viscosity at Different Temperatures	
Modeling Heat Transfer in the Mantle – Part I	
Modeling Heat Transfer in the Mantle – Part I	
Visualizing Convection in Earth's Interior	

Name: _____ Pd:_____ Date:_____

Viscosity of the Mantle

Investigation Question: How do properties of a substance affect its ability to flow?

Part I – Viscosity of different substances

Make a prediction: Which substance will flow the fastest down the incline? _____

Why do you think that this substance will flow the fastest? _____

_____

_____

Investigating our prediction:

1. Set up your incline:
    a. Cover your cutting board completely with the sheet of wax paper and tape securely into place.
    b. Using your protractor, stack books to set the cutting board on at 45 degree incline.
    c. Place newspaper under the cutting board to catch any spills.
    d. Using your marker and ruler, mark a starting line at the top of the cutting board. Using your ruler, measure 25cm from the starting line and draw a finish line.
2. In the data table below, record your observations of each substance - describe the properties of the substance.
3. Have one group member make sure the stopwatch is cleared and is ready to time. Another group member will pour 10mL of water on the starting line. When the water reaches the finish line, stop the watch. Record the time in the data table below.
4. Clean off the wax paper with your paper towel. Make sure there is none of the substance left on the wax paper that could affect the next trial.
5. Repeat steps 2 to 4 for honey, oil, shampoo, and pudding.
6. If there is another substance you or your teacher want to test, record it in the table below!

Substance	Description of Substance	Time (in s) to go 25 cm (3 Trials)		
Water				
Honey				
Oil				
Shampoo				

Pudding				

Let's revisit our question!

1. Make a claim: Which substance flowed the fastest down the incline?_____

_____

2. What evidence do you have that supports this claim? _____

_____

_____

_____

3. Why do you think this is? What reasons can you give for your claim?_____

_____

_____

_____

Making connections - Flowing in Earth Science

We have been talking about substances "flowing." A substance's resistance to flow is referred to as its viscosity. A substance that flows more easily has low viscosity. A substance that has high viscosity does not flow easily. Sort the substances we tested above by either high or low viscosity.

High Viscosity	Low Viscosity

Liquids are not the only thing that can flow; in fact, all states of matter can flow - gases and solids too. The Earth's mantle is a solid but is able to flow. Thinking about what we know of viscosity, does the Earth's mantle have a high or low viscosity? What may change the viscosity of this substance? Jot some ideas in the space below that you can discuss with your class.

Part II – Viscosity at different temperatures

Make a prediction: How will changing the temperature of the honey change how fast it flows down the incline? _____

Why do you think this? _____

_____

_____

Investigating our prediction:

1. Prepare your cutting board set up as you did in Part I. Your teacher will give you 3 containers of 10 mL of honey.
2. Measure the temperature of each substance with the thermometer and record the temperature in the data table below.
3. Have one group member make sure the stopwatch is cleared and is ready to time. Another group member will pour 10mL of water on the starting line. When the water reaches the finish line, stop the watch. Record the time in the data table below.
4. Clean off the wax paper with your paper towel. Make sure there is none of the substance left on the wax paper that could affect the next trial.
5. Repeat steps 2 to 5 for other two samples of honey.

Temperature	Time to go 25 cm			Average Time to go 25cm
	Trial 1	Trial 2	Trail 3	

Representing our data: On a piece of graph paper, create a bar graph that represents our data.

Let's revisit our question!

1. Make a claim: How did changing the temperature effect how the honey flowed?

_____

_____

2. What evidence do you have that supports this claim? _____

_____

_____

_____

3. Why do you think this is? What reasons can you give for your claim?_____

_____

_____

_____

Putting it all together: Our investigation question was "How do the properties of a substance affect its ability to flow?" Using what we learned in this investigation can we answer this question?

1. I claim: _____

_____

_____

2. I can support my claim because: _____

_____

_____

_____

3. This evidence supports my claim because: _____

_____

_____

_____

Making connections - Flowing in Earth Science

Looking at the temperature of the Earth's interior layers, are they all the same temperature? What effect will temperature differences inside Earth have on the mantle's viscosity? What have we learned that can help us answer the essential question, "how do Earth's plate move?"

Name: _____ Pd:_____ Date:_____

Modeling Heat Transfer in the Mantle

Investigation Question: How can the transfer of heat from Earth's interior lead to the movement of tectonic plates on Earth's surface?

Pre-activity: Complete the following table with the definition and example of different types of heat transfer.

	Definition	Real-life Example
Convection		
Conduction		
Radiation		

Part I- Modeling heat transfer inside Earth

In the last activity we talked about the viscosity of the Earth's interior - the mantle is able to flow very slowly over long periods of time. In this activity, we will use a **model** to see how convection occurs within the Earth. We use **models** in science to represent something that's too big, too small, or happens in a time period that's too hard for us to see in real life. The mantle is a solid, but the water in our model is a liquid because we aren't able to make a solid flow in the time and temperatures we have available in our class!

During the activity, we will record the temperature in two places - deep and shallow areas of the dish - in the table below.

Make a prediction - where will the water be hotter?_____

Why do you think it will be hotter there? _____

_____

_____

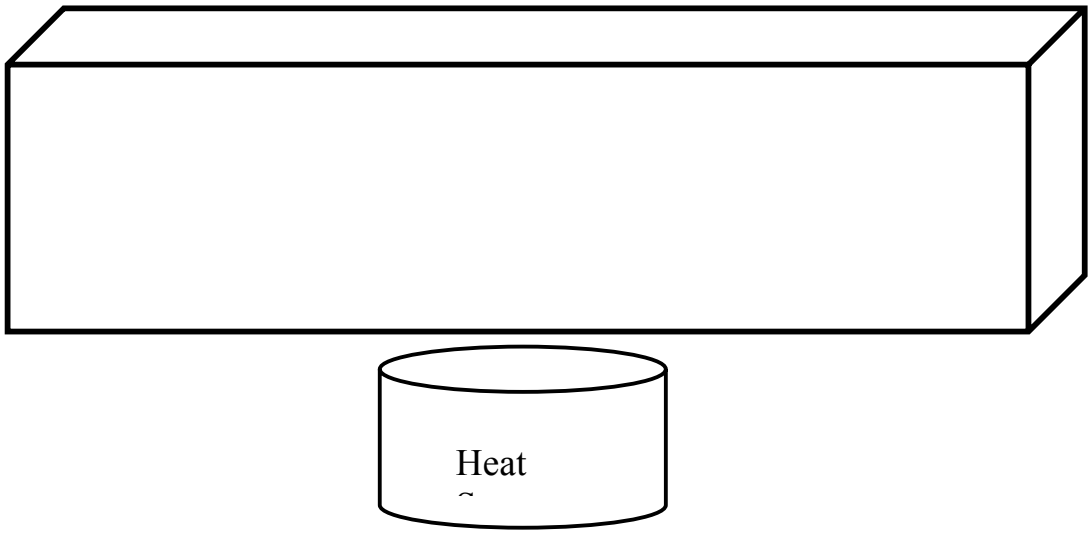
Record the temperatures of the deep and shallow parts of the dish in the table below.

Time (in minutes)	Temperature – Deep (in degrees C)	Temperature – Shallow (in degrees C)
0		
2		
4		
6		
8		
10		

<u>SAFETY NOTE:</u> Please keep away from the flame. Loose hair should be tied up and loose clothing secured.

After 10 minutes, we will add drops of food coloring to the center of the model. Watch as the food coloring moves around in the dish. Draw a picture of what you see in the diagram below. Write any notes underneath the picture.

Observations



Based on your observations, what kind of heat transfer do you think is happening in the model?

_____

What evidence supports this claim?_____

_____

_____

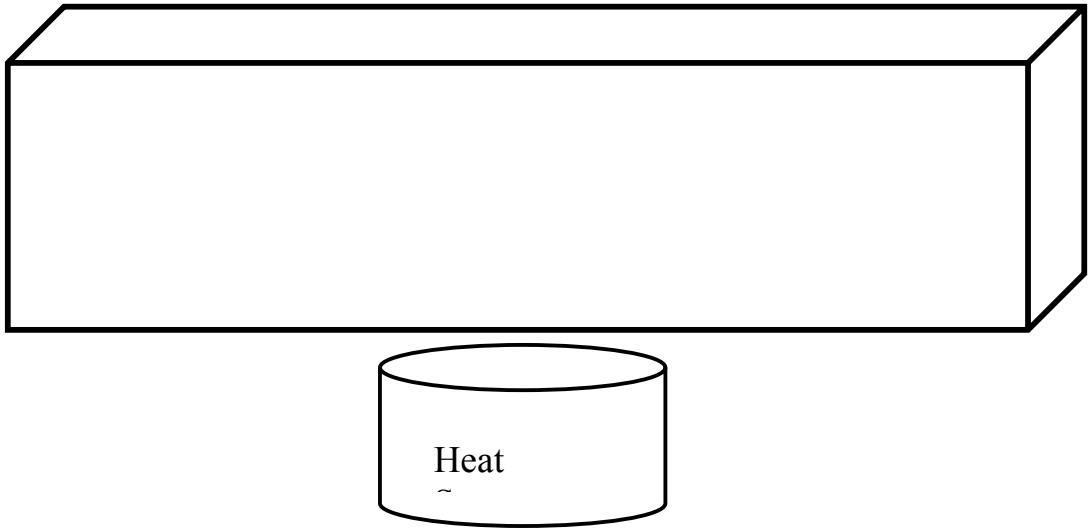
Part II - Modeling plates

Now, we will add a new component to our model, we will use a piece of foam to model the Earth's plates. Make a prediction - what do you think will happen when we place the foam at the center of the model?

_____

_____

In the space below, draw a picture that shows what happened to the foam when we placed it in the center of the model.



Putting it all together: Our driving question was "How can the transfer of heat from Earth's interior lead to the movement of tectonic plates on Earth's surface?" Using what we learned in this investigation, can we answer this question?

1. I claim: _____

_____

_____

2. I can support my claim because: _____

_____

_____

3. This evidence supports my claim because: _____

_____

_____

_____

Making connections - Using Models

How is the model we used different from the Earth's tectonic plates and mantle, which it is representing?

_____

_____

_____

_____

_____

_____

Looking at the model we are using, what do the water, sterno can and foam pieces represent in the actual tectonic plate system?

Sterno can: _____

Water: _____

Foam pieces: _____

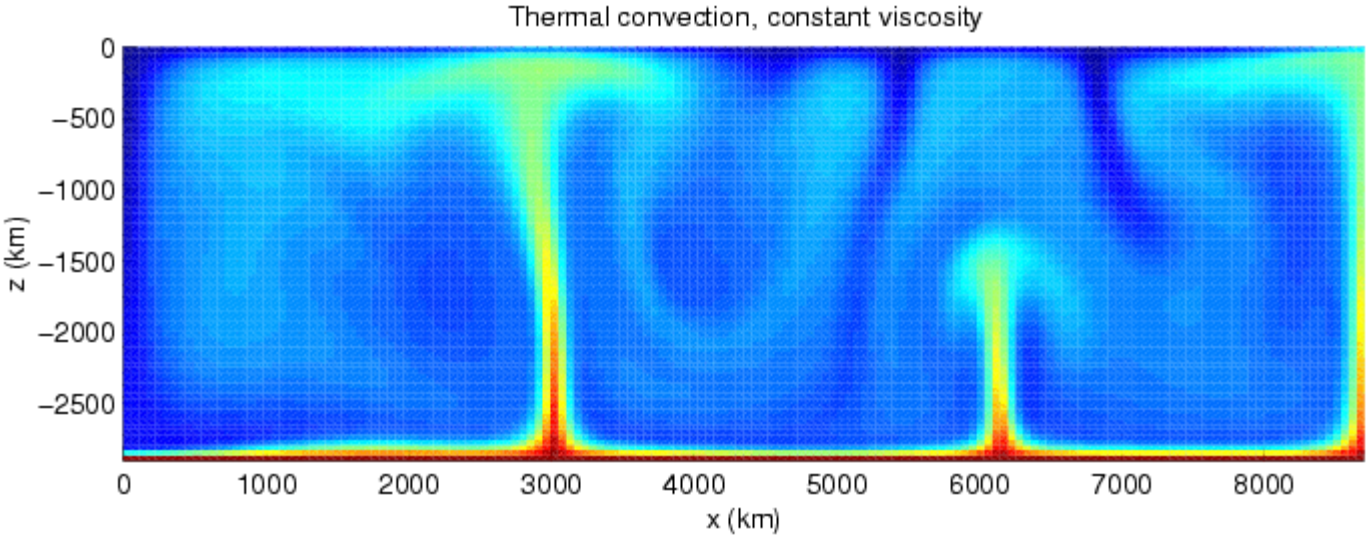
How can this help us answer the question "how do Earth's plate move?" Add evidence to your essential question graphic organizer.

Name: _____ Pd:_____ Date:_____

Visualizing Convection in Earth's Mantle

(adapted from http://user.uni-frankfurt.de/~schmelin/what-is-convection.html - Englishversion)

In our last activity, we modeled the Earth's mantle using water. Today we will look at another model that is made using computer animation. As we look at the model, please answer the questions below:



(sample from visualization animation)

1. What do the colors in the model represent? (What does red mean compared to blue?)

_____

_____

_____

2. What patterns do you see in the model?

_____

_____

_____

3. What causes these patterns?

_____

_____

_____

4. What method of heat transfer do these patterns represent? _____

_____

5. Since this is a model of the Earth's mantle, how does the pattern of heat transfer from earth's interior to earth's surface affect the Earth's plates?

_____

_____

_____

6. Compare this model to the model we created yesterday with water. How are they similar and different? Which one do you think is better at showing us what Earth's mantle is like? Why?

_____

_____

_____

_____

_____

_____

7. What evidence from this activity can help answer our essential question "Why do Earth's plates move?"

Adapted from "Convection in a Fluid" Activity:
https://www.teachengineering.org/activities/view/cub_solar_lesson02_activity

Name: _____ Pd:_____ Date:_____

Summative Assessment

Question: How do Earth's plates move?

Claim: Earth plates move because _____

_____

I can support my claim with the following evidence:

_____

_____

_____

_____

_____

_____

_____

_____

_____

_____

The reason that this happens is because:

_____

_____

_____

_____

_____

_____

_____

	3 – Excellent	**2** – Acceptable	**1** – Needs Revision
Claim	□ Concise statement □ Directly related to question/hypothesis □ Focuses on most important feature	□ Two of three are met, or three are partially met	□ Two or more are not met
Evidence	□ Several pieces of evidence are presented, including students' own observations and accurate measurements □ Directly related to question/hypothesis □ Provides a reasonable amount of evidence (depends on grade level)	□ Two of three are met, or three are partially met	□ Two or more are not met
Reasoning	□ Conclusions about the experiment connect background knowledge and science concept(s) studied in class □ Directly related to question/hypothesis and shows a "big picture" understanding □ Explanation is of reasonable length (depends on grade level)	□ Two of three are met, or three are partially met	□ Two or more are not met