HS.Earth's Systems

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Students who demonstrate understanding can:

HS-ESS2-c. Apply scientific reasoning to show how empirical evidence from Earth observations and laboratory experiments have been used to develop the current model of Earth's interior.* [Clarification Statement: Examples of evidence may include results from drill cores (rock composition with depth), gravity (density with depth), Earth's magnetic field, seismic waves (elastic properties with depth), and laboratory experiments on Earth materials (composition, density, and elastic properties with pressure).]

HS-ESS2-d. Use a model of Earth's interior including the mechanisms of thermal convection to support the explanation for the cycling of matter within the Earth. [Clarification Statement: Explanations of cycling of matter should focus on the plate tectonic process, with ocean lithosphere sinking down into the mantle at subduction zones and new rock coming to the surface at ocean spreading centers, but can also include non-plate tectonic processes such as hot spot mantle plumes. Models of the mechanisms should include the major forces associated with the surface expression of convection, whose impacts on Earth's surface include land formation, volcanic activity and uplift, orogeny, basin formation, crustal deformation, and replenishment of Earth's atmosphere and ocean.]

HS-ESS2-i. Analyze the physical and chemical properties of water to make valid scientific claims about the impact of water on the flow of energy and the cycling of matter within and among Earth systems.* [Clarification Statement: Claims about the flow of energy should include the role of water in the convective transfer of energy through oceanic and atmospheric circulation; the cycling of matter refers to both the flow of water through the various hydrologic cycles, which connect the ocean with other water reservoirs, and the many roles that water plays in moving mineral and rock materials through Earth's systems.]

HS-ESS2-a. Use Earth system models to support explanations of how Earth's internal and surface processes operate concurrently at different spatial and temporal scales to form landscapes and sea floor features. [Clarification Statement: The appearance of the land (e.g., mountains, basins, valleys, plateaus, platforms) and sea floor features (e.g., trenches, ridges, fracture zones, seamounts, abyssal plains, continental slopes) are a result of both constructive forces (e.g., volcanism, tectonic uplift, orogeny) and destructive mechanisms (e.g., stream processes, coastal wave action, mass wasting, weathering, erosion, shoreline progressions).] [Assessment Boundary: Details of the formation of major geographic features of Earth's surface are not assessed.]

HS-ESS2-b. Construct an evidence-based argument about how a natural or human-caused change to one part of an Earth system can create feedback that causes changes in that system or other systems.* [Clarification Statement: Modern civilization depends on major technological systems and these are critical aspects of decisions about technology usage. Local real world examples could include how removing ground vegetation causes an increase in water runoff and soil erosion; building reservoirs increases groundwater recharge; installing a coastal rock jetty changes currents and resulting beach erosion patterns; removing wetlands causes a decrease in local humidity that further reduces the wetland extent; diminishing glacial ice reduces the amount of sunlight reflected from Earth's surface, which increases surface temperatures and further reduces the amount of ice.]

The performance expectations above were developed using the following elements from the NRC document *A Framework for K-12 Science Education*:

Science and Engineering Practices

Developing and Using Models

Modeling in 9–12 builds on K–8 and progresses to using, synthesizing, and developing models to predict and explain relationships between systems and their components in the natural and designed world.

- Develop, revise, and use models to predict and support explanations of relationships between systems or between components of a system. (HS-ESS2-d),(HS-ESS2-a)
- Use models (including mathematical and computational) to generate data to support explanations and predict phenomena, analyze systems, and solve problems. (HS-ESS2-d),(HS-ESS2-a)

Analyzing and Interpreting Data

Analyzing data in 9–12 builds on K–8 and progresses to introducing more detailed statistical analysis, the comparison of data sets for consistency, and the use of models to generate and analyze data.

- Use tools, technologies, and/or models (e.g., computational, mathematical) to generate and analyze data in order to make valid and reliable scientific claims or determine an optimal design solution. (HS-ESS2-i)

Constructing Explanations and Designing Solutions

Constructing explanations and designing solutions in 9–12 builds on K–8 experiences and progresses to explanations and designs that are supported by multiple and independent student-generated sources of evidence consistent with scientific knowledge, principles, and theories.

- Apply scientific reasoning, theory, and models to link evidence to claims to assess the extent to which the reasoning and data support the explanation or conclusion. (HS-ESS2-c)
- Construct and revise explanations based on evidence obtained from a variety of sources (e.g., scientific principles, models, theories, simulations) and peer review. (HS-ESS2-b)

Connections to Nature of Science

Scientific Knowledge is Based on Empirical Evidence

- Science knowledge is based on empirical evidence. (HS-

Disciplinary Core Ideas

ESS2.A: 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-c)
- Motions of the mantle and its plates occur primarily through thermal convection, which involves the cycling of matter due to the outward flow of energy from Earth's interior and gravitational movement of denser materials toward the interior. (HS-ESS2-d)
- Earth's systems, being dynamic and interacting, cause feedback effects that can increase or decrease the original changes. A deep knowledge of how feedbacks work within and among Earth's systems is still lacking, thus limiting scientists' ability to predict some changes and their impacts. (HS-ESS2-a),(HS-ESS2-b)

ESS2.B: Plate Tectonics and Large-Scale System Interactions

- The radioactive decay of unstable isotopes continually generates new energy within Earth's crust and mantle, providing the primary source of the heat that drives mantle convection. Plate tectonics can be viewed as the surface expression of mantle convection. (HS-ESS2-d)
- *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)* (HS-ESS2-d)
- *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-a)

ESS2.C: The Roles of Water in Earth's Surface Processes

- The abundance of liquid water on Earth's surface and its unique combination of physical and chemical properties are central to the planet's dynamics. These properties include water's exceptional capacity to absorb, store, and release large amounts of energy, transmit sunlight, expand upon freezing, dissolve and transport materials, and lower the viscosities and melting points of rocks. (HS-ESS2-i)

ETS1.B: Developing Possible Solutions

- When evaluating solutions, it is important to take into account a range of constraints, including cost, safety, reliability, and aesthetics, and to consider social, cultural, and environmental impacts. (HS-ESS2-b)

ETS1.C: Optimizing the Design Solution

- The aim of engineering design is not simply to find a solution to a

Crosscutting Concepts

Scale, Proportion, and Quantity

- The significance of a phenomenon is dependent on the scale, proportion, and quantity at which it occurs. (HS-ESS2-a)

Energy and Matter

- Energy drives the cycling of matter within and between systems. (HS-ESS2-d),(HS-ESS2-i)

Structure and Function

- The functions and properties of natural and designed objects and systems can be inferred from their overall structure, the way their components are shaped and used, and the molecular substructures of its various materials. (HS-ESS2-c)

Stability and Change

- Much of science deals with constructing explanations of how things change and how they remain stable. (HS-ESS2-b)

Connections to Engineering, Technology, and Applications of Science

Interaction of Science, Engineering, and Technology

- Science and engineering complement each other in the cycle known as research and development (R&D). Many R&D projects may involve scientists, engineers, and others with wide ranges of expertise. (HS-ESS2-c)

Influence of Engineering, Technology, and Science on Society and the Natural World

- New technologies can have deep impacts on society and the environment, including some that

*The performance expectations marked with an asterisk integrate traditional science content with engineering through a Practice, Disciplinary Core Idea, or Crosscutting Concept.

ESS2-c) ▪ Science disciplines share common rules of evidence used to evaluate explanations about natural systems. (HS-ESS2-c) ▪ Science includes the process of coordinating patterns of evidence with current theory. (HS-ESS2-c)	problem but to design the best solution under the given constraints and criteria. (HS-ESS2-c) ▪ When evaluating solutions, all relevant considerations, including cost, safety, reliability, and aesthetics, and to consider social, cultural, and environmental impacts, should be included. (HS-ESS2-i),(HS-ESS2-b)	were not anticipated. Analysis of costs and benefits is a critical aspect of decisions about technology. (HS-ESS2-b)

Connections to other DCIs in this grade-level: will be added in future version.

Articulation to DCIs across grade-levels: will be added in future version.

Common Core State Standards Connections: [Note: these connections will be made available soon.]
ELA/Literacy –

Mathematics –

*The performance expectations marked with an asterisk integrate traditional science content with engineering through a Practice, Disciplinary Core Idea, or Crosscutting Concept.

Optics / Lab Activity

This lesson's Neat-o Interdisciplinary Idea is optics.

Often, optics is a topic covered in a physics class, not necessarily in an Earth science class. However, understanding how light waves are refracted and reflected at the interface between two materials will help us later when we have to visualize how seismic waves travel through the Earth. That's why we're going to have a little optics lab experiment here. The ultimate overriding objective in this lesson is for you to make your own observations using real seismic data and find the core-mantle boundary. Before we jump straight into the activity, let's back up and make sure we understand some principles of optics.

Lab Activity

In this activity, we will calculate the index of refraction of water by measuring the angles of incidence and refraction of light as it passes from air to water.

What you will need:

- Tank of water. A square or rectangular food storage container works well, as long as you can see through it and it is big enough. A fish tank would work really well, too.
- Paper
- Pen
- Straightedge
- Protractor
- Compass
- Three objects that you can see well when looking through the water. Upside down pushpins or screws work. I'm going to use Pez dispensers in my example.

The photo below shows my collection of materials for this activity.

Materials needed for this activity: I taped three big sheets of paper to the top of the table, I have a food storage container filled with water, a straightedge courtesy of Wes who has the office next door to me, a Sharpie marker, a compass, a protractor, and three Pez dispensers (Woodstock, Chewbacca, and SpongeBob SquarePants).

Directions

1. Save the Lesson 4, Activity: Optics Lab [1] worksheet to your computer. You will use this word processing document to record your work in the remaining steps.
   - Save the worksheet to your computer by right-clicking on the link above and selecting *Save link as...*
   - The worksheet is in Microsoft Word format. You can use either Word or Google Docs (free) to work on this assignment. You will submit your worksheet at the end of the activity, so it must be in Word (.doc) or PDF (.pdf) format so I can open it.
2. Mark the location of the tank of water on the paper.
3. Put one of your objects on one side of the tank of water so that if you look through the tank from the other side, you can see it through the water. I'm going to use Woodstock (see photos below):

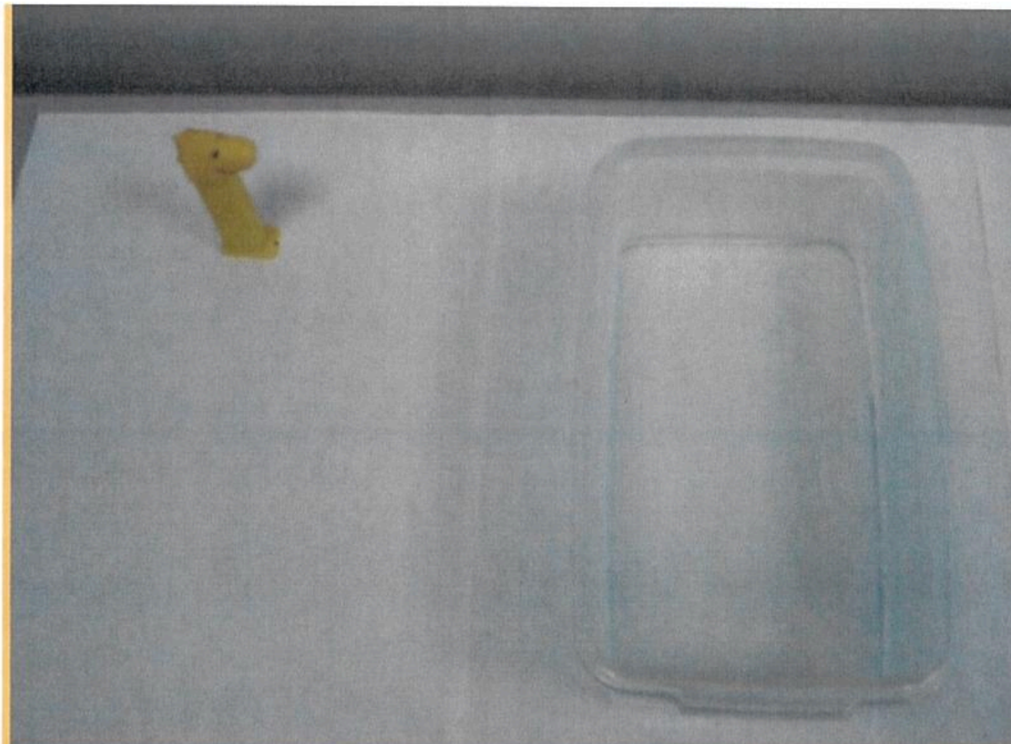


Illustration of step 3. Woodstock is standing on the left side of the tank of water.

4. Look from the other side of the tank at your first object and cover one eye (see photo below):

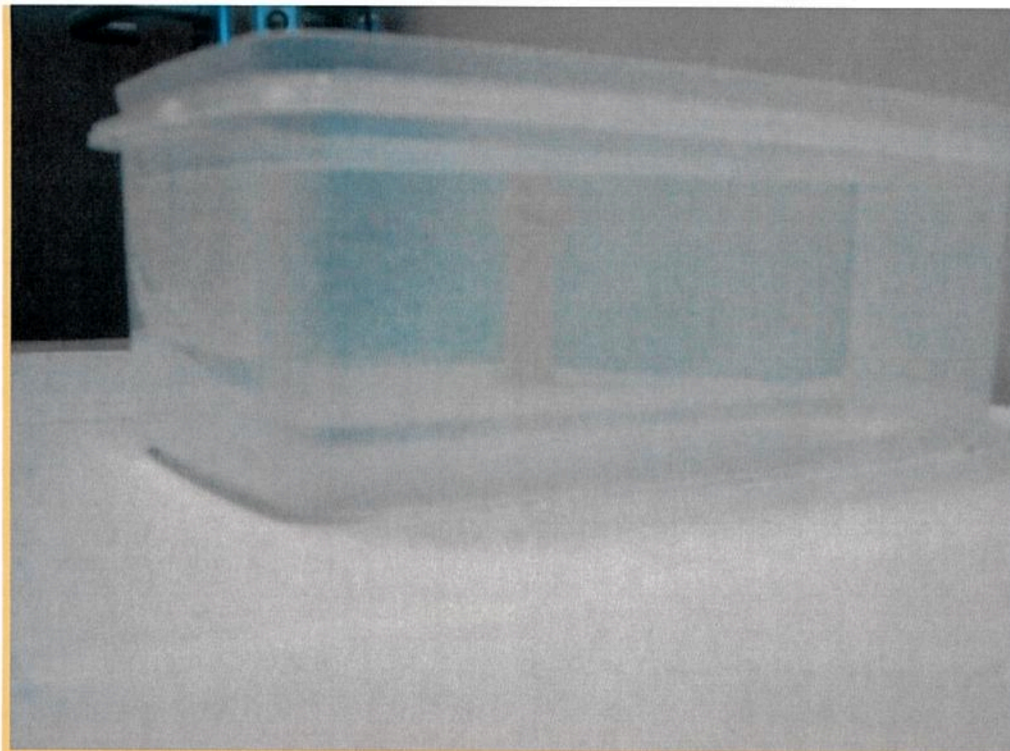
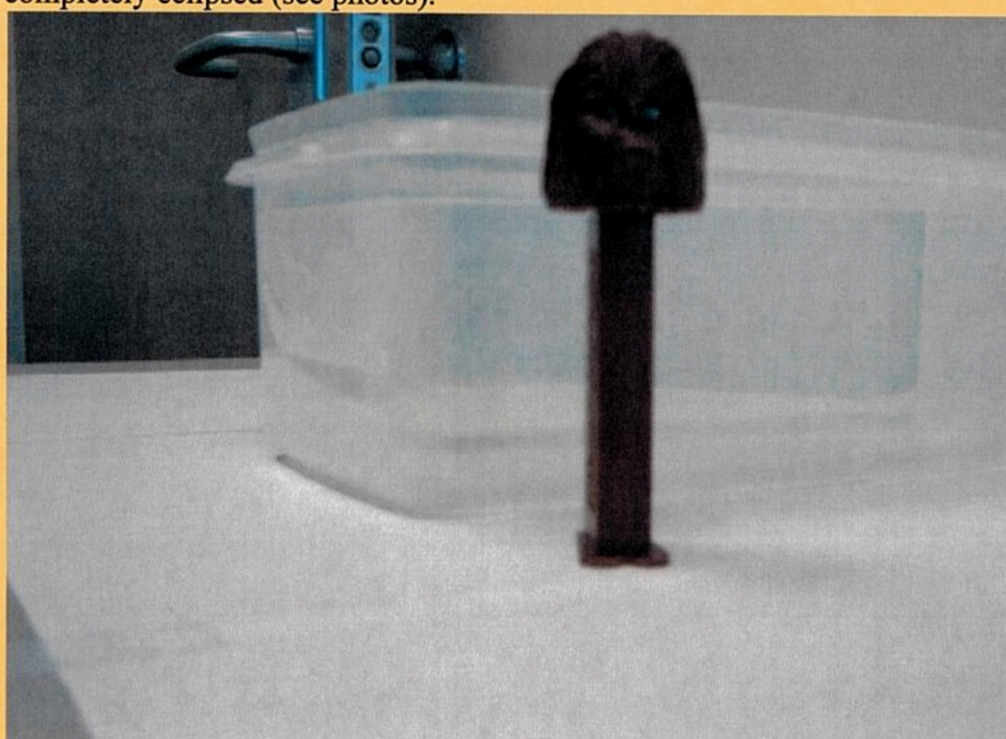


Illustration of step 4. I can see Woodstock through the tank full of water.

5. Now put one of your other two objects between your eye and the tank so that your first object is completely eclipsed (see photos).



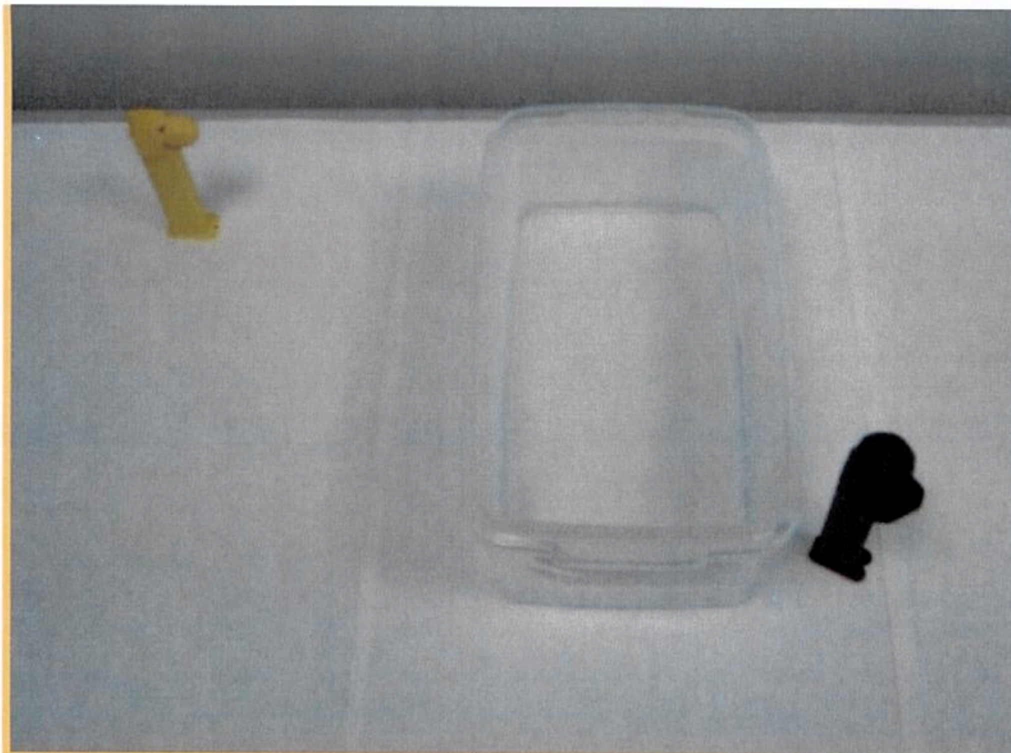
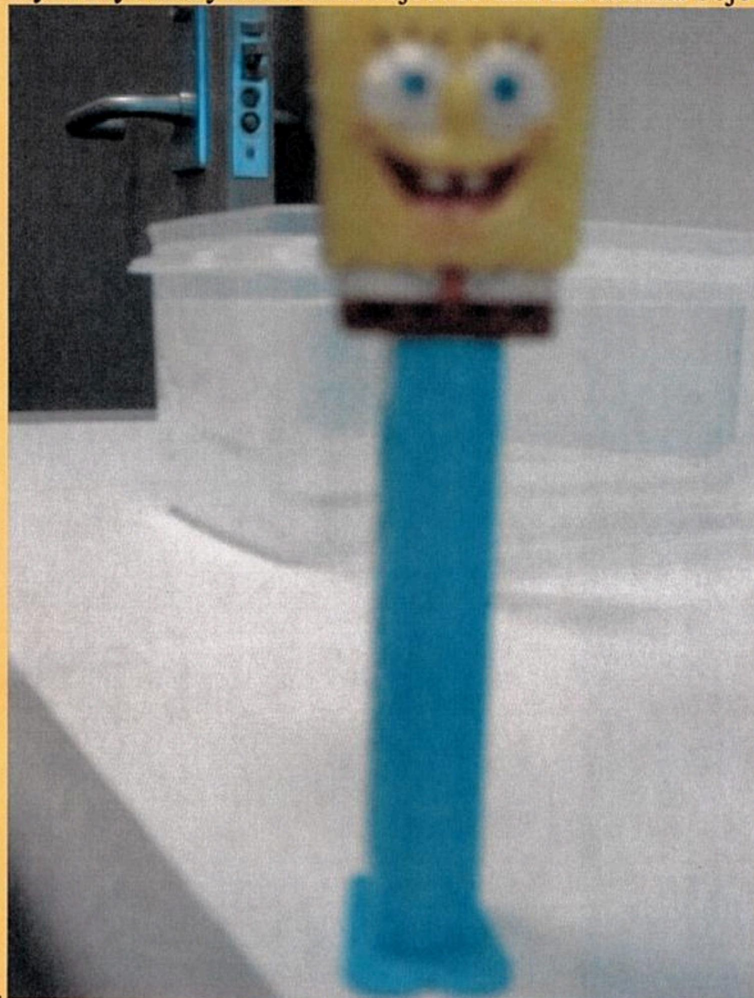


Illustration of step 5, eye view (top) and plan view (bottom). Chewbacca eclipses Woodstock.

6. Now put your third object between your eye and your second object so that the second object is completely eclipsed (see photos).



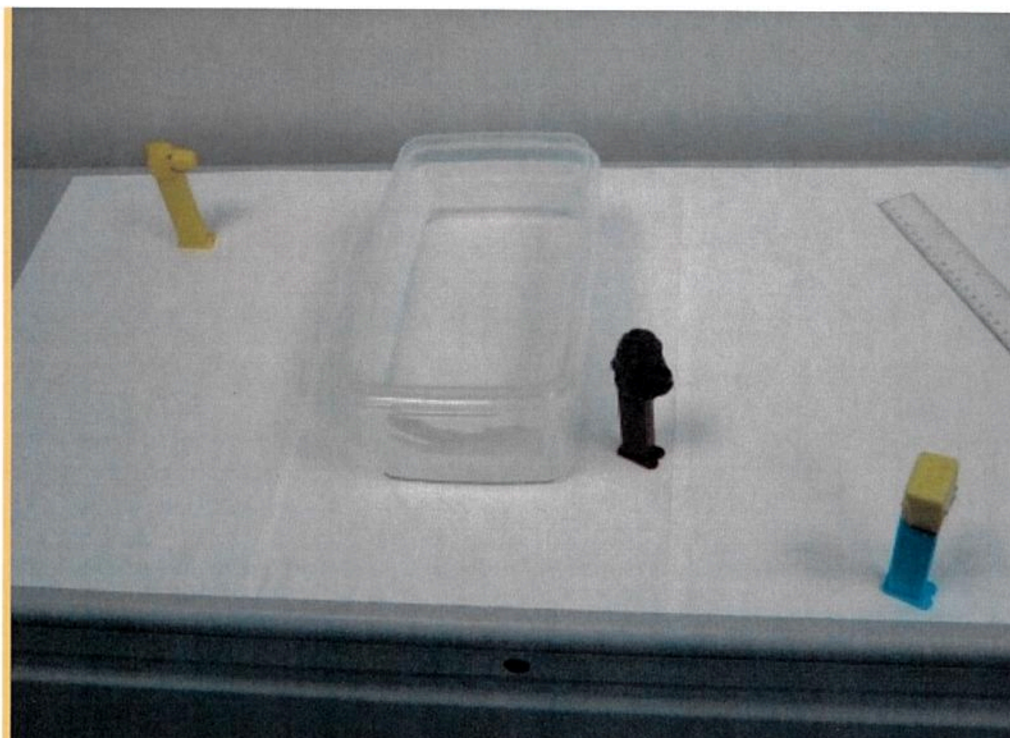


Illustration of step 6, eye view (top) and plan view (bottom). SpongeBob eclipses both Chewbacca and Woodstock.

7. Now take a pen and mark the location of your objects. I made a mark in the little divot right between their feet.
8. Now you can take your objects and the tank of water away from the paper. You should have an outline of your tank and three dots drawn on your paper.

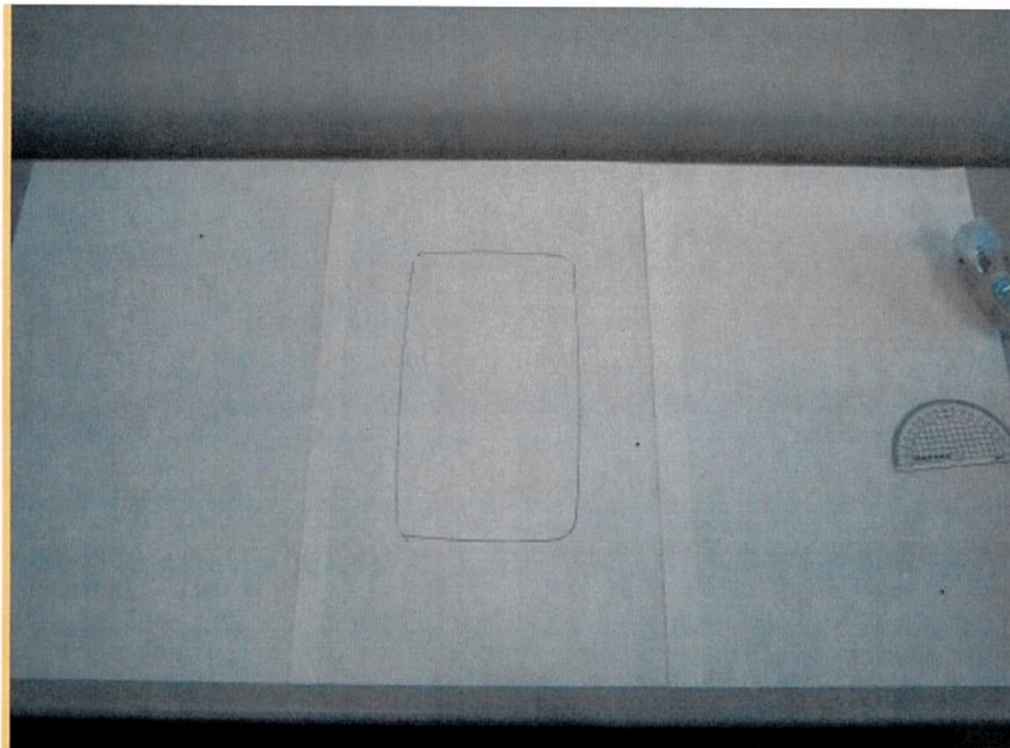
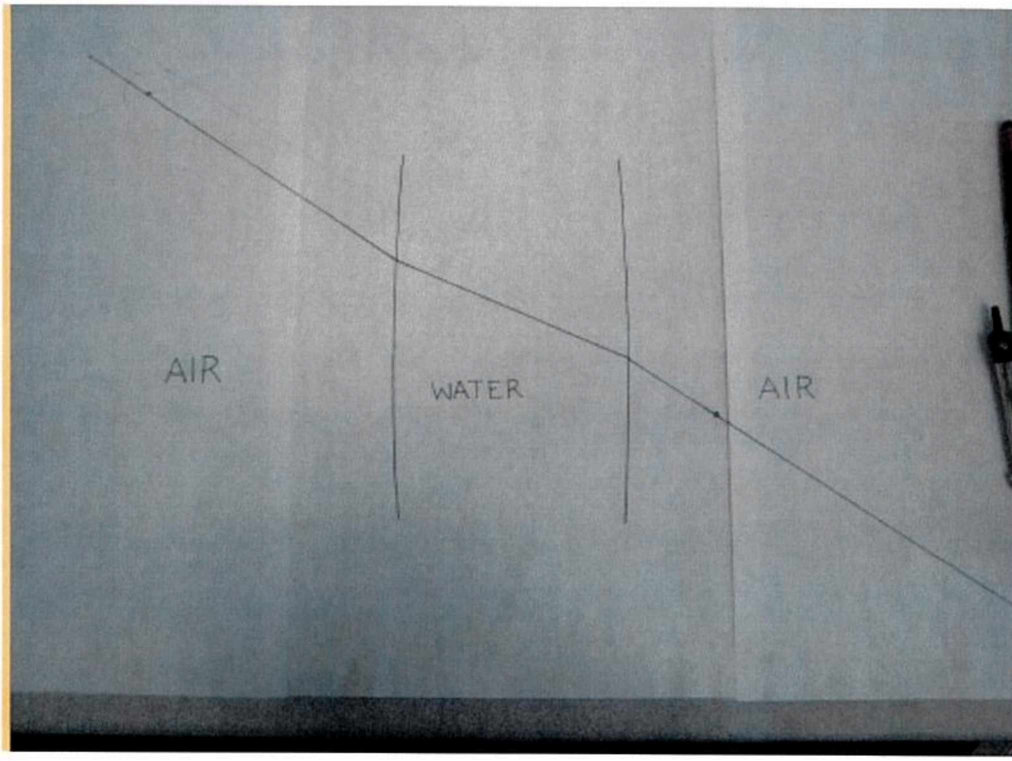


Illustration of step 8. There's the outline of the tank plus three dots showing the former locations of Woodstock, Chewbacca, and SpongeBob.

9. Connect the Chewbacca and SpongeBob dots with a line that extends to the outline of the tank.
10. Draw a line parallel to the Chewbacca-SpongeBob line that goes through the Woodstock point and connects to the outline of the tank on Woodstock's side of the tank. You can use a compass and straightedge to construct a parallel line. There is a Web site that gives a good tutorial showing how to do this: http://www.mathopenref.com/constparallel.html [2]
11. Use the straightedge to connect the two points on each side of the outline of the tank. Now you should have three line segments that show how light traveled from Woodstock through the air, through water, through air again, and to your eye.

Nitpicker alert! It is true that light was bent as it traveled from the air, through the wall of the tank and then through the water, then the wall on on the other side of the tank, then the air again. Unless your tank has really thick walls, like, for example, the underwater viewing area of polar bear exhibits at zoos that have glass several inches thick, we should be able to ignore the effects of the thickness of the tank walls.



12. Draw a line perpendicular to the tank outline at the point at which the incident ray from Woodstock to the tank intersects the tank outline.
13. Measure the angle of incidence. This is the angle between the Woodstock-tank line segment and the perpendicular line.
14. Measure the angle of refraction. This is the angle between the perpendicular line and the ray path inside the tank. See photo below.

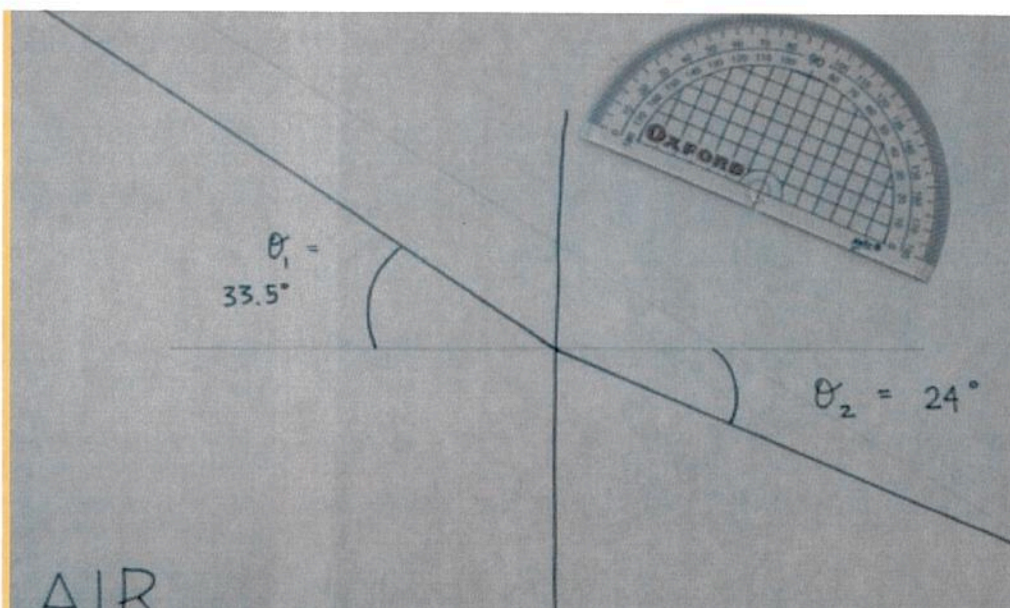


Illustration of step 14. The angle of incidence (θ_1) = 33.5° and the angle of refraction (θ_2) = 24°. Note that the protractor is just sitting there as a prop. I obviously did not measure the angles from way over there!

15. Replace the tank, put Woodstock in a different place and repeat the above procedure. You may also leave Woodstock in the same place and move your eye to a different place. Either way, repeat several times with either or both of the above variations.
16. Using the worksheet for *Lesson 4 Activity: Optics Lab*, and fill out Table 1 with your angle measurements.
17. Eat all the Pez. This will ensure that your blood sugar is sufficiently high to carry out the next set of calculations.
18. Continue completing the *Lesson 4 Activity: Optics Lab* worksheet.

Calculating the index of refraction

1. Fill out the table below with your measurements of the angle of incidence and the angle of refraction.

Table 1. Measured angles for the Refraction of Water lab

Trial #	Angle of incidence	Angle of refraction
Eliza's example	33.5°	24°

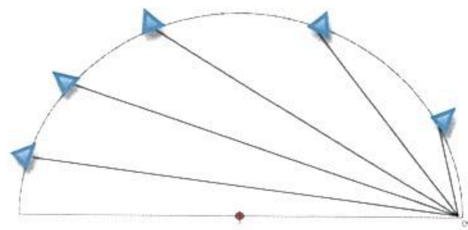
2. Plot the angle of incidence vs. the angle of refraction.
3. Describe/interpret your plot. (i.e., Is there a clear relationship between the angle of incidence and the angle of refraction?)
4. Now calculate the sine of the angle of incidence and the sine of the angle of refraction and fill out a new table of values:

Table 2. Sine of angles of incidence and refraction

Trial #	Sin(angle of incidence)	Sin(angle of refraction)
Eliza's example	0.552	0.407

5. Plot the sine of the angle of incidence vs. the sine of the angle of refraction.
6. Describe/interpret your the plot from #5. (i.e., Is there a clear relationship between these quantities?)
7. The index of refraction of a material is found by dividing the sine of the angle of incidence by the sine of the angle of refraction. In this experiment, we can make that calculation for each trial, or we can fit a straight line to the points plotted in #5. The slope of the line should be the index of refraction. Calculate the index of refraction of water for your dataset.
8. The accepted value of the index of refraction of water is 1.33. Look back over your data and discuss possible sources of error. Draw a line whose slope is 1.33 on your plot from #5 so that you can determine whether you were consistently off in the same direction, or if your results are randomly scattered. [*Even if each of your trials resulted in a perfect job and you got 1.33 every time, I still want you to do this! In my example, I get a value of 1.357, not too bad, but I'm not going to win any awards for precision measurement-making with this result. The most obvious source of slop for me is that the Pez dispensers are pretty thick. This introduces some uncertainty about where to place them in order to for them to eclipse each other in my line of sight.*]
9. What is the largest angle of refraction (of light through water) theoretically possible and why? What was the largest angle of refraction you could reliably measure with your experimental setup and why?
10. Paste in a photo or two of your experimental setup, for posterity.

Determining Earth's Internal Structure



May, 2010 v3.2 Michael Hubenthal – hubenth@iris.edu

Adapted from Earth's Interior Structure - Seismic Travel Times in a Constant Velocity Sphere. (Braile, 2000), Earth's Interior Structure: Addendum (Hubenthal, 2006) and What's THAT Inside our Earth? DLESE Teaching Boxes (2008).

Time – 80-90 Minutes

Suggested Level – Intermediate
Easily modified for high school or undergraduates

5E Phase - Exploration. Students should have already learned about earthquakes and seismic waves prior to beginning this investigation.

Materials List

- Introduction
  - 1 Blown egg (one for each section you teach as they may break)
  - Classroom computer and video projector
  - Slide presentation
    www.iris.edu/hq/resource/determining_internal_structure
- Activity 1
  - Theoretician's worksheets (enough for half of class)
    Materials below are for each group of ~3 theoreticians
    - Semi-Circle Earth Scale Model – both left and right half
    - Meter sticks
    - Rulers
    - Protractors
    - Tape
  - Seismologist's worksheets (enough for half of class)
    Materials below are for each group of ~3 seismologists
    - Seismic record section (see Appendix A)
    - Rulers
  - Seismologist/Theoretician spreadsheet
    http://www.iris.edu/hq/resource/determining_internal_structure
- Activity 2 (class set)
  - Full Circle Earth Scale Model
  - Scissors
  - Rulers
  - Protractors

Content Objectives - By the end of the exercise, students should be able to:

- Demonstrate that Earth can't be homogenous.
- Explain how the internal structure of Earth (concentric layers of different density and composition) is inferred through the analysis of seismic data.
- Explain the role models play in the scientific process, especially when used in combination with observational data.
- Explain how models are refined through the collection of additional data

- Discuss how working in a team to make data-gathering and procedural decisions provides an efficient means for completing tasks, provides peer support to check work and to develop conceptual understanding.

Lesson Description

In this unique lesson (Table 1), students complete two related activities to examine seismic evidence and determine that the Earth must have a layered internal structure and cannot have a homogeneous composition. This lesson is also unique in its approach to the process of science. Using an inquiry approach, students are divided into two teams (theoreticians and seismologists) to test the simplest hypothesis for Earth's internal structure; a homogeneous Earth. Theoreticians create a scale model of a homogeneous Earth and using an average seismic wave velocity make predictions about when seismic waves should arrive at various points around Earth. Seismologists then interpret actual seismic data from a recent earthquake to determine seismic arrivals at various points around Earth. Following this the two groups then compare and interpret the implications of their data using a second scale model.

OPERA	Time (min)
Open	5
Prior knowledge	10
Explore/Explain	30
Reflect	15
Apply	20
	80-90

Table 1. This instructional sequence includes two activities. The procedure for each activity is described below.

Note: To make instructional decisions of the author explicit to all teachers a step-by-step approach is included in the speaker's notes section of the associated Powerpoint. While this results in a somewhat prescriptive resource, this is not the intent. We encourage all readers to alter their instruction to more fully fit their own teaching situation.

Instructional Sequence

Open (5 Minutes) - Guided questioning plus the image of an egg encourages students to consider how they could "know" what is inside of something without "seeing or experiencing" it. Student attention is captured and the point is emphasized when the teacher shows and then tosses a pin-hole egg to an unsuspecting student with "unexpected" results. **Sides 2 and 3**

Prior Knowledge (10 Minutes) - Guided questioning plus the image of Earth from space is used to elicit and make explicit students' prior knowledge about Earth's interior structure as well has helping students to identify "how they know" this information. The teacher guides the discussion to suggest that students' own evidence from life experience (excluding lava seen on TV) suggests that there are rocks/dirt underground. By applying Occam's Razor, which says that the simplest explanation that explains all the data tends to be the best one, a testable hypothesis for students is that Earth is made of solid rock all the way throughout (homogeneous). Given the size of Earth, a model is needed to test this. **Slides 4 – 7**

(Optional) **Slides 8** emphasizes why models are needed in science (if you have already covered this explicitly in previous instruction this should be a review for emphasis).

Explore/Explain (30 Minutes) – **Activity 1** emphasizes the idea of testing a hypothesis by comparing modeled data to observations. Half the students will create a scale, homogeneous Earth model to predict how long it *should* take seismic waves to reach various distances around Earth. Simultaneously the other half of the students will analyze a set of seismograms from a real earthquake to determine how long it takes for the seismic waves released from a real earthquake to arrive at various points on Earth's surface. Students will then graph their data and explore how well the model fits reality. Ultimately students will conclude that the observations do not match the predictions so they can reasonably assume that the Earth is not homogenous or made entirely of rock. ***Slides 9 - 19***

Reflect (15 Minutes) – In **Activity 2**, students reflect further on the data and identify an anomalous feature in the observed data. By creating a second scale Earth model students can map this anomaly back to the real Earth that defines the P-wave shadow zone. ***Slides 22 - 25***

Apply (20 Minutes) – In the continuation of **Activity 2** students apply their new understanding of the P wave shadow zone to multiple earthquakes distributed around the globe. As students map out the shadow zone for each event, a pattern defining the boundary of the outer core emerges. ***Slides 26 - 29***

Activity 1 – Comparing model data with observations

Teacher Preparation

- Copy student handouts (half the class will be seismologists and the other half theoreticians)
- Print out and copy a Record Section for each seismologists group (either the sample from http://www.iris.edu/hq/resource/determining_internal_structure or use the instructions in Appendix A of this document to obtain one from a recent earthquake)
- Measure each half of the Semi-circle Earth Scale Model to verify that it printed with a radius of 19.9cm. If it is not correct make sure that printing options to "scale the page to fit the printable area" and "auto-rotate and center" are turned off and reprint
- Make enough copies of the Semi-circle Earth Scale Model for each theoretician group to have one.

Procedure

1. Assign students into small groups; groups of three work well.

2. Divide the groups into half. For the exercise one half will be Seismologists while the remaining students will be Theoreticians.

3. Distribute the following to the seismologists:
   - Seismologist worksheet
   - Record Section
   - Rulers

4. Distribute the following to the Theoreticians:
   - Theoretician worksheet
   - Semi-Circle Earth Scale Model
   - Meter sticks
   - Rulers
   - Protractors
   - Tape

5. Indicate that you will first review the instructions for the seismologist because the Seismologist's work has the fewest steps to remember (but it takes just as long) and then the Theoreticians, who have more steps. Plus it is very useful for both groups to listen to the others instructions to they have a sense of what the other group is doing.

6. Review Seismologist instructions **Slides 10 – 14**.

7. Review Theoretician instructions **Slides 15 – 19**.

8. Allow the groups time to complete the assignment using the worksheets.

9. Have the Seismologists and the Theoreticians combine their data. There are three ways to facilitate the combination;
   - *Quick* – Groups report out their findings to the teacher who combines the data into the spreadsheet that graphs automatically. This is done using a video projector in front of the class. *Note: This works best to collect the predicted model before the observed data.*
   - *Medium* – Pair each group of seismologists with a group of theoreticians to create multi-discipline teams. Each group will then enter their data together onto a

preformatted spreadsheet that automatically graphs the team's data. *Note: A class set of computers is required.*

- *Long* – Pair each group of seismologists with a group of theoreticians to create multi-discipline teams. Each individual group constructs a graph of their data by hand. Next, the team then compares the two graphs to see if the predicted model matches the observations. *Note: Graph paper is required.*

9. Interpret the data with students

There are several items that can be discussed with students when examining their data. Figure 1 below shows sample student data. *Your students' observed data might look slightly different depending on the density of seismic stations thus the # of degrees below are approximate:*

- Emphasize that the model data does accurately predict reality.
  - Prominent discrepancy – Something interrupts the waves
    - The model data follows a continuous curve while the observed data has a noticeable jump between ~100 and 120 degrees.
    - Students will explore this feature further in Activity 2.
  - Other discrepancies - the velocity of seismic waves in the real Earth cannot be constant
    - Observed data arrives later than predicted close to the event
    - Observed data arrives earlier than predicted at ~90 degrees
    - Observed data arrives very late after ~120 degrees
- The curving points of the model data appear surprising, as this should indicate that the seismic waves were accelerating in the model despite the assumption of a constant velocity of 11km/s. This occurs because the distances we are plotting are on a nearly spherical Earth. Thus, the distance the energy travels to reach each station becomes proportionally less the close on the far side of Earth. For example, the distance the energy travels to reach a station on the model at 60 degrees = 19.8cm, 90 degrees = 28.1cm, 120 degrees = 34.2cm. and 150 degrees = 38.2cm. Thus the interval between 60 and 90 is 8.3cm, between 90 and 120 is 6.1cm, and between 120 and 150 is 4cm. Thus the energy is not accelerating.

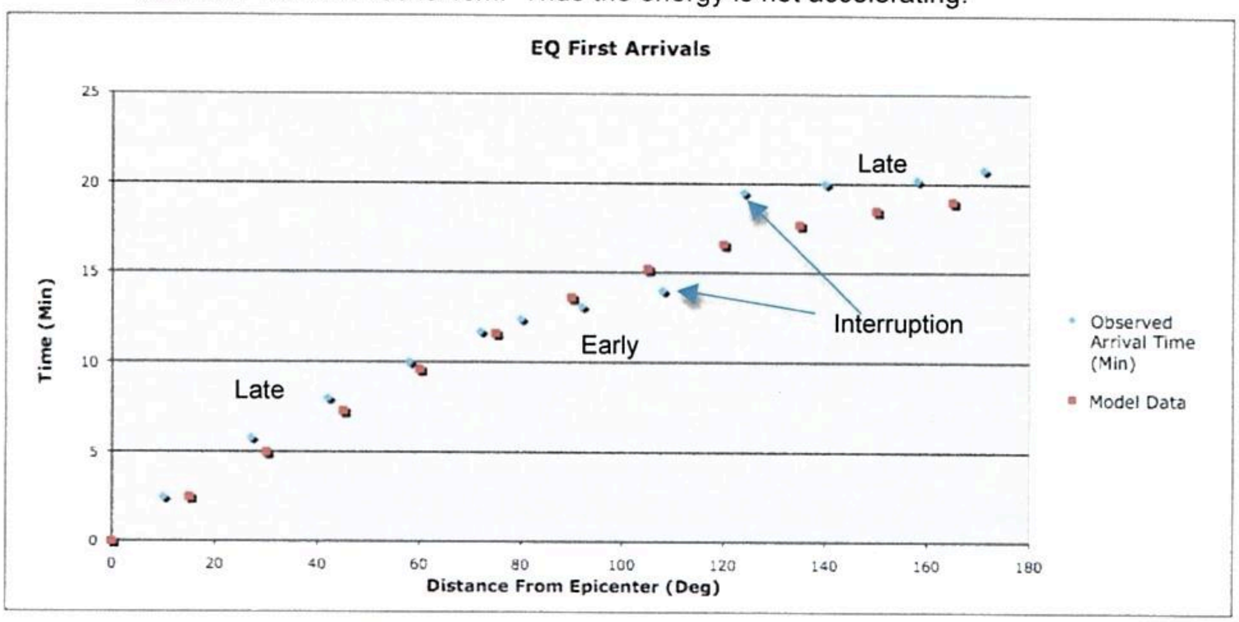


Figure 1: Student graph of model versus observed arrival times

Activity 2 – Examining the implications

Teacher Preparation

- Measure the Full-circle Earth Scale Model to verify that it printed with a radius of 5cm. If it is not correct make sure that printing options to "scale the page to fit the printable area" and "auto-rotate and center" are turned off and reprint
- Make copies of the Full-circle Earth Model for each student.

Procedure

1. Provide each student with the following:
   - copy of Full-circle Earth Scale Model
   - protractor
   - ruler
   - scissors

2. Students should indicate the epicenter of an earthquake at 0 degrees on the right edge of the Earth A of their model with a dot. **Slide 22**

3. Examine the graph of the observed data they previously generated to determine where the interruption of the seismic waves appears to occur.

4. Students should measure a geocentric angle based on their data (*108 degrees based on the example data above. You data may vary slightly*), to the northern hemisphere and make a mark on Earth's surface. Use your ruler to connect the epicenter to the mark you just drew on Earth's surface. **Slide 23**

5. Repeat this procedure but mark the southern hemisphere's surface. **Slide 24**

6. Label the area inside the angles drawn as the P-wave shadow zone. **Slide 25**

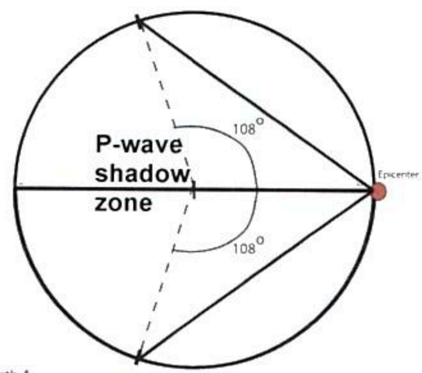


Figure 2. Based on seismic data students can model the P-wave shadow zone.

7. Have students reflect on the following discussion questions in their lab notebooks:
   - What sort of structure have we determined so far?
   - How has the seismic data helped us determine Earth's interior structure?
   - Examine the record section again for this area and consider how this "shadow zone" might be like a persons shadow on the ground.

8. Now that students have developed a model of the P-wave shadow zone, lead students to see that with more data, we might develop a more revealing image.

9. Instruct students to cut out the wedge-shaped P-wave shadow zone. This represents the area that does not receive direct P-waves from an earthquake. **Slide 26**

10. To model the occurrence of additional earthquakes place the point of the wedge shaped cut-out on surface of Earth B while aligning the curved arc of the wedge with the opposite side of Earth B. The point on the cone indicates the location of another earthquake epicenter. **Slide 27**

11. Students should trace the straight edges of the wedge to indicate the area where P-waves from the earthquake do not arrive.

12. Have students repeat this procedure for a number of earthquakes at different locations, each time tracing out the P wave shadow zone. This is an excellent time to explore the idea of how much data is adequate. **Slide 28**

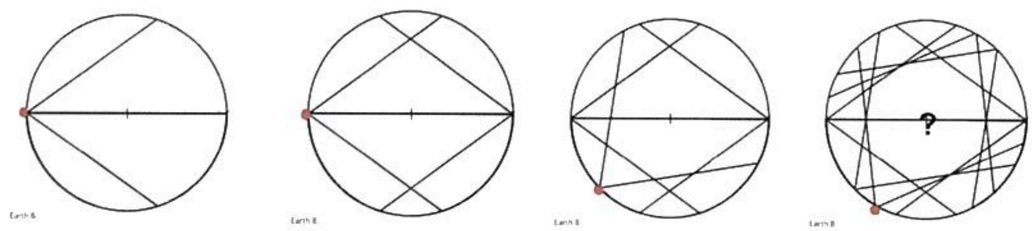


Figure 3. By mapping the P-wave shadow zone for multiple earthquakes, Earth structure becomes apparent.

13. Have students reflect on the following discussion questions in their lab notebooks:
    - As additional earthquake data is added, what shape is being defined in the interior of Earth Model B?
    - What do you think this new inner circle represents?
    - Why has our model improved from the point of previous questions?

14. Calculate the radius of the core of their Earth Model B using the scale provided. The scale of the model is 1cm: 127,420,000 and there are 100,000cm in 1km.

15. Show students the IRIS poster "Exploring the Earth Using Seismology." Convey that the radius of the outer core of Earth is estimated to be ~3486km, that while this exercise reveals a smooth boundary between the core and mantle current research suggests a boundary that has a substantial amount of topography and review the concepts covered. (Slide 29)

16. Have students reflect on the following discussion questions in their lab notebooks:
    How well does your model radius of the outer core match?
    Where are there likely sources of error?
    Considering the core was discovered only in 1906 is it possible that the current model may have further refinements?

Sources of error include: accuracy of tools used, issues of scale etc, students miss-interpretation of the seismic data or sparseness of data to carefully define the boundary (e.g. a record section might only have data from a station at 92 degrees and then another at 118 degrees).

Teacher Background

Discovery of Earth's Core

Figure 4. Richard Oldham (1858–1936)

Irish geologist Richard Oldham made two fundamental discoveries that have greatly influenced the development of the field of seismology. First, through a detailed study of the Assam earthquake of 1897 and in 1900 Oldham was the first to identify clearly the primary (P) and secondary (S) seismic waves that had been predicted by the mathematician Siméon Poisson on theoretical grounds. Secondly, although Earth's core had been previously inferred from the Earth's gravity, Oldham provided the first direct evidence that the Earth had a central core in 1906. Similar to the activities above, he examined the arrivals of the primary waves. Oldham writes… "there remain two important questions to be answered, namely the size of the core and the rate of transmission of the waves in it. As regards the size of the core, we have seen that it is not penetrated by the wave-paths which emerge at 120°; and the great decrease at 150° shows that the wave-paths emerging at this distance have penetrated deeply into it. Now the chord of 120° reaches a maximum depth from the surface of half the radius, and we have seen that the wave paths up to this distance are convex towards the centre of the Earth, so it may be taken that the central core does not extend beyond 0.4 of the radius from the centre."

P-wave Shadow Zone

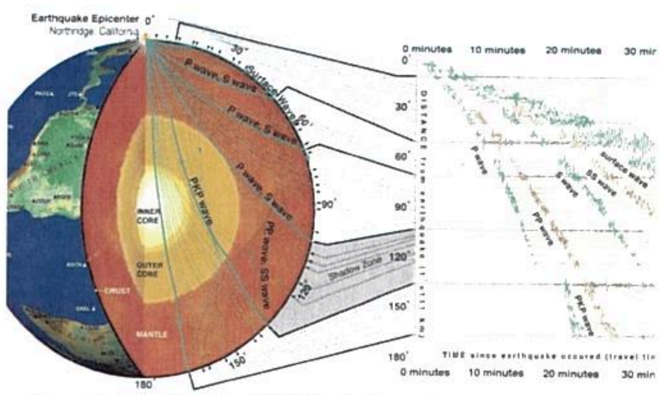


Figure 5. Seismic data, 1994 Northridge, CA earthquake, and the energy's travel path through Earth

A common misconception put forth by figures in many Earth Science textbooks is that no seismic energy arrives with in the shadow zone. As you can see in the record section, Figure 5, lots of seismic waves (including compressional) are recorded by seismographs located in the shadow zone. This energy has been refracted or reflected to arrive there. Thus, it is only "direct" P-waves that don't arrive in the shadow zone. This phenomena is very similar to a student's shadow on the ground. Their shadow is not the absence of all light. Rather it is an area that is not able to receive direct light but does receive light that has refracted around the student or has reflected off of nearby objects.

Current research now suggests that P wave shadow zone actually begins at ~98 degrees away from the epicenter. However, strong arrivals from P waves diffracting around the core of Earth can be seen out to approximately 104 degrees away before decaying significantly. For large events, like the 2/27/10 M8.8 Chile earthquake shown in Figure 6, these diffracted P waves can be seen well beyond 120 degrees. For example, if one carefully examines the data for the stations within the shadow zone you will notice that the first arrival of seismic energy is slightly delayed and has a noticeably lower amplitude than the direct P wave arrivals at ~100 degrees.

Appendix A – Obtaining Seismic Record Sections

A record section (Figure 6 above) is a set of seismograms from a single earthquake recorded at various stations around the globe. These seismograms are plotted vertically with time on the Y-axis and distance away from the epicenter in degrees on the X-axis. To obtain a record section for use with this activity two options exist.

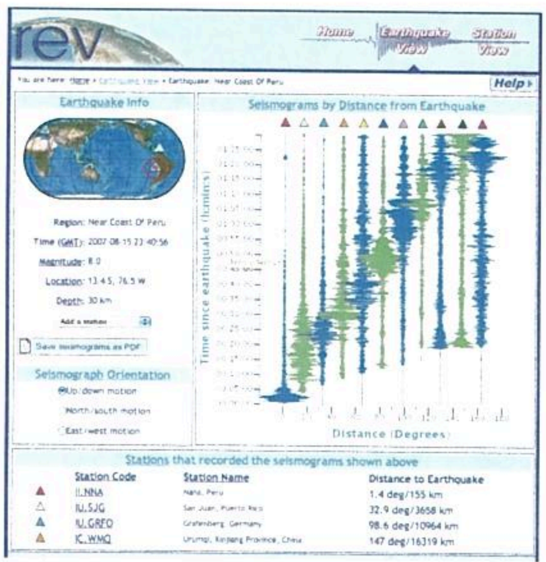
Option 1

A seismic record section from the Haiti earthquake has been provided for use with this activity in the downloadable file "Earth_Structure_Handouts.zip" available at http://www.iris.edu/hq/files/programs/education_and_outreach/lessons_and_resources/docs/REVEarthStructure/Earth_Structure_Handouts.zip

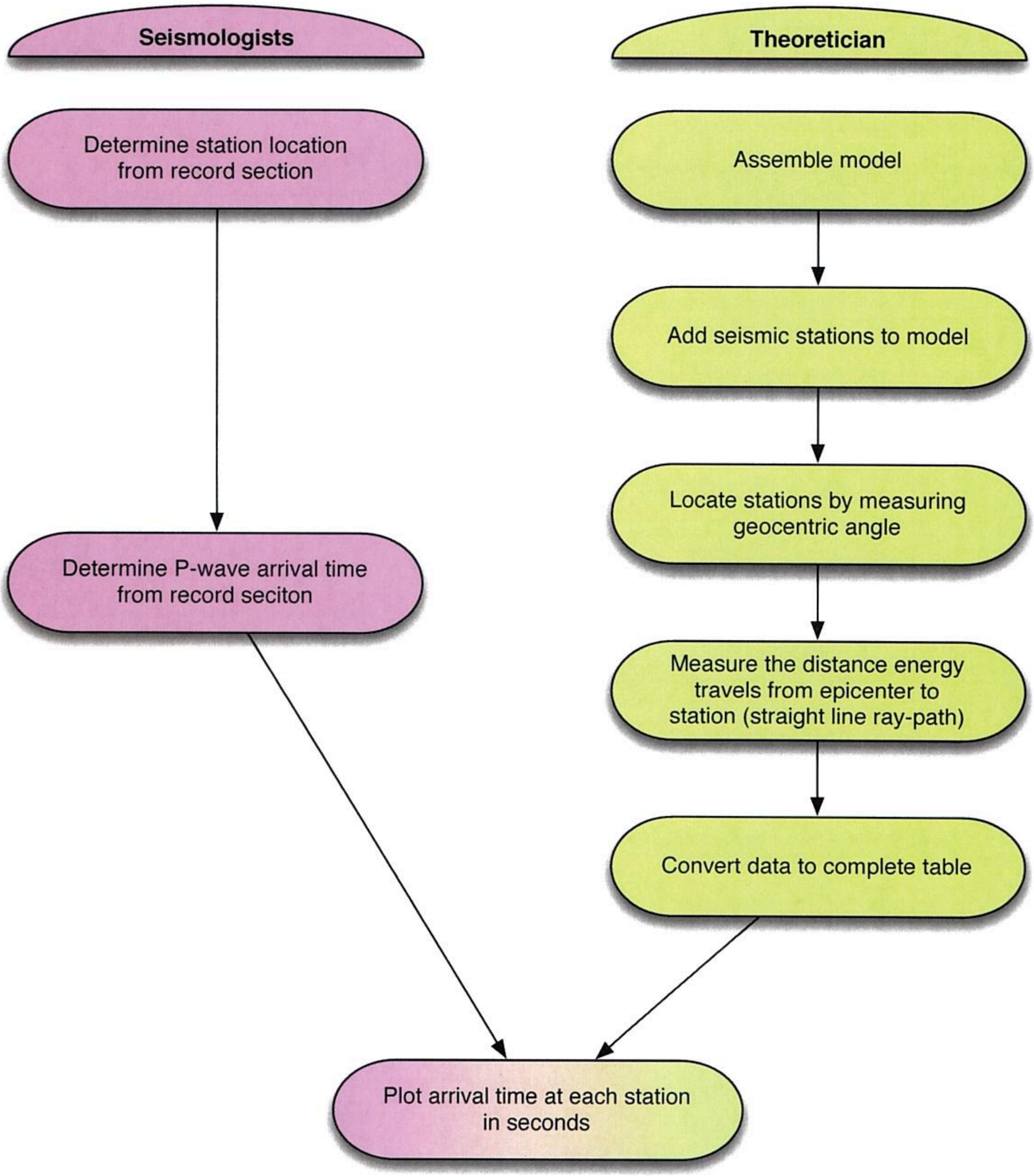
Option 2

To get a record section for a recent newsworthy event, visit the Rapid Earthquake Viewer (REV) at: http://rev.seis.sc.edu/. Please note that REV does not contain all earthquakes that occur. Instead, to make it easier for non-seismologists to get reasonable data, REV provides only earthquakes that have occurred recently, are larger than M 4.0 and have reasonably good data available.

1. Click on Earthquake view
2. Select an earthquake of interest from the world map. Recent events > M 6 but < M 8 are ideal for this activity as they are large enough to have been adequately recorded globally but not so large that the diffracted P phase is strongly recorded in the P wave shadow zone (described previously).
3. The next page (shown at right) has three components
    a. An event information box in the upper left,
    b. A record section displayed on the right side of the page
    c. A list of stations in the record section across the bottom of the page



4. Examine the record section and determine if it has a relatively even distribution of seismograms ~ every 10 to 12 degrees. This is especially important between 100 degrees and 120 degrees.
5. If not, add additional stations at the desired location from the drop-down menu found in the details box at the top left of the page. In some cases, stations may not be available at the specific distance you would like for two reasons. First, there may be no station there because of the oceans. Alternatively, the stations at that distance may not have good data available.
6. Continue to add stations until the record section has an adequate distribution of seismograms.
7. Select the save as PDF button from the event information box.
8. Print this pdf.



Activity 1 – Comparing model data with observations

Seismologist worksheet

Materials (for each pair)

Background: The simplest solution to the question "What is beneath our feet" is a homogeneous Earth, or one comprised entirely of the rock we see at the surface. Since seismic waves travel through Earth, they make a useful tool to "probe" the inside of Earth to discover what might actually be inside.

Task: Your task is to help test if Earth is homogeneous by analyzing a set of seismograms from a single earthquake to determine how long it *actually* takes for the seismic waves released from an earthquake to arrive at various points on Earth's surface.

Implications: If your findings match the findings of the theoreticians then Earth is homogeneous or all rock throughout. However, if your observations do not match the theoreticians' findings, than we can reasonably assume that the Earth is not homogenous or made entirely of rock and will need to develop a new model.

Record section
Ruler

Procedure to Determine Travel Time for Waves

A record section (Figure 1) is a special way of displaying a collection of seismograms from a single earthquake recorded at different points on Earth. Each seismogram is plotted according to its distance from the epicenter on the x-axis (the distance from the seismograph to the epicenter is provided in degrees as measured by the geocentric angle shown in Figure 2) and the time since the earthquake on the y-axis.

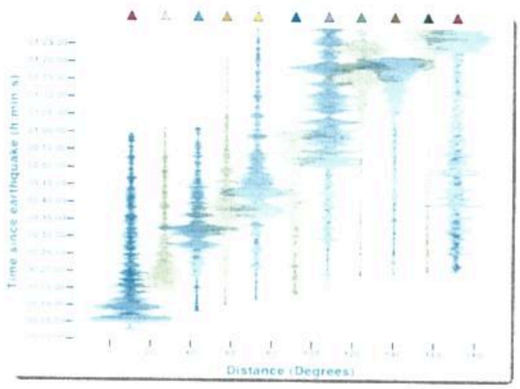


Figure 1: A record section is a special way of displaying a collection of seismograms from an earthquake.

Step 1: Record the distance of each seismograph from the earthquake (represented by its seismogram in the record section), in terms of geocentric angle in the table below.

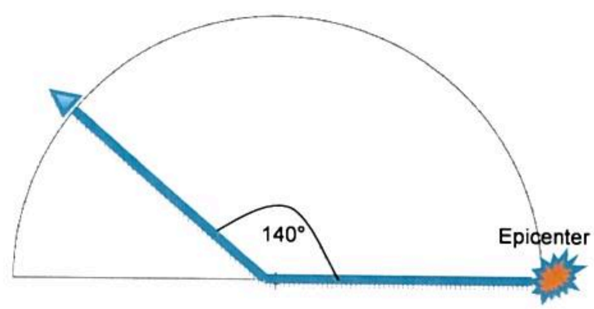


Figure 2: The geocentric angle is measured from the focus of the earthquake, through the center of Earth to the station location at the surface.

Step 2: Examine each seismogram and identify the first arrival of energy at that station (Figure 3). Using a ruler read the scale on the y-axis to determine how long it took the energy to travel to that station. Record this information in the table below.

Step 3: Compare your results with another group of seismologists who used the same earthquakes and stations.

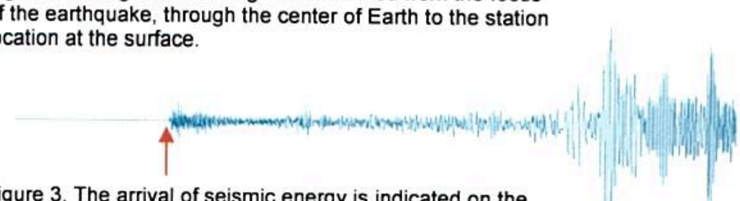


Figure 3. The arrival of seismic energy is indicated on the seismogram by a change from the background or previous signal

Step 4: Provide your teacher with your group's final data or enter the data from your table into the spreadsheet or graph provided by your instructor.

Seismologist Data Table

Station Number	Station Distance (degrees)	Travel time (min)

Questions for the team to answer in their science notebook:

- Describe any difficulties you and your team had generating your data.
- Describe any areas where error might have been introduced into your data.
- Describe any trends and oddities you notice in your data.
- Compare the arrival times the theoreticians found with what the seismologists observed in Earth. Describe how they are like and unlike one another.
- What does this imply about our hypothesis that the Earth's interior is homogeneous Earth, or comprised entirely of the rock we see at the surface? How do we know?

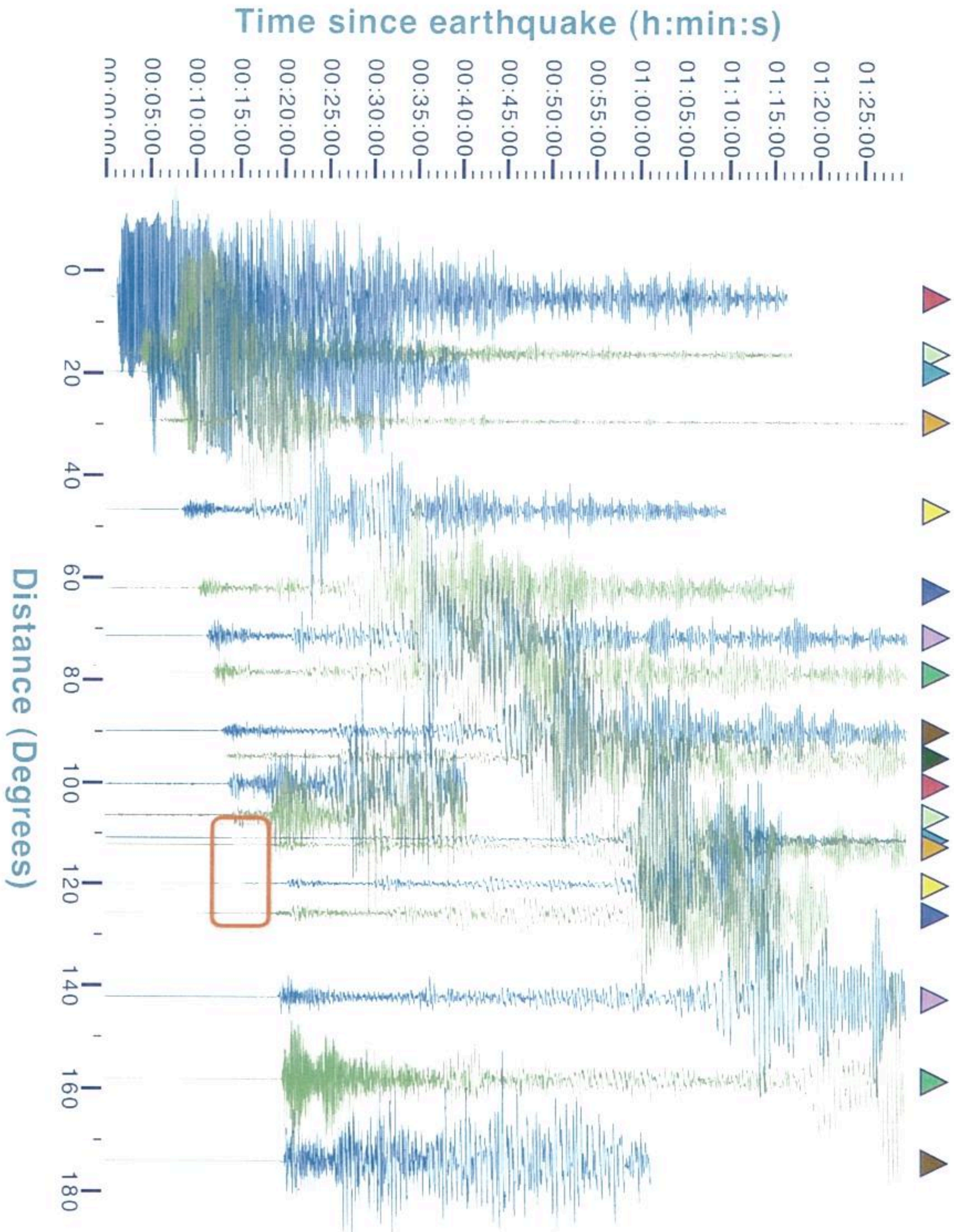


Figure 6. Seismic data from the 2/27/10 M8.8 Chile earthquake. Note the diffracted P arrivals highlighted within the orange box.

Theoretician's worksheet

Background: The simplest solution to the question "What is beneath our feet" is a homogeneous Earth, or one comprised entirely of the rock we see at the surface. Since seismic waves travel through Earth, they make a useful tool to "probe" the inside of Earth to discover what might actually be inside.

Task: Your task is to help test this hypothesis by creating a model of a homogeneous Earth, using the known velocity of seismic waves in rock ~ 11km/s. From this model you will predict how long it *should* take seismic waves to reach various distances around Earth.

Implications: If your findings match the findings of the seismologists then Earth is homogeneous or all rock throughout. However, if your observations do not match the seismologists' findings, than we can reasonably assume that the Earth is not homogenous or made entirely of rock and will need to develop a new model.

What is the Scale of the Model?

a. What is the radius of the model (Figure 1)?

_________cm

b. What is the scale of this model?

1cm:_______________________cm

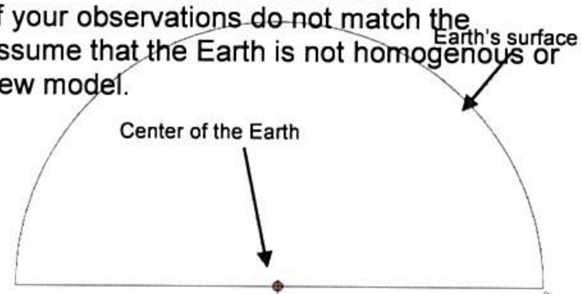


Figure 1: Scale, cross-section model of one of Earth's hemispheres.

Below is some information that will help you.
The mean radius of the Earth is 6371km
1km = 100,000cm

Materials (for each pair)

1 Ruler
1 Meter stick
1 Protractor
Earth Scale Model – Both left and right halves
Tape

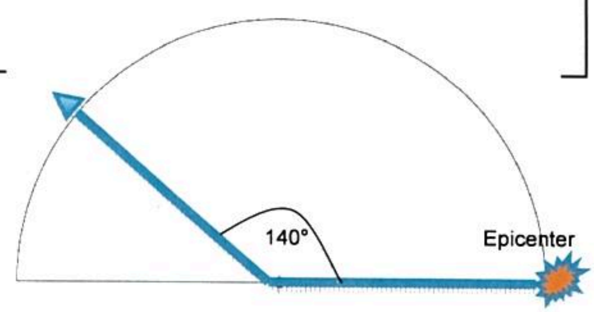


Figure 2: A **geocentric angle** is measured from the focus of the earthquake, through the center of Earth to the station location at the surface.

Procedure to Develop Predictions

Step 1: Draw a star at 0° to indicate the epicenter of the earthquake.

Step 2: Draw triangles on the surface of the model to indicate seismometers to record the arrival of the seismic waves. Assign each triangle a number and record that in Column A of the data table below. Unless instructed otherwise, you may place them anywhere you want but consider the following: What range of angles do you want the model to cover?

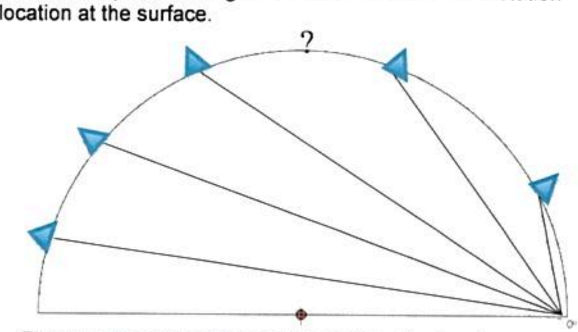


Figure 3: An earthquake occurs at 0° and seismic energy radiates out in all directions and arrives at seismic stations at the surface.

What would be "enough" data?

Step 3: Determine the location of the stations you added, with your protractor by measuring the *geocentric angle* (Figure 2). Record the geocentric angle for each station in Column B of the data table.

Remember: One degree of geocentric angle corresponds to an arc of ~111km on the surface!

Step 4: *Earthquake!* Draw straight lines representing seismic waves (Figure 3) from the epicenter to the seismograph. Measure the length of these paths in centimeters (cm) and record this distance in Column C of the data table.

Step 5: Convert the model distances to real Earth distances by converting (cm) in Column C to (km) in Column D. You will need the scale of the model you calculated previously.

Step 6: Calculate the time it takes the seismic waves to travel to each station using the constant velocity of the seismic waves in our model (11km/s) . Record this time in Column E of the data table. Convert the seconds to decimal minutes in Column F of the data table.

Step 7: Compare your results with another group of seismologists who used the same earthquakes and stations.

Step 8: Provide your teacher with your group's final data or enter the data from your table into the spreadsheet or graph provided by your instructor.

Theoretician Data Table

A	B	C	D	E	F
Station Number	**Station Location** Δ (degrees)	**Distance seismic waves travel in model** (cm)	**Actual Distance seismic waves travel** (km)*	**Travel Time** (s)**	**Travel Time** (min)

Conversion Notes
*model distance (cm) scaled to distance at Earth's scale (km): Refer to 1b above. 1cm = ~32,000,000cm or 1cm on the model = 320 km
** speed of seismic waves in constant velocity Earth of 11 km/s;

Questions for the team to answer in their science notebook:

- Describe any difficulties you and your team had generating your data.
- Describe any areas where error might have been introduced into your data.
- Describe any trends and oddities you notice in your data.
- Compare the arrival times the theoreticians found with what the seismologists observed in Earth. Describe how they are like and unlike one another.
- What does this imply about our hypothesis that the Earth's interior is homogeneous Earth, or comprised entirely of the rock we see at the surface? How do we know?

Theoretician's worksheet v2

Background: The simplest solution to the question "What is beneath our feet" is a homogeneous Earth, or one comprised entirely of the rock we see at the surface. Since seismic waves travel through Earth, they make a useful tool to "probe" the inside of Earth to discover what might actually be inside.

Task: Your task is to help test this hypothesis by creating a model of a homogeneous Earth, using the known velocity of seismic waves in rock ~ 11km/s. From this model you will predict how long it *should* take seismic waves to reach various distances around Earth.

Implications: If your findings match the findings of the seismologists then Earth is homogeneous or all rock throughout. However, if your observations do not match the seismologists' findings, than we can reasonably assume that the Earth is not homogenous or made entirely of rock and will need to develop a new model.

What is the Scale of the Model?

a. What is the radius of the model (Figure 1)?

_________cm

b. What is the scale of this model?

1cm:______________________cm

Below is some information that will help you.

The mean radius of the Earth is 6371km

1km = 100,000cm

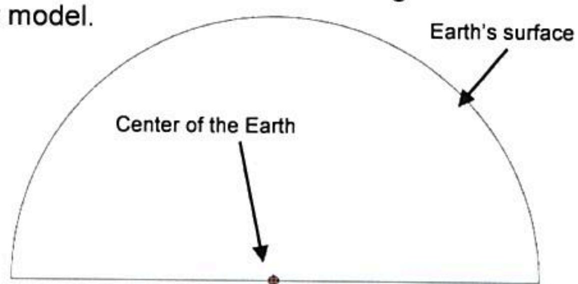


Figure 2: Scale, cross-section model of one of Earth's hemispheres.

Materials (for each pair)

1 Ruler
1 Meter stick
1 Protractor
Earth Scale Model – Both left and right halves
Tape

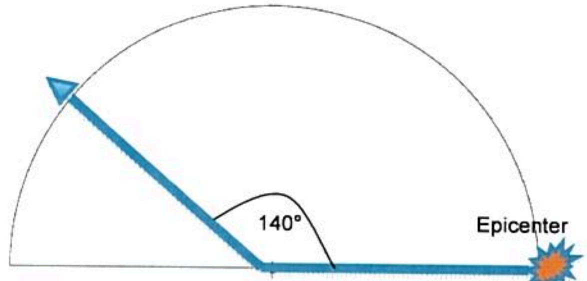


Figure 2: A **geocentric angle** is measured from the focus of the earthquake, through the center of Earth to the station location at the surface.

Procedure to Develop Predictions

Step 1: Draw a star at 0° to indicate the epicenter of the earthquake.

Step 2: Draw triangles on the surface of the model to indicate seismometers to record the arrival of the seismic waves. Assign each triangle a number and record that in Column A of the data table below. Unless instructed otherwise, you may place them anywhere you want but consider the following: What range of angles do you want the model to cover? What would be "enough" data?

Step 3: Determine the location of the stations you added, with your protractor by measuring the *geocentric angle* (Figure 2). Record the geocentric angle for each station in Column B of the data table.

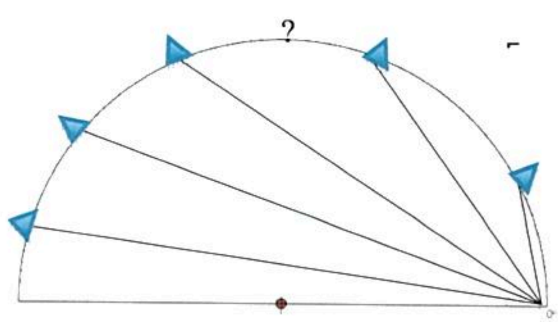


Figure 3: An earthquake occurs at 0° and seismic energy radiates out in all directions and arrives at seismic stations at the surface.

Remember: One degree of geocentric angle corresponds to an arc of ~111km on the surface!

Step 4: *Earthquake!* Draw straight lines representing seismic waves (Figure 3) from the epicenter to the seismograph. Measure the length of these paths in centimeters (cm) and record this distance in Column C of the data table.

Step 5: Convert the model distances to real Earth distances by converting (cm) in Column C to (km) in Column D. You will need the scale of the model you calculated previously.

Step 6: Calculate the time it takes the seismic waves to travel to each station using the constant velocity of the seismic waves in our model (11km/s) . Record this time in Column E of the data table. Convert the seconds to decimal minutes in Column F of the data table.

Step 7: Compare your results with another group of seismologists who used the same earthquakes and stations.

Step 8: Provide your teacher with your group's final data or enter the data from your table into the spreadsheet or graph provided by your instructor.

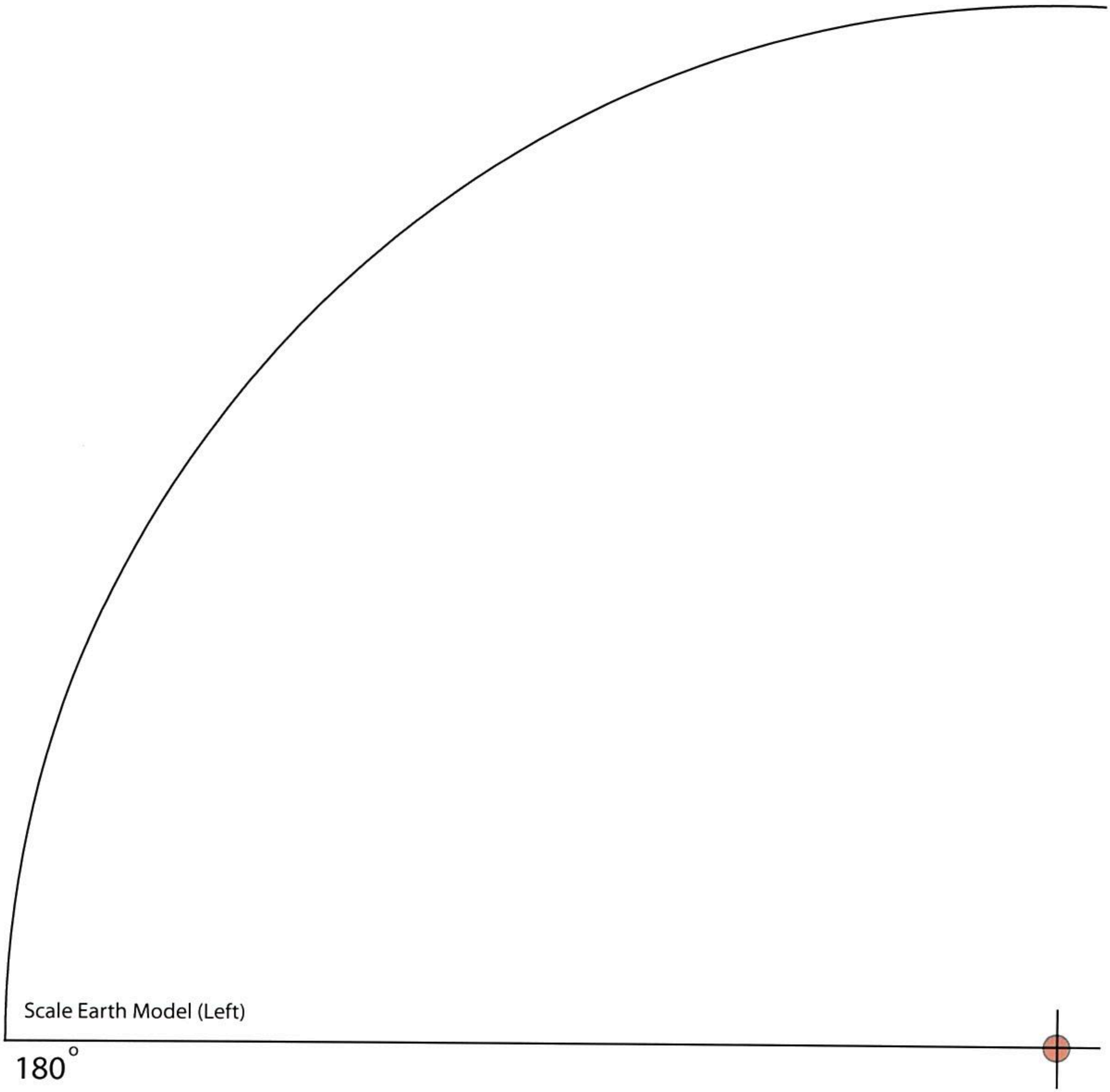
Theoretician Data Table

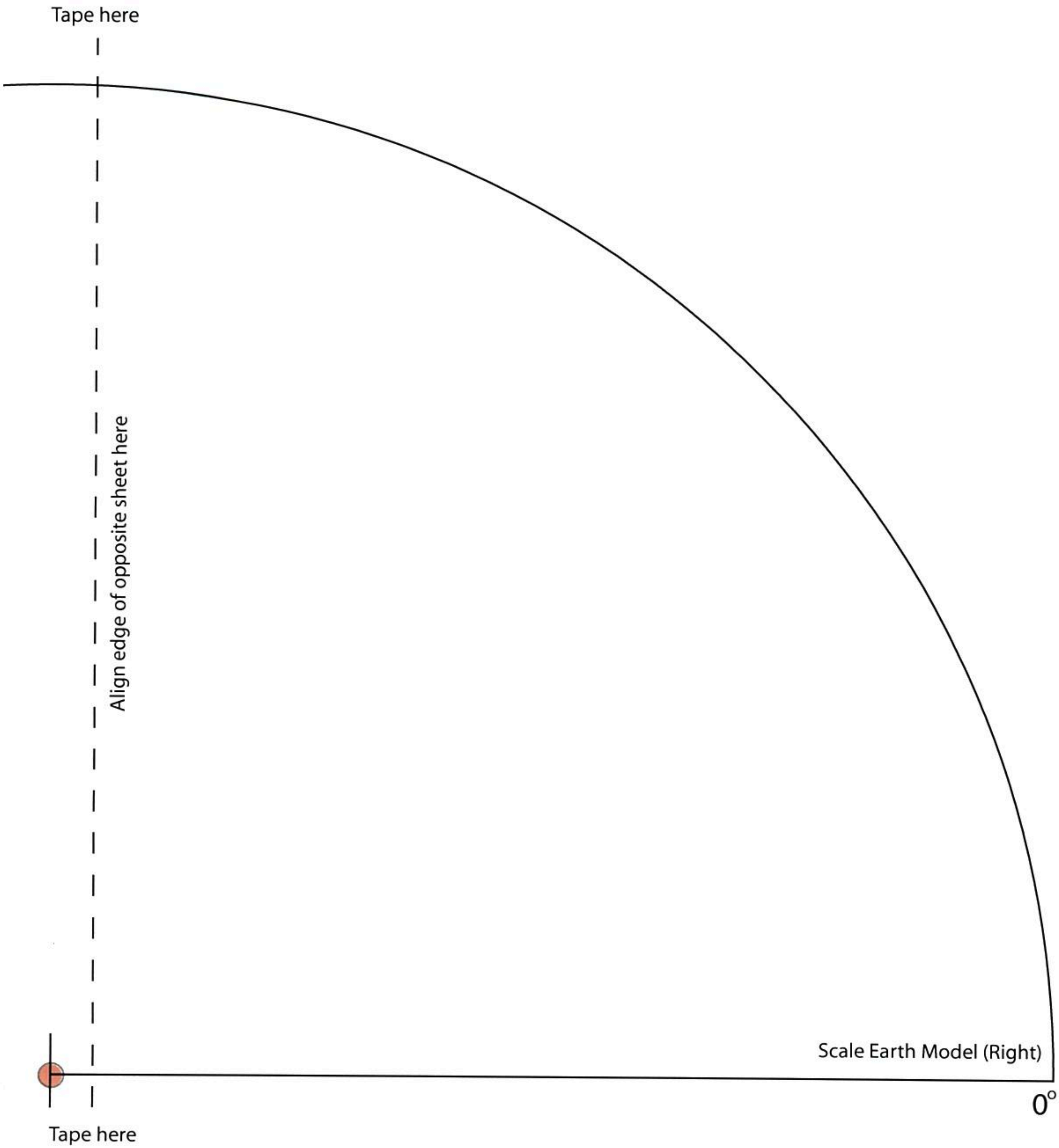
A	B	C	D	E	F
Station Number	**Station Location** Δ (degrees)	**Distance seismic waves travel in model (cm)** (measure in cm)	**Actual Distance seismic waves travel in Earth (km)** (Column C x 320km/cm)	**Travel Time (Sec)** (Colum D/ 11km/s)	**Travel Time (min)** (Column E / 60s)

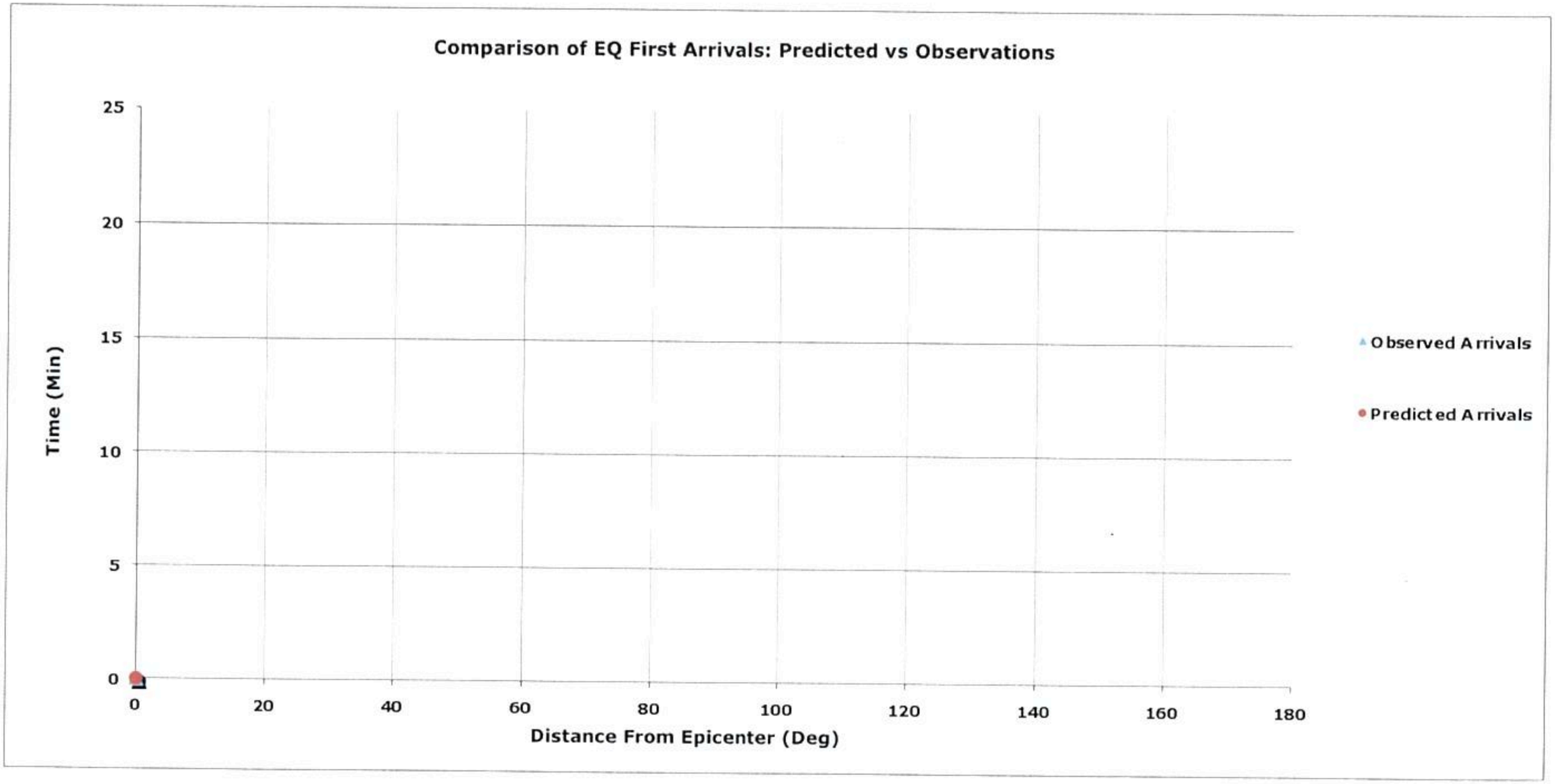
Conversion Notes
*model distance (cm) scaled to distance at Earth's scale (km): Refer to 1b above. 1cm = ~32,000,000cm or 1cm on the model = 320 km
** speed of seismic waves in constant velocity Earth of 11 km/s;

Questions for the team to answer in their science notebook:

- Describe any difficulties you and your team had generating your data.
- Describe any areas where error might have been introduced into your data.
- Describe any trends and oddities you notice in your data.
- Compare the arrival times the theoreticians found with what the seismologists observed in Earth. Describe how they are like and unlike one another.
- What does this imply about our hypothesis that the Earth's interior is homogeneous Earth, or comprised entirely of the rock we see at the surface? How do we know?

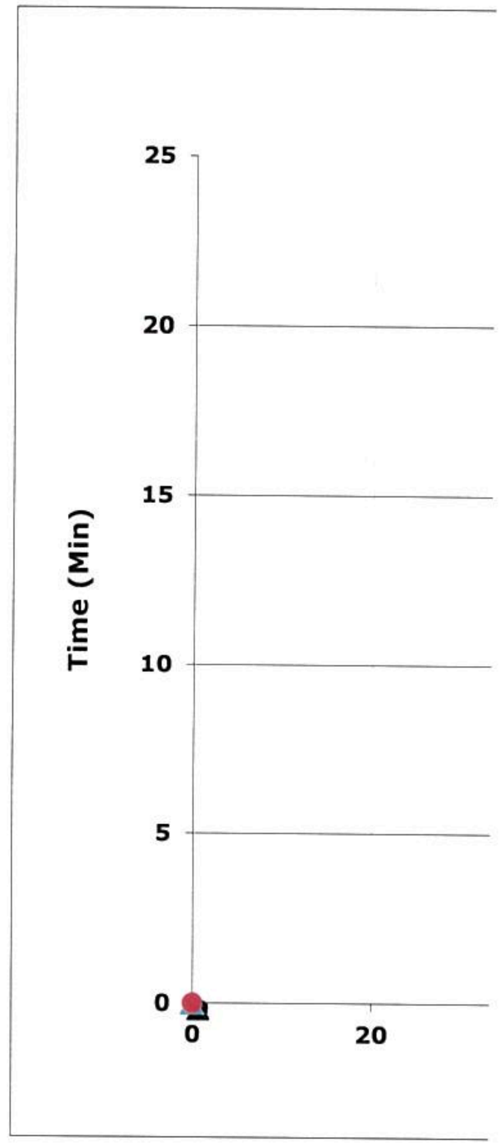

Scale Earth Model (Left)
180°


Tape here
Align edge of opposite sheet here
Scale Earth Model (Right)
0°
Tape here


Comparison of EQ First Arrivals: Predicted vs Observations
Time (Min)
25
20
15
10
5
0
0
20
40
60
80
100
120
140
160
180
Distance From Epicenter (Deg)
Observed Arrivals
Predicted Arrivals

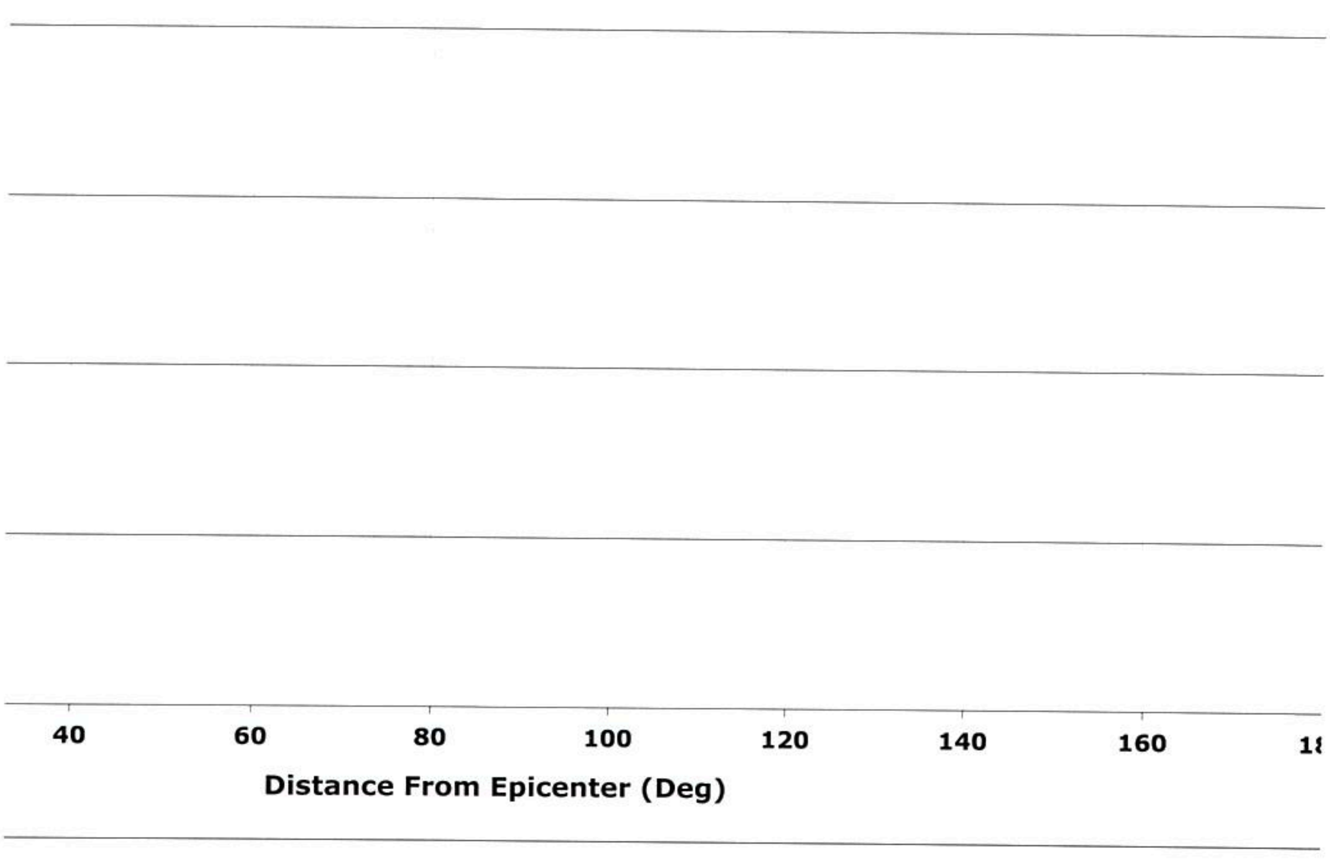
Seismologist Data	Units			
Distance	(Deg from Epicenter)	0	0	0
Observed Arrival Time	(Minutes)	0	0	0

Theoretician Data	Units			
Distance	(Deg from Epicenter)	0	0	0
Predicted Arrival Time	(Minutes)	0	0	0

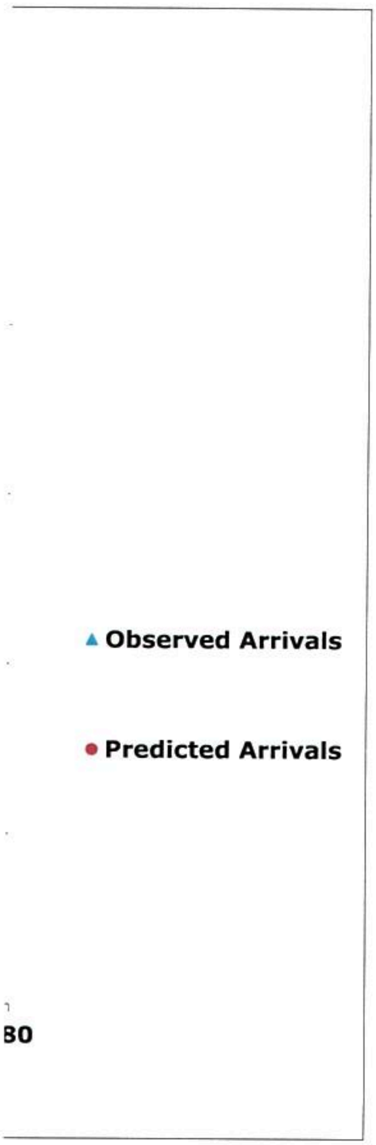


0	0	0	0	0	0	0
0	0	0	0	0	0	0
0	0	0	0	0	0	0
0	0	0	0	0	0	0

Comparison of EQ First Arrivals: Predicted vs Observations



0	0	0	0	0	0	0
0	0	0	0	0	0	0
0	0	0	0	0	0	0
0	0	0	0	0	0	0



0
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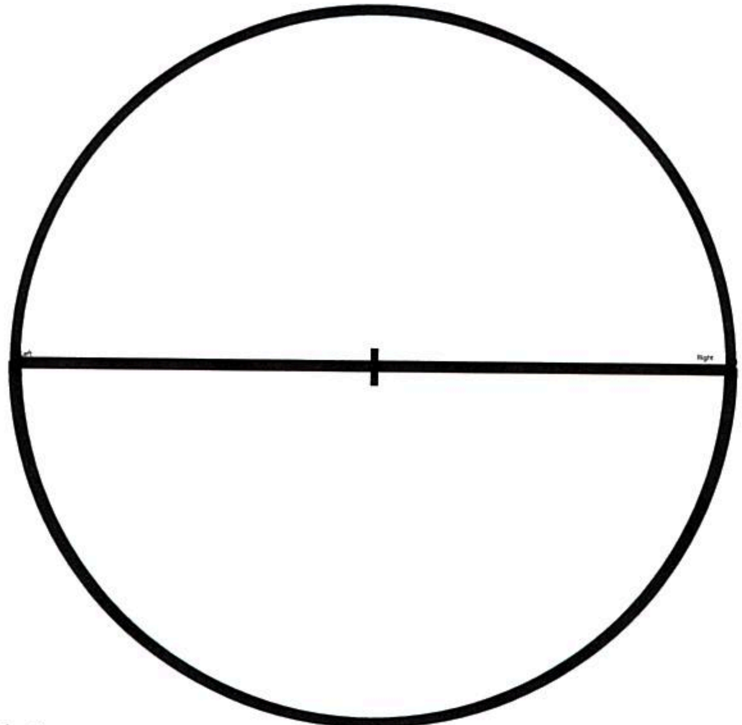
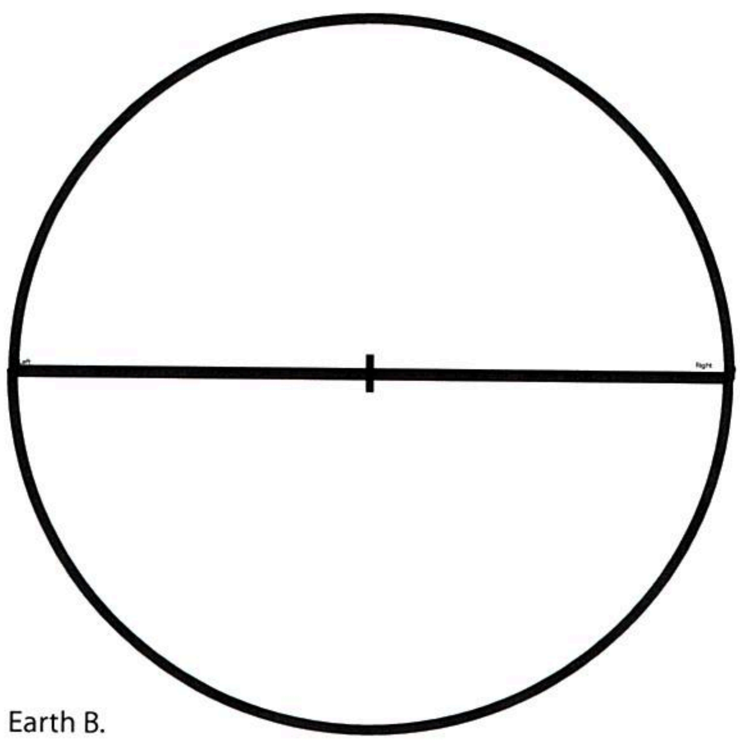


Earth A.



Earth B.

Earth Scale Model 2 - 1cm:127,420,000cm

the IRIS CONSORTIUM

Exploring the Earth Using Seismology

IRIS is a university research consortium dedicated to monitoring the Earth and exploring its interior through the collection and distribution of geophysical data.

IRIS programs contribute to scholarly research, education, earthquake hazard mitigation, and the verification of the Comprehensive Test Ban Treaty.

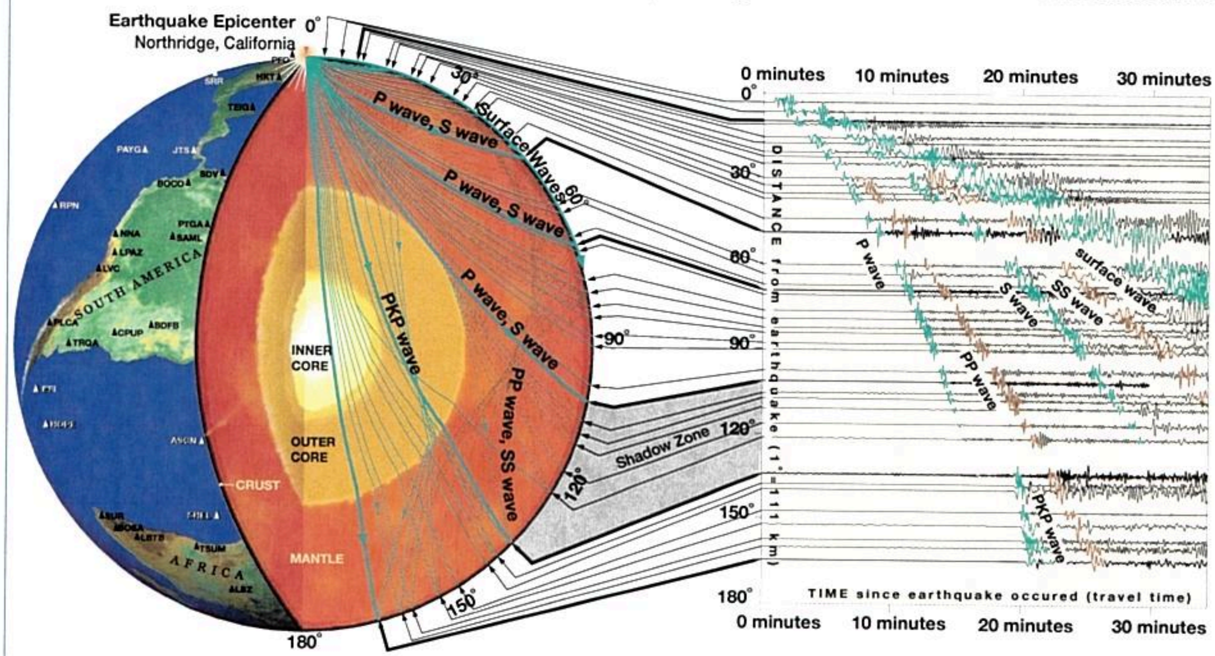
Support for IRIS comes from the National Science Foundation, other federal agencies, universities, and private foundations.

This figure was produced in cooperation with the US Geological Survey, and Purdue University.

Earthquakes create seismic waves that travel through the Earth. By analyzing these seismic waves, seismologists can explore the Earth's deep interior.

On January 17, 1994 a magnitude 6.9 earthquake near Northridge, California released energy equivalent to almost 2 billion kilograms of high explosive. The earthquake killed 51 people, caused over $20 billion in damage, and raised the Santa Susana Mountains north of Los Angeles by 70 centimeters. It also created seismic waves that ricocheted throughout the Earth's interior and were recorded at geophysical observatories around the world. The paths of some of those seismic waves and the ground motion that they caused are shown below.

On the right, the horizontal traces of ground motion (seismograms recorded at various locations around



the world) show the arrival of the different seismic waves. Although the seismic waves are generated together, they travel at different speeds. Shear waves (S waves), for example, travel through the Earth at approximately one-half the speed of compressional waves (P waves). Stations close to the earthquake record strong P, S and Surface waves in quick succession just after the earthquake occurred. Stations farther away record the arrival of these waves after a few minutes, and the times between the arrivals are greater.

At about 100 degrees distance from the earthquake, the travel paths of the P and S waves start to touch the edge of the Earth's outer core. Beyond this distance, the first arriving wave — the P wave — decreases in size and then disappears. P waves that travel through the outer core are called the PKP waves. They start to appear beyond 140 degrees. The distance between 100 and 140 degrees is often referred to as the "shadow zone".

We do not see shear (S) waves passing through the outer core. Because liquids can not be sheared, we infer that the outer core is molten. We do, however, see waves that travel through the outer core as P waves, and then transform into S waves as they go through the inner core. Because the inner core does transmit shear energy, we assume it is solid.

A poster version (100 by 70 cm) of this figure is available from the IRIS Consortium.

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Lesson 2: The Science of Water

Student Materials

Contents

The Science of Water Lab Activities: Student Directions

Lab Station A: Surface Tension Lab

Purpose

The purpose of this lab is to investigate the property of the surface tension of water. This lab will look at the way that water sticks to itself to make a rounded shape, the way that water behaves as a "skin" at the surface, and a comparison of water's surface tension with two other liquids, oil and soapy water.

Safety Precautions

- Wearing goggles is dependent on your school's safety criteria.
- Caution needs to be exercised around hot plates and the alcohol burner.
- Caution needs to be exercised around hot water and hot glassware.
- Do not eat or drink anything in the lab.
- Do not wear open-toed sandals in the lab.
- Wear long hair tied back to prevent touching the substances at the lab stations.

Materials

- 3 pennies
- Available water
- Small containers of water, oil, and soapy water
- A dropper for each of the containers
- A square, about 4" x 4", of wax paper

Procedures

Counting Drops on a Penny

1. Check to make sure all of the materials needed are at your lab station.
2. Using a dropper bottle containing only water, count the number of drops of water that you can balance on top of a penny. When the water falls off of the penny, record the number of drops. Wipe the water off of the penny.
3. Repeat this procedure of counting and recording drops with oil and then with the soapy water.

Comparing the Shape of a Drop

4. Drop a small sample of each of the liquids—water, oil, and soapy water—on the wax paper. Draw the shape and label the shape of the drops made by each of the liquids on your worksheet. Wipe off the wax paper.
5. Answer the questions on your worksheet.

Lab Station B: Adhesion/Cohesion Lab

Purpose

The purpose of this lab is to investigate the property of **cohesion** and **adhesion** of water.

- **Cohesion** is the molecular attraction exerted between molecules that are the same, such as water molecules.
- **Adhesion** is the molecular attraction exerted between unlike substances in contact.

Cohesion causes water to form drops, surface tension causes them to be nearly spherical, and adhesion keeps the drops in place (http://en.wikipedia.org/wiki/Adhesion).

This lab will work with capillary tubing of various diameters to see the rate at which water is able to "climb" up the tubes. This is very similar to the way that water enters a plant and travels upward in the small tubes throughout the plant's body. The "stickiness" of the water molecule allows the water to cling to the surface of the inside of the tubes.

You will see how the diameter of the tube correlates with the rate of traveling up the tube by measuring how high the dye-colored water column is at the end of the time intervals.

Safety Precautions

- COOL GLASSWARE FOR A FEW MINUTES BEFORE PUTTING INTO THE COOLING BATH OR THE GLASSWARE WILL BREAK.
- Wearing goggles is dependent on your school's safety criterion.
- Do not eat or drink anything in the lab.
- Do not wear open-toed sandals in the lab.
- Wear long hair tied back.

Materials

- 4 pieces of capillary tubing of varying small sized diameters (no greater than 7mm in diameter), 8-24 inches in length
- Metric ruler
- Pan of dyed (with food coloring) water into which to set the capillary tubing
- Clamps on ring stands to stabilize the tubing so that it remains upright in a straight position

Procedures

1. Check to make sure all of the materials needed are at your lab station.
2. Set the capillary tubing into the dye-colored water from the largest diameter tubing to the smallest. Make certain they are all upright and secure.
3. Record the height of each of the tubes in the table on your worksheet every 2 minutes.

4. After 10 minutes, release the capillary tubing, wrap the tubing in paper towels, and deposit them in an area designated by your teacher.
5. Answer the questions about this experiment on your lab sheet.

Lab Station C: Can You Take the Heat?

Purpose

The purpose of this lab is to investigate the heat capacity of water. You will measure the temperature of water (specific heat of water is 4.19 kJ/kg.K) and vegetable oil (specific heat of vegetable oil is 1.67 kJ/kg.K) over equal intervals of time, and will record your data and findings on your lab sheet.

Specific heat is the amount of energy required to raise 1.0 gram of a substance 1.0° C.

Safety Precautions

- Cool hot glassware slowly. Wait a few minutes before placing in cold water or the glass will break.
- Wearing goggles is dependent on your school's safety criterion.
- Do not eat or drink anything in the lab.
- Do not wear open-toed sandals in the lab.
- Wear long hair tied back.
- Use caution when working with fire or heat. Do not touch hot glassware.

Materials

Assemble two Erlenmeyer flasks or beakers, each containing one of the liquids, with a thermometer suspended into each liquid, from a clasp attached to a stand, inserted about midway into the liquid.

- 2 equal amounts, about 100 mL, of water and vegetable oil
- 2 250-mL Erlenmeyer flasks or 2 250-mL beakers
- 2 thermometers
- 2 Bunsen burners or 1-2 hot plates
- 2 ring stands: each ring stand will have a clamp to hold the thermometer. Use a screen if using a Bunsen burner rather than hot plate(s).
- Cold water bath for cooling the Erlenmeyer flasks or beakers

Procedures

1. Set the cooled flasks containing their solutions on the ring stands or hot plate.
2. Take the initial temperature reading of each of the liquids.
3. Turn on the hot plate to a medium temperature, or, if using Bunsen burners instead, light them, adjusting the flame of each to the same level.
4. Record the temperature of the liquid in each flask every 2 minutes until 4 minutes after each liquid boils. Record the temperature in the table on your lab sheet.

5. After recording the final temperatures, move the Erlenmeyer flasks or beakers with tongs or a heat-resistant set of gloves into the cooling bath. Add small amounts of ice as needed to keep the water temperature cold.

DO NOT THRUST HOT GLASSWARE DIRECTLY INTO ICY WATER BEFORE COOLING BECAUSE THE GLASS WILL BREAK!

6. Answer the questions about this experiment on your lab sheet.

Lab Station D: Liquid at Room Temperature Data Activity

Purpose

The purpose of this activity is to discover how unusual it is, based on a substance's molecular weight, that water is a liquid at room temperature.

Safety Precautions

None are needed, since this is a paper and pencil activity.

Materials

- Water is Weird! Data Table
- Lab worksheet for recording trends

Procedures

Data table 1 shows the physical properties of a variety of substances. This table is typical of one that a chemist would examine to look for trends in the data. For instance, is there any correlation with the color of the substance and its state of matter? Is there any correlation between the state-of-matter of a substance and its density? How does water compare to other substances?

1. Examine the data table. Look for relationships between the physical properties of some of these substances. What do you notice that fits into any patterns? What is the opposite or is unusual to the most common pattern?
2. Discuss the trends with your lab partner. Record your thoughts on your lab worksheet.
3. Answer the questions about this experiment on your lab worksheet.

Water is Weird!
Data Analysis Activity

Water is Weird! How Do We Know?

We have been discussing the many ways that water is weird. Water seems pretty common to us. How do we know that it is unusual? Let's compare water to some other substances and see what we can find, using the data table below.

Record the trends that you notice on your lab worksheet.

Data Table 1: Physical Properties of Some Substances

Substance	Formula	Molar mass, grams	State of matter at normal room conditions	Color	Specific Heat J/g K	Density of gas, liquid, or solid	Boiling Temperature, °C
Water	H_2O	18.0	liquid	colorless	4.19	0.997 g/cm^3	100
Methane	CH_4	16.0	gas	colorless		0.423^{-162} g/cm^3	-161.5
Ammonia	NH_3	17.0	gas	colorless		0.70 g/L	-33
Propane	C_3H_8	44.1	gas	colorless		0.493^{25} g/cm^3	-42.1
Oxygen	O_2	32.0	gas	colorless	0.92	1.308 g/L	-182.9
Carbon dioxide	CO_2	44.0	gas	colorless		1.799 g/L	-78.5
Bromine	Br_2	159.8	liquid	red	0.47	4.04	58.8
Lithium	Li	6.94	solid	silvery, white metal	3.58	0.534 g/cm^3	1342
Magnesium	Mg	24.3	solid	silvery, white metal	1.02	1.74 g/cm^3	1090

Lab Station E: Now You See It, Now You Don't
A Dissolving Lab

Purpose

The purpose of this activity is to introduce the idea that different types of liquids may dissolve different substances.

Safety Precautions

- Wearing goggles is dependent on your school's safety criterion.
- Do not eat or drink anything in the lab.
- Do not wear open-toed shoes.
- Tie long hair back.

Materials

- 6 plastic cups
- 6 plastic spoons
- Water
- Oil
- Granulated salt
- Granulated sugar
- Iodine crystals

Procedures

1. Fill 3 plastic cups 1/3 to 1/2 full with water.
2. Fill 3 plastic cups 1/3 to 1/2 full with oil.
3. Put about a half-teaspoon of salt into the water in one cup and another half-teaspoon of salt into the oil in one cup.
4. Stir each for about 20 seconds or until dissolved.
5. Record your observations in the table on your lab sheet.
6. Repeat this procedure with sugar.
7. Repeat this procedure using iodine crystals BUT only drop 2 or 3 crystals into the water and into the oil.
8. Record your observations and answer the questions about this experiment on your lab sheet.

Lab Station F: Predict a New World!
Inquiry Activity

Purpose

We all know that ice floats; we take it for granted. However, in nature, the solid form of a substance being less dense than the liquid form is extraordinary. What we don't know or think about much is how our world would be affected if ice did not float in water. This "thought" activity is explores the worldly implications if ice had a greater density than water.

Safety Precautions

None are required because this is a paper and pencil activity.

Materials

- A fish bowl with some fish and live plants

Procedures

1. Read the following. Look at the fish bowl. Think. Write your thoughts on your lab worksheet.

   Assume that there will be one change in the way that nature behaves: On the day after tomorrow, worldwide, ice (the solid form of water) will now become denser than water, rather than its current state, which is less dense.

   What will be the impact of this change?

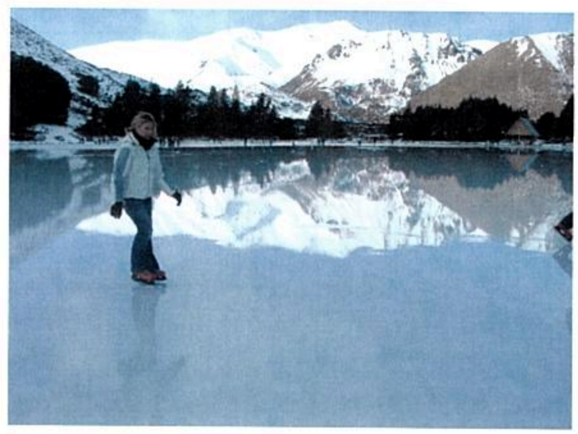

Figure 1. Beautiful lake in early winter. [1]

2. Discuss this with your lab partner.
3. Answer the questions about this experiment on your lab worksheet.

Reference

1. http://snow.reports.co.nz/snow_ida_800.jpg

Name________________________________ Date_____________________ Period ______

The Science of Water Lab Activities: Student Worksheets

Directions: Go to the lab stations assigned by your teacher. Follow the directions for each lab that are posted at each of the lab stations. Conduct the lab activity and record your data on the lab write-up sheet. Answer the questions asked on the lab sheet. Be sure to pay special attention to the purpose of each lab before beginning the lab. You are encouraged to talk to your lab partners about the lab and to ask your teacher questions.

Lab Station A: Surface Tension Lab

Drops of Water

Fill in the table below with the number of drops you added to the penny of each substance before the liquid spilled over.

	Water	**Oil**	**Soapy Water**
Number of Drops			

Questions

1. What does a high surface tension do to the number of liquid molecules that can stay together?

2. Based on your evidence, compare the surface tension of these four substances.

3. After placing a few drops of each of the liquids on the wax paper, draw what the drops look like from the side view. Be sure to capture the relative height/flatness of the drop

Water Oil Soapy Water

Name______________________________ Date____________________ Period ______

Lab Station B: Adhesion/Cohesion Lab

Questions

1. Define adhesion

2. Define cohesion

3. Ask your teacher to provide you with the diameter of the capillary tubes if they are not labeled. In the table below, record the height of the liquid in capillary tubing of different diameters as you take your measurements.

Diameter of capillary tubing				
2 minutes				
4 minutes				
6 minutes				
8 minutes				
10 minutes				

4. Based on your evidence, what statement can you make about water's speed of climbing a capillary tube relative to the diameter (size of the opening) of the capillary?

5. What does this mean about how fast water is able to "climb" tubes within plants?

Name________________________________ Date______________________ Period ______

Lab Station C: Can You Take the Heat? Student Lab Sheet

Specific heat is the amount of energy that it takes to raise 1.0 gram of a substance 1.0° C. Fill out the table as you conduct your experiment.

Liquids	Water Temperature	Vegetable Oil Temperature
2 minutes		
4 minutes		
6 minutes		
8 minutes		
10 minutes		
12 minutes		
14 minutes		

Questions

1. Based on your evidence, which substance has the highest specific heat? The lowest?

2. Think about and explain the relationship between high specific heat of a liquid and hydrogen bonding.

3. Compare the boiling temperatures of water and of oil. What is the relationship between hydrogen bonding and boiling temperature?

4. What happened to the temperature of the water and the oil after boiling? Explain why.

Name______________________________ Date____________________ Period ______

Lab Station D:
Liquid at Room Temperature Data Activity

Questions

1. What trends do you notice in the data table? Explain.

2. What is unusual about the most common pattern? Explain.

3. How does water compare to other substances?

Name_______________________________ Date_____________________ Period ______

Lab Station E: Now You See It, Now You Don't
A Dissolving Lab

A **solvent** is the liquid that is doing the dissolving. A **solute** is the substance that will be dissolved in the liquid.

Record your observations about how quickly and thoroughly each of the solutes dissolves in water and oil in the table below.

SOLVENT	SOLUTES		
	Salt	**Sugar**	**Iodine Crystals**
Water			
Oil			

Questions

1. Summarize what you found in your experiment, based on your recorded observations.

2. Why do you think that some substances dissolve easier in one type of liquid than in another?

Name______________________________ Date____________________ Period ______

Lab Station F: Predict a New World!
Inquiry Activity

Questions

1. Summarize your thoughts about the impact on the world if ice were denser than water.

Name________________________________ Date______________________ Period ______

The Science of Water: Student Quiz

Write down your ideas about each question below.

1. Why does all bonding occur between atoms, ions, and molecules?

2. Draw a water molecule. Label the atoms that make up the water molecule with their chemical symbol. If there is an electrical charge or a partial electrical charge on any of the atoms, indicate that by writing the symbols on the atoms:

   + = positive charge — = negative charge

   δ^+ = partial positive charge δ^- = partial negative charge

3. Explain the term "polar" molecule.

4. Why does water have an increased surface tension compared to most other liquids?

5. What is "hydrogen bonding"? What makes these bonds unique?

6. a. Define or describe "specific heat."

b. How does water's specific heat have an impact on our climate?

7. Is water's specific heat, compared to other liquids:

High ☐ or Average ☐ or Low ☐ ?

8. Are water's melting and boiling temperatures, compared to other liquids:

High ☐ or Average ☐ or Low ☐ ?

9. a. What happens to the temperature of the water in a pot on a heated stove as it continues to boil?

b. Explain what the energy is being used for that is heating the water at the boiling temperature.

10. Explain how a spider can walk on water.

11. Fill out the following table: Name and explain five of water's unique properties, and provide an example of the phenomenon in nature caused by each of these properties.

Property of Water	Explanation of Property	Phenomenon Property Causes

Name________________________________ Date_____________________ Period ______

Reflecting on the Guiding Questions: Student Worksheet

Think about the activity you just completed. What did you learn that will help you answer the guiding questions? Jot down notes in the spaces below.

1. Why are water's unique properties so important for life as we know it?

What I learned in these activities: What I still want to know:

2. How do we make water safe to drink?

What I learned in these activities: What I still want to know:

3. How can nanotechnology help provide unique solutions to the water shortage?

What I learned in these activities: What I still want to know:

4. Can we solve our global water shortage problems? Why or why not?

What I learned in these activities: What I still want to know: