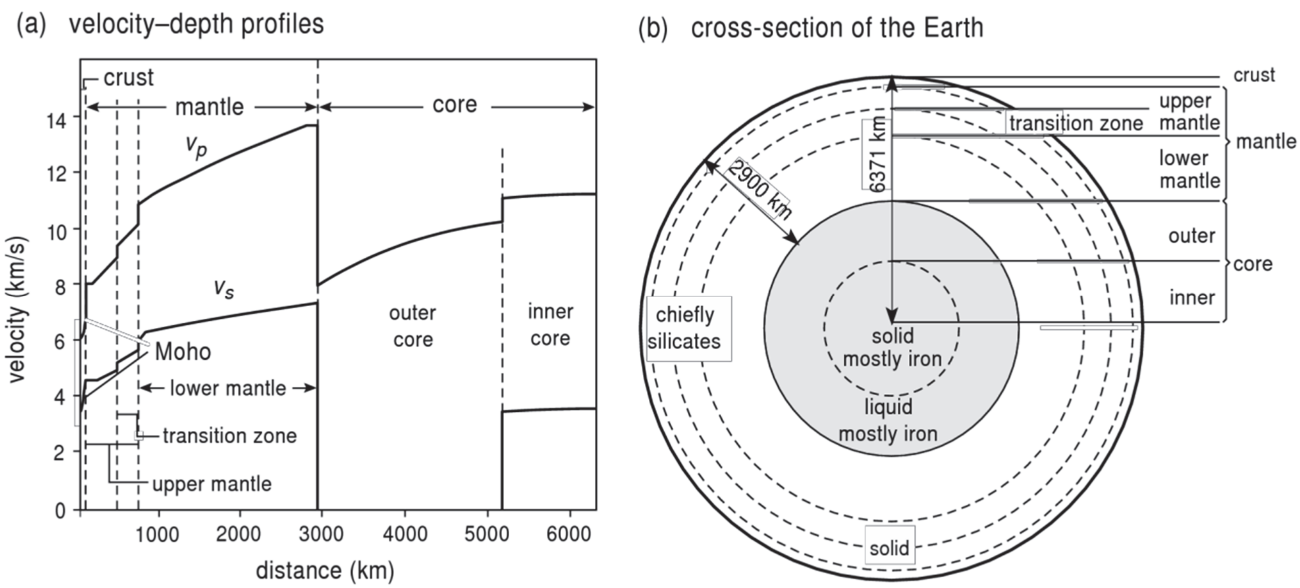
GEOL 460 Solid Earth Geophysics
Lab 5: Global Seismology

Name: ____ Date: _____________

Part I. Seismic Waves and Earth's Structure

While technically "remote" sensing, the field of seismology and its tools provide the most "direct" geophysical observations of the geology of Earth's interior. Seismologists have discovered much about Earth's internal structure, although many of the subtleties remain to be understood. The typical cross-section of the planet consists of the crust at the surface, followed by the mantle, the outer core, and the inner core. Information about these layers came from seismic travel times and analysis of how the behavior of seismic waves changes as they propagate deeper into the Earth. Today we are going to examine seismic waves in the Earth and we will take a look at how and what seismologists know about Earth's core. Here is a summary of the current understanding of Earth structure:



To look into what seismic waves can tell us about the core, we need to know how they travel in the Earth. While seismic energy travels as wavefronts, we often depict them as rays in figures and sketches. A ray is an idealized path through the Earth and is drawn as a line traveling through the Earth. A wavefront is a surface of energy propagating through the Earth.

We'll begin by looking at some **videos of wavefronts and rays** to get a handle on how these things behave in the Earth. These animations were made by Michael Wysession and Saadia Baker at Washington University in St. Louis. The videos are posted on the website for this lab and one may download them as mp4 files (for viewing offline). If the videos go too fast, pause them.

<u>Rays:</u>

- Scroll down and select "Ray Tracing-S+SS+SSS." This will show you many ray paths for these phases and will also plot a graph above showing the travel times and distances where the phases can be recorded at the surface. The semi-circle you are looking at is a cross-section through half of the Earth. The thick red lines represent the Crust and the Core-Mantle Boundary.
- Watch the video a few times so that you can focus on different aspects of the animation.
- Watch the video a final time, and focus on the green rays that represent the S phase. Notice how if you connect the ends of all the rays together, they make an arc.

Wavefronts I: The arc you saw connecting the rays together in the previous video is the wavefront. You will see it (without the lines for the rays) in the next video. Red colors represent motion into the screen and blue represents motion out of the screen.

- Select "PREM Velocity Model." PREM is a standard seismic velocity model for the Earth. This animation will show the wavefronts as they travel through the Earth, including their behavior in response to changing seismic velocity with depth.
- Watch the video. This time, across the top you will see the seismograms that would be generated by these phases for stations at three different distances from the earthquake.
- The video will cycle through a second time. This time the phases will be labeled along the wavefronts they produce. Take a look at all of the different versions of the shear waves in the animation.
- Watch the video again and focus on the S-wavefront (the biggest arc, leading the way across the Earth). Pay attention to the shape of the wavefront arc.

Wavefronts II: This is what wavefronts would look like if velocity in the Earth did not change with depth.

- Select "Homogeneous Earth Model." Since this is their first video, it includes a short introduction about the authors and the logistics of the animations.
- Focus on the S-wavefront again, in particular watch for how it behaves differently than it did when it traveled through the realistic Earth model.

Part I Questions

Ray Animations:

1. Do the seismic rays travel in straight lines? Why? We will investigate this in more detail later in this lab.

2. About how far (in epicentral angle) can the S ray travel before it is no longer recorded at the surface?

3. What does S, SS, and SSS mean? What defines these phases? (be specific)

4. Look at the ScS and Sdiff animation. What is the definition of the ScS phase? (Don't worry about Sdiff for now).

Wavefront Animations (PREM):

5. Is the wavefront a uniform arc or does it change curvature as it propagates? I.e. does the wavefront change shape as it propagates? Why? (Hint: there are two reasons!)

6. There are lots of different labels on different wavefronts. These are all different seismic phases. How can a single earthquake create all of these phases? What is the name of this process?

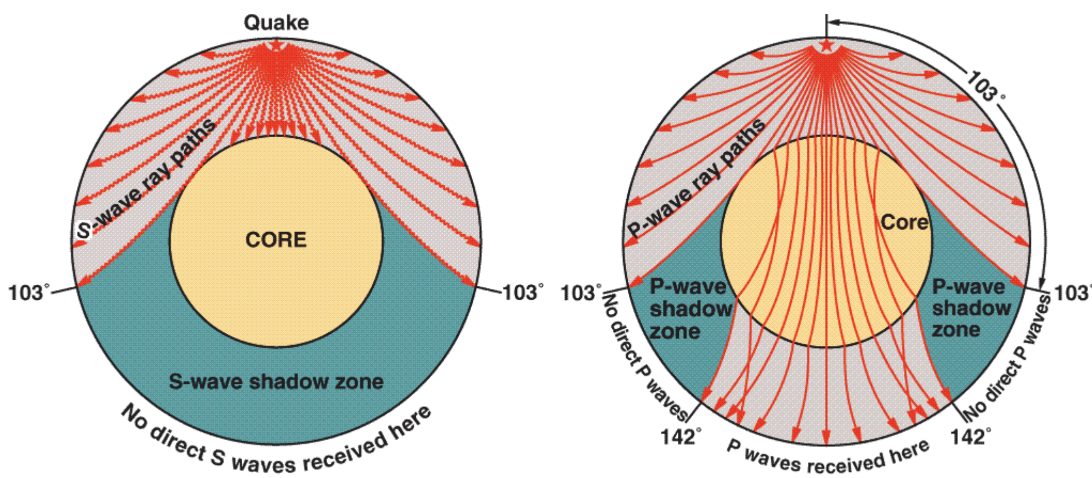
Wavefront Animations (Homogeneous Earth):

7. What are the major differences in model assumptions between this video and the one using the PREM velocity model?

8. How do we know that the Earth does not have a homogeneous velocity structure with depth?

Part II. Shadow Zones

A shadow zone is an area of the globe where certain seismic stations will not receive direct energy from an earthquake. This means that the direct seismic waves (or rays) don't reach the surface at certain distances from the earthquake epicenter. Shadow zones exist for both P-wave and S-waves, though they take up different areas. The S-wave shadow zone is one big area, and the P-wave shadow zone is two smaller areas (in this cross-section):



An FYI: People are often interested in how long it takes for a wave to go straight through the Earth to the other side. These waves are PKIKP (P-wave in mantle, P-wave in outer core, P-wave in inner core, P-wave in outer core, P-wave in mantle) and SKIKS (S-wave in mantle, P-wave in outer core, P-wave in inner core, P-wave in outer core, S-wave in mantle). Travel times? PKIKP = 1212.08 s (20.2 minutes). SKIKS = 1636.38 s (27.3 minutes).

The figure above puts an earthquake at the North Pole and shows the shadow zones through a cross-section of the earth. The way shadow zones were originally detected, though, is through the lack of a recording by certain seismic stations for certain earthquakes.

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Part II Questions

1. What causes the S-wave shadow zone, and what mechanical property of the Earth causes this? (Get quantitative!)

2. What causes the P-wave shadow zone and why is the P-wave shadow zone different from the S-wave shadow zone?

Part III. Earth's Core

The existence and details of seismic shadow zones led researchers to investigate Earth's core. Richard Dixon Oldham first suggested the presence and size of the core in 1906 using the shadow zone concept. Thirty years later, Inge Lehmann used finer details of the shadow zone to "discover" Earth's inner core.

Your task now is to use what you know about the shadow zone to calculate the size of the core. You can get a rough estimate of the size of the core by estimating the path of the S-wave that is recorded at 103° (right before the shadow zone starts) as a straight line through the Earth connecting the earthquake and the seismic station. Do the following on the next page in the space provided. The drawing need not be exactly to scale, but it must be neat and be reasonably close to scale or else it will be confusing.

- **a.** Sketch out a circle to represent a cross-section of the Earth.
- **b.** Mark a point in the center of the circle to represent the center of the Earth.
- **c.** Draw one line connecting the center of the Earth to any point on the surface.
- **d.** Draw another line connecting the center of the Earth to a point on the surface that is 103° epicentral angle away from the first point you chose.

- **e.** Draw a straight line through the Earth connecting your two surface points. This represents the path of the S-wave. We call this the ray path.
- **f.** Now you have a triangle drawn inside the Earth. The height of this triangle is the radius of the core. Draw a line for the core's radius, and then sketch out the circle with that radius that represents the core.
- **g.** Use a little trigonometry and the radius of the Earth (6371 km) will get you the radius of the core. Be sure to show your work and carefully explain what you did and why. This should require a calculation and not any measurements.

Cross Sectional Sketch of the Earth

Part III Questions

1. What value (in km) did you calculate for the radius of the core? (Show your work here)

2. What is the "actual" radius (in km) of the core? (Use the first figure in this lab.) What was your % error?

$$\%\ \text{Error} = \frac{\text{Experimental} - \text{Theoretical}}{|\text{Theoretical}|} \times 100.$$

3. Our method for calculating the size of the core was a simplification. What is the key factor that we ignored? Given this simplification, would you expect for your estimate to be too large or too small? Why?

4. Inge Lehman used shadow zones to learn about the inner core. What are (or what could be) some differences in seismic wave behavior in the outer and inner cores that could help her make this discovery?

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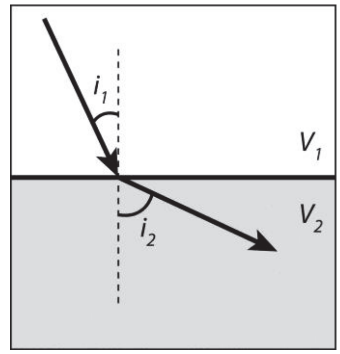
Part IV. Refraction of Seismic Rays and Snell's Law

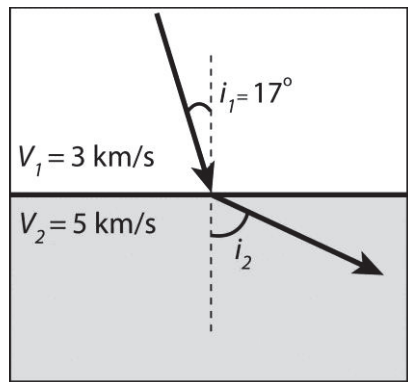
Answer the following questions in the space provided. You must circle your numerical answers to get full credit. Snell's law states that:

$$\frac{\sin i_1}{v_1} = \frac{\sin i_2}{v_2}$$

Where i_1 is the angle of incidence of a ray as it a layer with a seismic velocity of v_1 and i_2 is the angle of refraction as the ray enters a new layer with a seismic velocity of v_2.



1. In the picture to the right, $i_1 < i_2$. Which seismic velocity is faster?



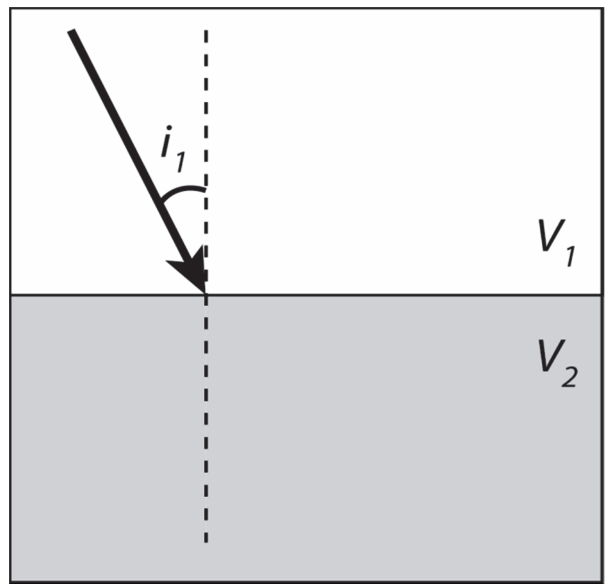
2. Use the figure to the right,
   a. What is the angle (i_2) at which the ray will exit the interface?
   b. Make a plot in Excel of angle of refraction, i_2 (horizontal-axis), vs. angle of incidence, i_1 (vertical-axis, both axes in degrees), for the two layer scenario given in part a. To do this, you will need to re-arrange the Snell's law equation (solve for i_1). Plot the angle of refraction from 0-90 degrees in intervals of one. On this same graph also make a plot assuming the second layer has a velocity of 10 km/s. Plot the data as two curves (of different colors) with no symbols. Use a brief but clear legend to let the reader know which curve is which. Include a hard copy of your graph (in color) at the back of this assignment. Provide a brief typed figure caption (3 sentences max) below the plot that tells the reader what parameters were plotted for each curve and what the curve represents. Your plot and figure caption should easily fit onto a single page.
   c. In your Excel plot for part b, you plotted the entire range of possible angles of refraction (0-90°). What are the predicted ranges of the angles of incidence in each scenario you tested? Fill in your values below.

When V1 = 3 km/s and V2 = 5 km/s: _______ ≤ i1 ≤ ________

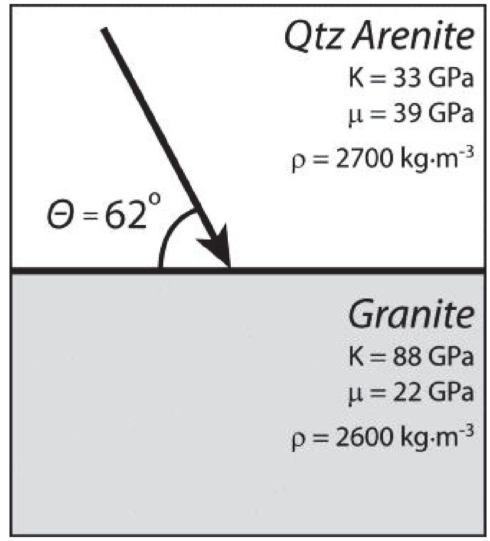
When V1 = 3 km/s and V2 = 10 km/s: _______ ≤ i1 ≤ ________

d. From your plot, it should be clear that some angles of incidence are mathematically invalid when considering the refraction of a ray. What happens if the angle of incidence exceeds the maximum mathematically valid value? Hint: Is there another option for the ray other than refraction? (2 sentences max)

e. The "critical angle," i_{crit}, is defined as the maximum angle of incidence that still produces a refracted ray…i.e. the angle of incidence that results in no ray transmission into the lower medium (i.e. i2 = 90°). This is called "critical refraction." Draw and label the critically refracted ray in the image to the right, and clearly label i_2 and its value. Write two sentences that describe the critically refracted ray's path and which velocity must be larger (V_1 or V_2?) for critical refraction to occur.



In the figure to the right, a P-ray traveling through a layer of quartz arenite meets a layer of granite.



a. Determine V_p and V_s for the quartz arenite. Be careful about units! You should get reasonable seismic velocities for both layers.

b. Determine V_p and V_s for the granite.

c. Determine the angles of reflection for the reflected P- and S-rays (i.e. i_{1p} and i_{1s}).

d. Determine the angles of refraction for the refracted P- and S-rays (i.e. i_{2p} and i_{2s}).

e. Make a clear hand-drawn sketch of your results and label the four resultant rays and their angles.

3. A seismic ray, traveling down from the surface of the Earth through the interior of a spherically layered planet, encounters a layer that extends from 3100 km to 3000 km radius. If the velocities above, within, and below the layer are respectively 10, 11, and 12 km/sec, and the ray was incident to the layer at 40°, then it leaves the layer at an angle of: ______________________

Hint: Drawing a sketch of this before you begin is very helpful