ES 104 Laboratory # 5
EARTHQUAKES:
Epicenter Determination, Seismic Waves, and Hazards

Introduction

Earthquakes are vibrations of Earth caused by large releases of energy that accompany volcanic eruptions, explosions, and movements of Earth's crust along fault lines. The earthquake vibrations are waves of energy that radiate through Earth away from the **focus**. These waves of energy can be recorded on a seismograph, which produces a recording called a **seismogram**. Seismographs record the two types of **body waves**: **Primary** waves (P-waves) and **Secondary** waves (S-waves). They also detect **Surface** waves called Love waves (L-waves) and Rayleigh waves (R-waves).

Travel-time curves are graphs that indicate how long it takes each type of seismic wave to travel a distance measured on Earth's surface. The difference between the S-wave arrival time and the P-wave arrival time corresponds to the distance of the seismograph station from the earthquake focus. This time difference can be converted easily into distance using the travel-time curves (Figure 2).

Goals and Objectives

- Learn to locate an earthquake epicenter using p-wave and s-wave arrival time differences and travel time curves.
- Know the essential components of a seismometer and how seismometers record earthquakes.
- Describe the relation between earthquakes, volcanoes, and plate boundaries.
- Understand earthquake-induced liquefaction and landslide hazards and how they relate to site geology.

Useful Websites

- http://quake.wr.usgs.gov/info/1906/got_seismogram_lp.html
- http://www.jclahr.com/science/earth_science/tabletop/earthshaking
- http://www.sciencecourseware.org/VirtualEarthquake/VQuakeExecute.html
- http://staff.imsa.edu/science/geophysics/geosphere/tectonics/seismogram.html

Name______KEY________________________

Lab day ______Lab Time_____________________

Pre-lab Questions – Complete these questions before coming to lab.

Briefly define the following key words.

1. Earthquake

Break or rupture of rock, emanating from a focus, sending seismic waves through Earth materials

2. Primary Wave

Compressional wave from earthquake, moving fastest, and through all types of Earth materials. Material is alternately compressed and diliatated, parallel to the direction of wave propagation,

3. Secondary Wave

Shear wave from earthquake, moving slower than primary waves, through solid material only. Material is sheared side to side, perpendicular to the direction of wave propagation.

4. Epicenter

Location on Earth’s surface directly above the focus of the earthquake

5. Richter scale

Method of earthquake measurement based on the amplitude of seismic waves recorded at the seismometer. Must be corrected for distance, since the waves are smaller for earthquakes further from the station.

6. Tsunami

Sea wave initiated by undersea displacement of material, including landslides, volcanic eruptions and earthquakes

Question for Thought

7. How do earthquakes relate to plate tectonics?

Plate movement builds up strain that is released during earthquakes

Part A – Epicenter Determination

The epicenter of an earthquake is the point on Earth's surface at or above the earthquake's focus. In this exercise, you will determine the location of the epicenter of an earthquake that was recorded on seismograms at three different locations (Figure 1).

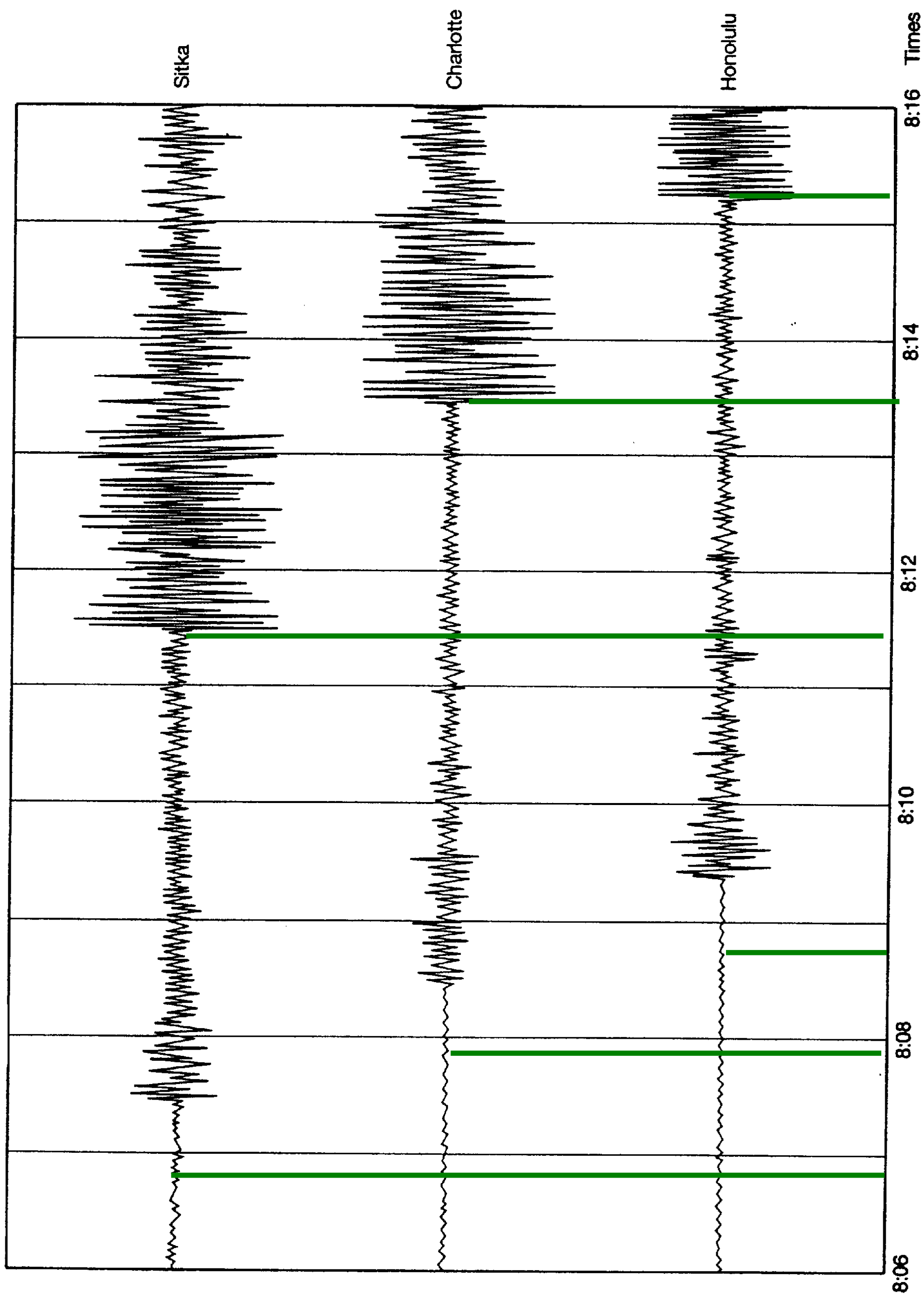


Figure 1: Seismograms recorded at three different locations for the same earthquake.

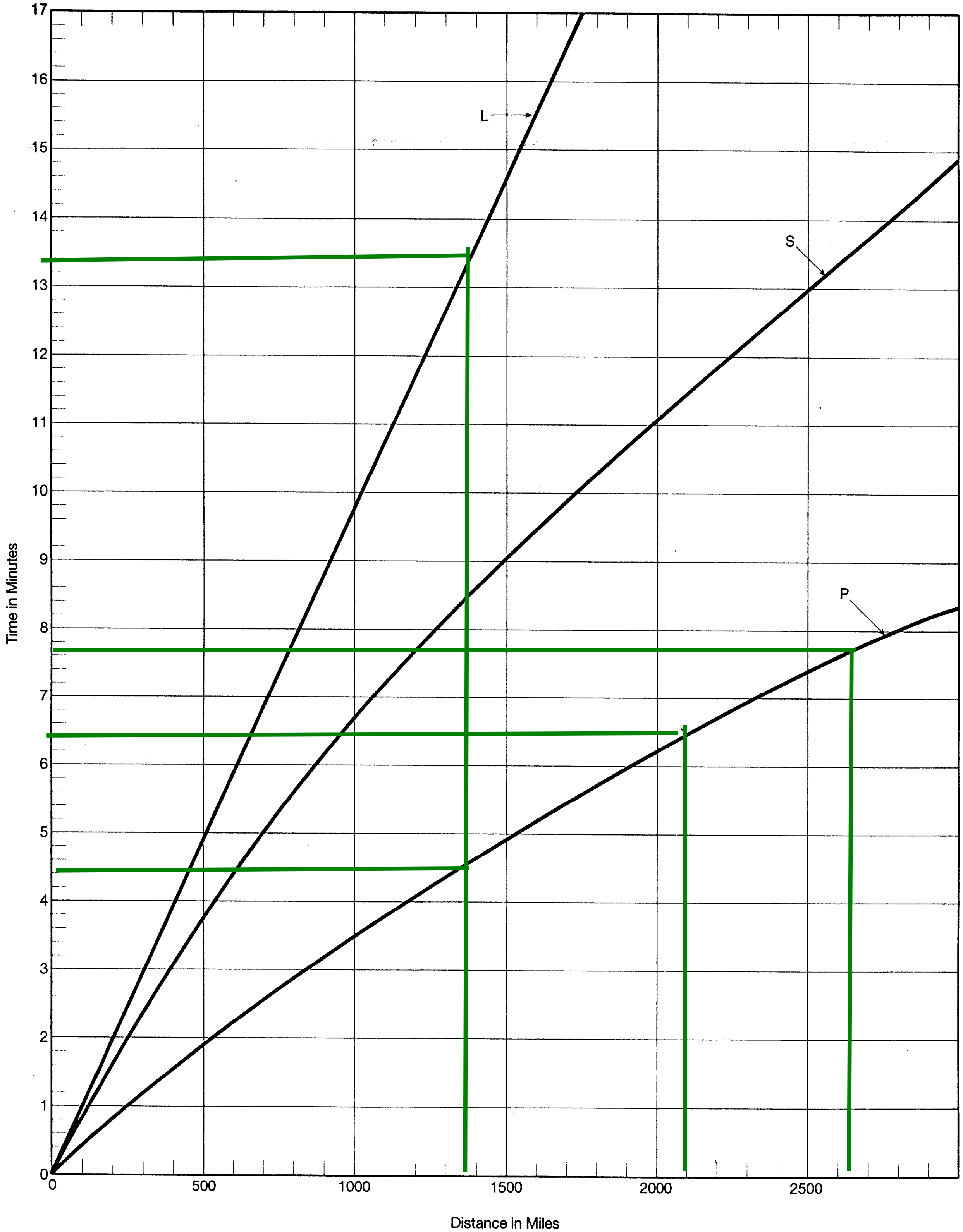


Figure 2: Travel-time curves for P-waves, S-waves, and L-waves.

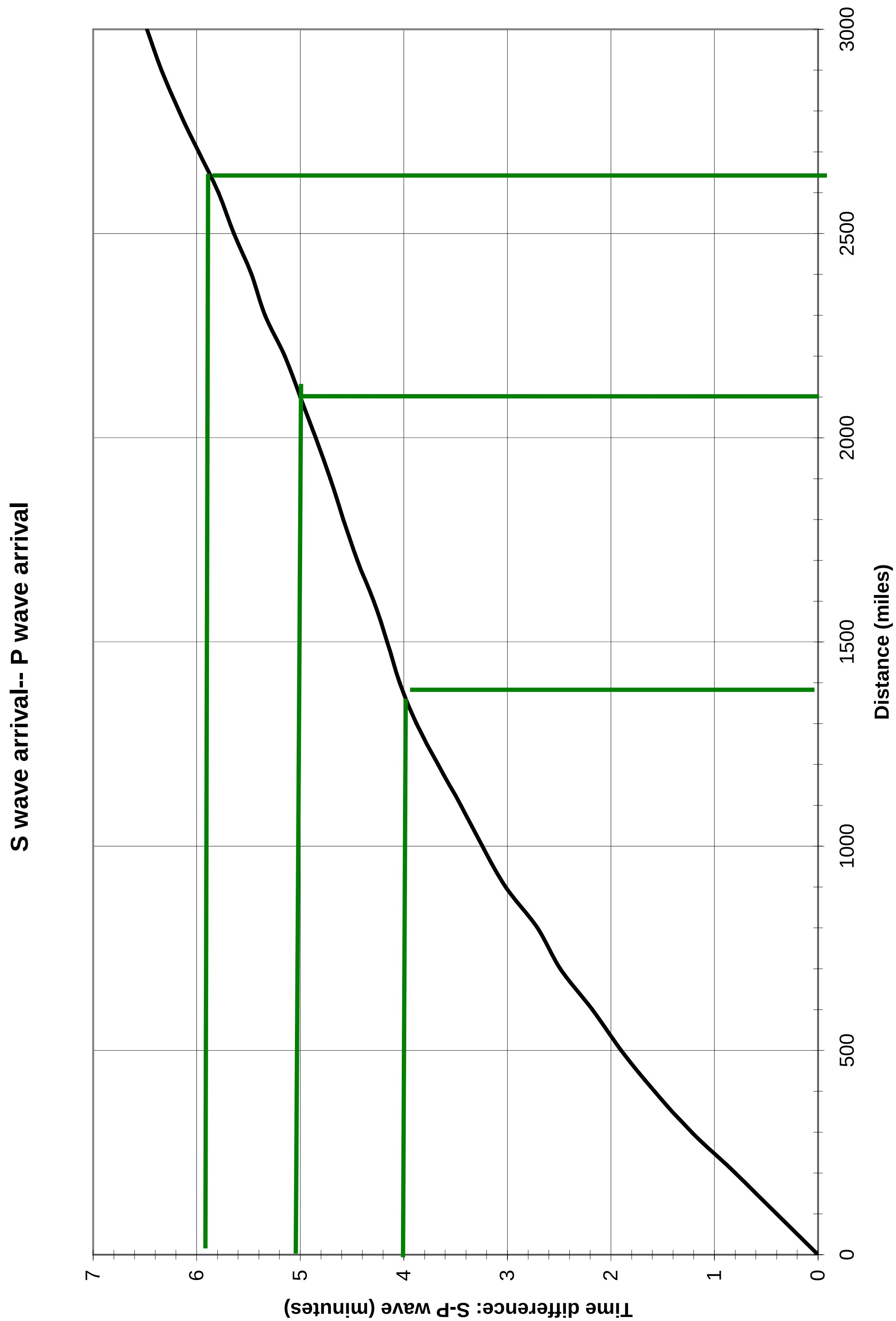


Figure 3: Travel-time graph to determine the distance to the epicenter.

1. Estimate to the **nearest tenth of a minute** (**NOT** seconds), the times of the **first arrival** of the P-waves and S-waves at each station in Figure 1. Times show it arrived after 8 AM. Record this in Table 1, below Subtract P-wave arrival time from the S-wave arrival time to determine the difference in travel time of P-wave and S-wave in minutes and tenths of minutes.

Table 1: Arrival times at seismic stations

Location of seismic station	**First P-wave Arrival** (time as hour: minute.tenths)	**First S-wave Arrival** (time as hour: minute.tenths)	**Difference in travel time between S & P**
Sitka, AK	8:07.4	8:11.4	4.0
Charlotte, NC	8:08.5	8:13.5	5.0
Honolulu, HI	8:09.3	8:15.2	5.9

2. Using the S-minus-P times and the travel-time curve (Figure 3), estimate the distances from the focus that correspond to these values. Record these in Table 2, below.

Table 2: Distance of focus to seismic station

Location	**Distance (miles)**
Sitka, AK	1390
Charlotte, NC	2100
Honolulu, HI	2650

3. Find the earthquake's epicenter using the distances you just obtained.
   a. Locate and mark the three seismic stations on the world map, Figure 3 (page 5-7):

      Sitka, AK: 57° N latitude, 135° W longitude
      Charlotte, NC: 35° N latitude, 81° W longitude
      Honolulu, HI: 21° N latitude, 158° W longitude

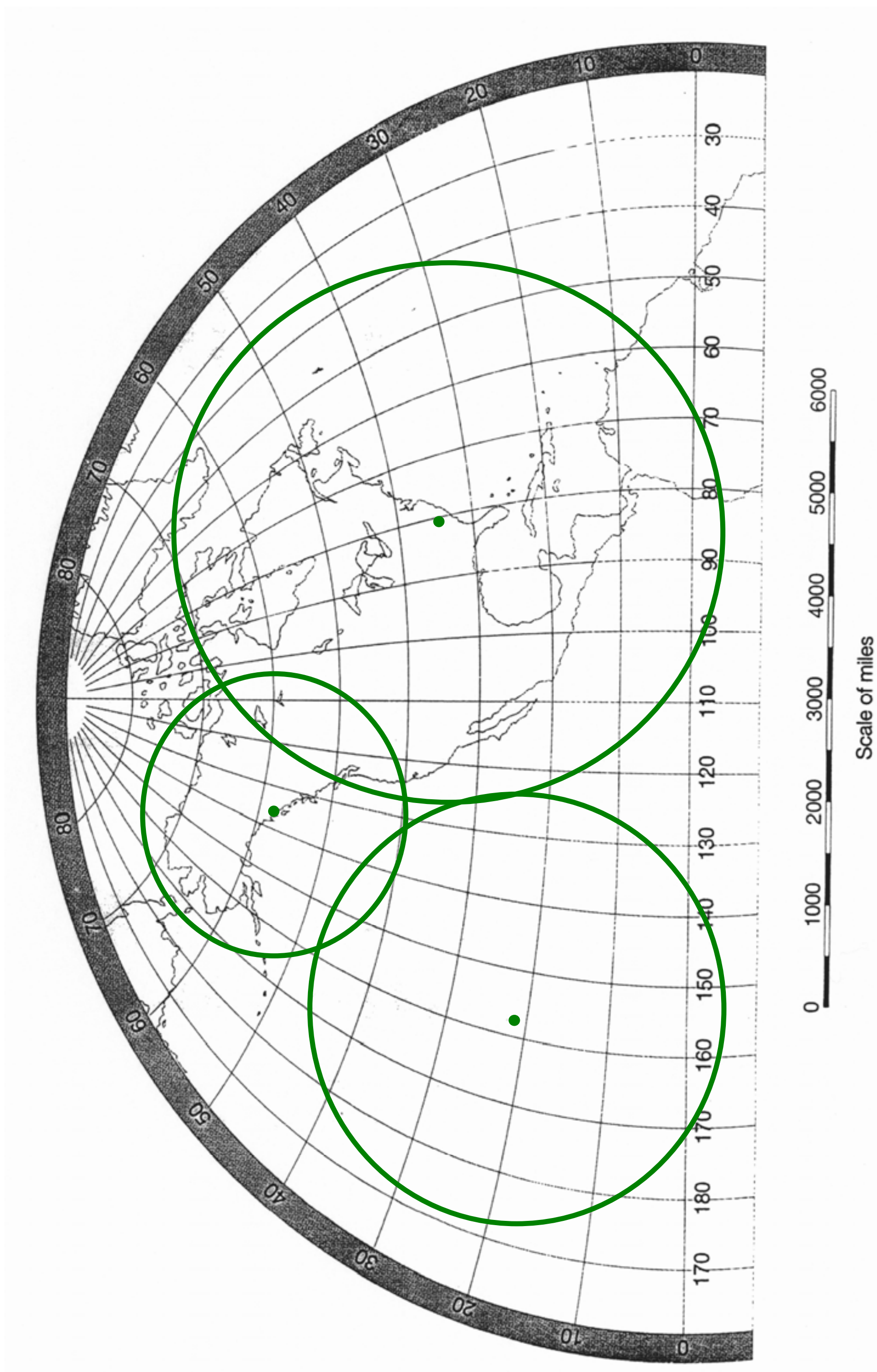


Figure 4: Map of Earth, for use in plotting data and locating the earthquake's epicenter.

b. Use a drafting compass to draw a circle around each seismic station. Make the radius of the circle equal to the distance between the station and the epicenter that you determined above. Use the scale for the world map to set this radius on the drafting compass. The circles you draw should intersect at one point, which is the epicenter. (If the three circles do not intersect at a unique point, choose a point equidistant between the three circles.) The location of the epicenter is:

Latitude between 30^{o}N and 40^{o}N Longitude between 110^{o}W and 13^{o}W Need to indicate N and W, and report correct one for each, not have them switched.

4. What is the **origin time** of the earthquake? That is, at what time did the earthquake occur? Using data from a single station, and Figure 2 or 3 to find out how long it takes to arrive, and the distance determined from epicenter to quake. Note the station, and show your calculations.

Using P waves
Sitka 8:07.4 minus 4.4 minutes = 8:03.0 AM
Charlotte 8:08.5—6.4 minutes= 8:02.1 AM
Honolulu 8:09.3—7.7 minutes=8:01.6 AM
The stations don't give the same origin time. Times in the 8:00+ ballpark are correct. Times between 2 AM and 4 AM are not, nor are times after arrival of P wave from table 2…you subtract minutes from minutes.

5. What time would you estimate did the L-waves from this earthquake begin to arrive at the **Sitka** station? (Use Figure 2)

Use your origin time, and add the length of time for L waves to arrive. Depending upon your determined distance of earthquake to Sitka, this should be between 13 and 15 minutes to arrive. You must ADD this to the origin time determined in question 4 to get the correct time that L waves arrive in Sitka.

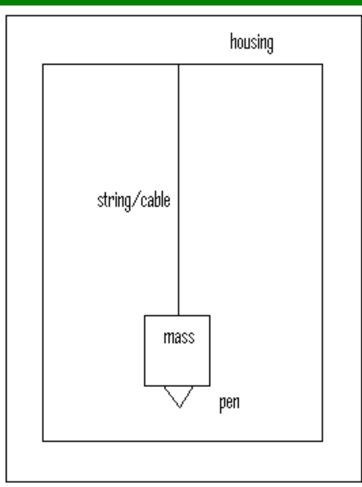
Part B - Seismometers

Seismometers are instruments designed to measure and record ground motion during an earthquake. The record kept by the seismometer is called a seismogram. Examine the seismometer at Lab Station B. The heart of the seismometer is a mass (the washers and magnets on the eye bolt in the bottle) suspended on a spring. During an earthquake, the housing of the seismometer (bottle, PVC pipe, and base) move, but the mass remains roughly stationary due to its inertia. To record the motion of the bottle relative to the mass on the spring, a coil of wire is wrapped around the bottle. The magnet on the bolt produces a changing magnetic field as it moves inside the wire coil. The changing magnetic field produces an electrical voltage in the coil. The computer measures the voltage and creates a plot of voltage vs. time; the larger the voltage, the larger the velocity of the mass.

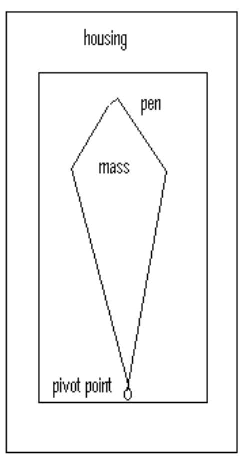
1. Given that the purpose of the seismometer is to measure motion during an earthquake, why is the mass on the spring suspended in oil? (Hint: consider how long the mass would vibrate after an earthquake if no oil were present.)

The oil dampens the bouncing of the spring, much as the shock absorbers of your car dampen the bouncing of the suspension.

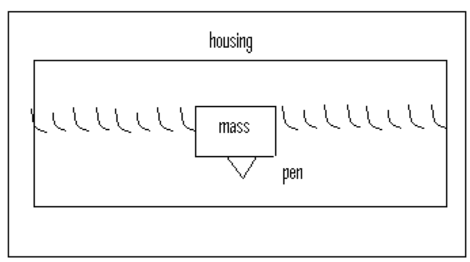
2. Real seismometers are extremely sensitive to ground motion and therefore record ground motion due to sources other than earthquakes. What sorts of natural and human-caused ground motions might show up as noise on a seismogram?
3. This seismometer is set up to measure vertical ground motions. Draw a picture of a seismometer that could measure horizontal ground motions. (You only need to draw the mass and whatever is attaching the mass to the seismometer housing).



Mass remains stationary as housing shakes in earthquake. Pen records the motion on paper moving below it.



Mass remains statioinary and housing shakes in earthquake. Relative motion due to mass mounted on the pivot point. Motion recorded by pen on paper moving above it.



This wouldn't work so great, as the mass would sag if supported by springs. If supported by solid supports, it would move with the housing, and not record the earthquake.

See page 194 in 11th edition of Tarbuck and Lutgens textbook on Earth Science for a horizontal meter.

Making Earthquakes

You are going to simulate earthquakes and record them on this seismometer. To simulate the earthquakes, you will drop 0.2 kg and
1 kg masses onto the wooden squares attached to the plywood base. The differing masses correspond to earthquakes of different size. Energy from the mass hitting the table will travel down the plywood base as an elastic wave where the wave will move the seismometer. The seismometer will then make a record of its motions. During a real earthquake, energy released at the focus of the earthquake travels to distant seismometers through seismic waves.

Directions

1. <u>Do not mess with any of the electronics attached to the seismometer!!!</u>

2. Use the menu command *Experiment>Delete ALL data runs* to delete all previous data runs on the computer.

3. Click *Start* to begin recording data from the seismometer.

4. Carefully drop the 1 kg mass from a height of 6.5 centimeters above the wooden block labeled 1. Use a ruler to measure the height precisely. The idea is to make all drops from the same height, to compare the effect of distance and magnitude on the seismogram.

5. Carefully drop the 1 kg mass from a height of 6.5 centimeters above the wooden block labeled 2.

6. Now repeat the drops at the two wooden blocks using the 0.2 kg mass. Be sure to keep the drop height at 6.5 centimeters.

7. Press *Stop* on the computer to stop recording data.

8. Adjust the horizontal and vertical scales on your seismogram so that all four earthquakes fit on the graph. Print your seismogram and label the 4 earthquakes with the mass dropped and the location of the earthquake.

Questions

1. Look at the seismogram that you made. How does the amplitude of the ground motion recorded by the seismometer relate to the magnitude of the earthquake (or in this case, the size of the mass dropped)?

The magnitude of the earthquake, or the size of the mass, is directly proportional to the amplitude of the ground motion, and the waves recorded on the seismogram.

2. How does the amplitude of the ground motion recorded by the seismometer depend on the distance to the earthquake epicenter for a given earthquake magnitude? Use this observation to explain why earthquake magnitude scales must correct for the distance from the seismometer to the earthquake epicenter to assign a magnitude to an earthquake using ground motion amplitudes recorded on a seismogram.

The amplitude of ground motion, and the waves recorded on the seismogram, diminished with distance from the earthquake. Note: the magnitude of the earthquake is not less, the ground-motion at distance is less.

3. Compare the duration of strong shaking between the 1 kg earthquake and the 0.2 kg earthquake. How does the duration of shaking relate to the earthquake magnitude? How do you think this affects the amount of damage that occurs to buildings during an earthquake?

The graph does not show duration well. Length of duration is related to damage: the longer the shaking, the more damage will occur.

Part C – Liquefaction

During earthquakes, soils and sediments saturated with water can lose their shear strength and begin to act like a fluid. This process is called liquefaction. In this experiment, you will cause sand saturated with water to liquefy.

Directions

1. Remove the 1 kg mass from the sand-containing column if the previous group has not already done so. If you cannot locate the 1 kg mass, it may be buried in the sand. Dig around until you find it.

2. Lift the column containing only water approximately 2 feet off the tabletop. You should see water flow up through the bottom of the sand in the other column. Allow water to flow into sand-containing column until all of the sand is suspended in the water. This, by the way, is how quicksand forms!

3. Place the water-containing column back on the table. Watch as the sand settles out of the water. This settling process causes the sand to be very loosely packed. Loose packing of sediment deposits increases the likelihood of liquefaction during an earthquake.

4. Once the water level in the sand-containing column has dropped to the surface of the sand, **gently** place the 1 kg mass on the sand. The 1 kg mass represents a building constructed on loosely packed, water-saturated sediment.

5. To simulate an earthquake, strike the sand-containing column sharply with the rubber mallet, aiming for the black X. Be careful not to hit the vertical plastic tubes on the outside of the column.

Questions

1. What happened to the 1 kg mass when you struck the column with the rubber mallet? Given this result, what sorts of hazards does liquefaction pose to buildings during an earthquake?

The mass sunk into the wet sand a considerable amount. Buildings could do the same if built on saturated, unconsolidated sediment.

2. In order for liquefaction to take place during an earthquake, the soils and sediments need to be saturated with water. How do you think the depth to the water table relates to the liquefaction hazard in a particular location? (Note: the water table is the top of the zone of sediments in the subsurface that are completely saturated with water. If you drill a water-well in your backyard, you hope that your well will reach the water table.)

The more unsaturated material between the building and the water table (water table is deeper), the less damage would be incurred.

3. Based on your observations while preparing for the liquefaction experiment, in what types of locations do you think you would find loosely-packed, liquefaction-prone sediment deposits? Can you think of any towns or cities in Oregon that might be built on these types of sediment deposits?

Along riverbanks, lakeshore, and even the sea. Portland, Salem, Newberg, Corvallis, Independence, etc.; some oceanside towns too.

4. Remove the 1 kg mass from the sand. Firmly tap the side of the sand-containing column several times while watching the sand closely. Place the mass back on the sand and strike the X on the side of the sand-containing column. What happened to the mass this time? Why?

It did not sink nearly as much…the sand was no longer saturated, and was somewhat consolidated by the tapping.

5. Does this result suggest any ways that liquefaction prone building sites could be prepared before construction to reduce damage due to liquefaction during a future earthquake?

Could drain the sites, and pre-compact them

Part D – Earthquakes Hazards

Examine the *Geologic Map of the West Salem Area* and the Earthquake Hazard Maps for this area. Answer the following questions:

1. Locate Minto Island (central) and McNary Field (southeast) on the *Geologic Map of the West Salem Area*. These areas are underlain by sediments labeled Qal, Qtlw, and Qlg. Write the name of the formation, and a brief description of the amounts of gravel, sand, silt and clay in each formation.
   a. **Qal** Alluvium:
      unconsolidated river sediment composed of sand and muck, with minor amounts of gravel, which is mostly at outlets of tributary streams. Saturated with water
   b. **Qtlw** Lower terrace of the Willamette River
      Somewhat consolidated river sediment, less muck, more gravel than the alluvium. Also less saturated
   c. **Qlg** Lynn Gravel
      More consolidated, higher (so less saturated) material that contains a greater amount of gravel than the other two formations.
2. Explain how the abundance/concentration of groundwater contained in these sediments may change in relation to the proximity of the Willamette River.

The closer you are to the river, the more saturated it will be. Also, elevation plays a role: lower, more saturated.

3. How does the type of sediment (Qal, Qtlw, or Qlg) relate to the liquefaction potential and relative earthquake hazard potential of these areas? (Refer to the *Liquefaction Susceptibility Map* and *Relative Earthquake Hazard Map* of the Salem area to support your answer.) What is the relationship between sediment grain size and liquefaction hazard?

Liquefaction potential greatest on Qal, least on Qlg, directly related to the saturation degree, age and elevation.

4. How does site proximity to a river relate to liquefaction hazard? (If you completed Part C, use your liquefaction observations from Part C in your answer,).

Closer to the river are more likely to be saturated, so greater potential

5. Locate portions of the *Geologic Map of the West Salem Area* which are underlain by Eocene-Oligocene sedimentary rocks (Toe). Would you build a beautiful new home overlooking the river in these areas? Why or why not? (Hint: Examine the susceptibility to earthquake damage in these areas and how this relates to the topography and geology from the *Liquefaction Susceptibility Map, Landslide Susceptibility Map,* and *Relative Earthquake Hazard Map* of the Salem area.).

The Eocene-Oligocene sedimentary rocks are not well-consolidated, and therefore prone to landslide where they are on steep slopes.

6. Examine the *Geologic Map of the West Salem Area*. Locate Fairview Hospital (Fairview Home on some maps) (southeast of McNary Field), West Salem and Marion Square Park (central), and the Salem Heights School and Morningside School (south central) on the map. Describe the geology and topography of each location in the table below.

Location	**Geology** (name of the rock units, and a short description of it)	**Topography** (steep slopes, gentle slopes, or flat)	**Ranking of Earthquake Susceptibility**
Fairview Hospital	**Lynn gravel**	**Gentle slopes**	**Moderate, low slope ange**
West Salem	**Marine sediment**	**Steep slopes**	**Great: steep, unconsolidated**
Salem Heights	**Columbia basalts**	**Steep slopes**	**Low: very competent rock**

7. Using the Relative Earthquake Hazard Map of the Salem area, rank each of the above locations in order of decreasing susceptibility to damage from earthquakes. Then describe why each is or is not susceptible to damage. (Refer to *Liquefaction Susceptibility Map* and *Landslide Susceptibility Map* of the Salem area and your answer to question 3 to support your answer.)

Name______KEY________________________

Lab day ______Lab Time_____________________

POST LAB ASSESSMENT

1. The Global Positioning System consists of a network of satellites that send out signals that are picked up by GPS receivers, such as the models used for navigation by hikers or in cars. The GPS receivers have a database indicating the location of each satellite. The satellite sends a signal of the time of broadcast. To determine their position, the GPS receivers use the known locations of the satellites, the time signals the satellites send to the receiver, and the speed of radio waves. Explain how the GPS receiver calculates its position, and why it uses at least four satellite signals to determine its position.

GPS uses travel time to determine distance to receiver from satellite. Intersection of four spheres determines exactly the location **in three dimensions:** latitude, longitude and **elevation**. The fourth satellite is required to find the third dimension. Descriptions not including this detail are not complete.

2. In lab 4 and lab 5, you have learned a great deal about earthquakes and earthquake hazards. Using this information, explain all of the factors that should be considered in determining the earthquake hazard at a given building site.
You would want to know likelihood of recurrence of a large quake, distance to known faults, rock type, slope, liquefaction potential