**Lab 7: Earthquakes**

When the stresses in a rock (which may or may not already be faulted) exceed the tensile strength of the rock, the rock ruptures at a point called the **focus** or hypocenter. This focus may lie on a pre-existing fault or be on a new fault entirely. This sudden release of energy is called an **earthquake**. What is felt during an earthquake are the vibrations of the solid earth caused by the passage of **seismic waves**. These type of waves are **elastic** because they do not cause any permanent deformation of the rocks they pass through.

The energy that propels these waves is called, predictably enough, **seismic energy**, and this energy **propogates** through rock away from the focus in all directions (spherically). While the waves are in earth material, there are two types: **P-** (or primary) waves and **S-** (or secondary) waves. P-waves travel through rock by alternately compressing and dilating the rock in the direction of motion. Practically, a P-wave feels like a jolt, like a truck has hit the side of the building you’re in. S-waves travel through rock by whipsawing the rock at right angles to the direction of wave motion. An S-wave produce a rolling type of motion, similar to the rocking of a boat on the ocean.

![Diagram of earth movements produced by (a) P-waves and (b) S-waves.](image)

**Figure 7-1.** Diagram of earth movements produced by (a) P-waves and (b) S-waves.

The location of the focus of an earthquake is defined by the **epicenter**, which is the position on the surface of the earth vertically above the focus (this is measured in latitude and longitude), and by the **focal depth**, the distance (in kilometers) from the epicenter to the focus.

1. Form a line of at least 10 people. Face outwards in the same direction and stand shoulder-to-shoulder. Station someone else as a timer (get a stopwatch) and, upon a signal from the timer, the person at one end should be shoved (not too hard) into his or her neighbor. The push will then be transmitted down the
line. When the motion reaches the opposite end of the line, the timer should record the time. This models motion associated with a P-wave.

a. P-wave travel time:

Keep everyone in the line, but this time, link by holding hands at arm’s length from your neighbor. The person at one end of the line should sway backwards and this motion should propagate down the line (similar to “crack the whip”). Again, time the length of motion and record it. This models motion associated with an S-wave.

b. S-wave travel time:

c. Which wave travels faster?

2. a. What would happen to the speed of the P-wave if everyone linked at the elbow, rather than stood shoulder-to-shoulder?

b. What property of the shaken rocks would question 2a model?

3. Do P-waves (or any seismic wave for that matter) travel faster through igneous rocks (density > 2.5 g/cm³) or through sedimentary rocks (density < 2.5 g/cm³). What does density have to do with speed?

When an earthquake occurs, seismologists must quickly determine both the magnitude and location of the earthquake (why? For instance, to be able to predict if a tsunami will occur).

The location of an earthquake can be determined using triangulation. A seismograph is an instrument which records the exact time when the seismic waves of an earthquake arrive at the seismograph station (called the arrival time). If the time of the actual fault rupture which generated the earthquake (the origin time) is known, then the time the seismic waves took to travel the distance between the focus and the seismograph station (the travel time) can be calculated by simple subtraction:

\[ \text{Travel Time} = \text{Arrival Time} - \text{Origin Time} \]

The arrival time and origin time of an earthquake are recorded not in local time, but in Greenwich Mean Time (GMT), which is broadcast via radio signal to the seismograph. Of course, if you know the scale of the seismogram, then it is easy to just read off the travel time.
On the next page are the traces of three seismographic station outputs during the magnitude 5.2 Duvall earthquake of May 2, 1996 (9:04 PDT). These output traces are called **seismograms**. **Seismographs** are instruments that record vibrations in the earth as seismic waves arrive at a seismographic station; last century, they were simply a pen held above a rolling drum covered in paper. These days, they are finely balanced electronics that can detect motion in all three directions (N/S, E/W, up/down). The seismographic stations are located all over the Puget Sound area; the three you will be using are shown on the map two pages hence.

4. Use the three seismograms (the recorded trace of ground motion) from seismic stations JCW, GSM and GMW (see figure 7-2) to determine the travel time of the P-waves at each station (the S-waves, of course, came later). **Note the units of the travel times.**

   JCW:  
   GSM:  
   GMW:  

5. In order to calculate a distance between the epicenter and the seismograph station from the travel time derived above, you need to know the velocity of the P-wave. What **formula** connects distance, velocity and time?

   Distance to epicenter =

   Now that you have the formula, and the additional information that P-waves travel, on average, at a velocity of **6.5 kilometers/second** through the crust, calculate the distance (in kilometers) to each seismograph station from the epicenter.

   JCW:  
   GSM:  
   GMW:  

   On the map provided (figure 7-3), use a **compass** (no, not the north/south kind) to draw a circle around each seismograph station, setting the circle size using the scale on the map and the distances calculated in question 5. In other words, since you can't tell in what direction the seismic waves came from, the circle represents every possible point the earthquake's epicenter could have been. Note that the intersection of three circles will give you a single point; that is the epicenter of the earthquake. Note why this process is called **triangulation** and also note that **if your circles don’t intersect, pick an "average" spot in the middle of where the circles come closest together.**
Figure 7-2 Seismograms from seismic stations JCW, GSM and GMW.
6. How far from Seattle is the epicenter (in kilometers), and in what direction?

7. For many earthquakes, the circles drawn from the seismic stations do not intersect. Give two reasons for this (hint: do earthquakes occur at the surface?).
There are several different **numerical** magnitude systems based on a **logarithmic** relation between ground motion and the amount of motion recorded on the seismogram; each **unit increase** in magnitude represents a **tenfold increase** in the duration of shaking and/or the amplitude of ground motion. Note that it does **not** mean that every unit increase represents a tenfold increase in the **energy** of an earthquake. These different systems yield slightly different magnitude estimates.

The most famous of these type of scales is the **Richter scale**, suggested in 1935 by Charles Richter, a seismologist at Caltech. The most commonly used scale today (based on the Richter scale) is the **moment magnitude** scale (suggested by Hiroo Kanamori at Caltech in 1979), which is calculated by determining the area (length times width) of the fault rupture, the duration of shaking and the type of rock broken and translating that information into a number.


8. What is the **advantage** of the **moment magnitude scale** over the other scales, such as the Richter scale?

There are many websites that are useful for looking up earthquakes and finding out all about them. A great site for local quakes is the University of Washington Geophysics Department ([http://www.geophys.washington.edu](http://www.geophys.washington.edu)). Once there, click on the “Pacific NW Earthquakes” link on the left side. The click on the “Notable Quakes” link in the Quick Links set. Scroll down the list of earthquakes until you get to the “Duvall, WA – May 2, 1996” link and click on that. Finally, scroll down on that page until you see the list for Seismic Plots and Aftershocks; click on the “Seismic Activity” link.

9. Examine the graphs of the magnitude and number of **aftershocks** of the Duvall temblor.

a. How has the daily **number** of aftershocks changed since the earthquake? Is it a **linear** or **logarithmic** (exponential decay-type) change?

b. What happened to the **probability** that were you going to experience an aftershock of about magnitude 3.5 as time went on?

10. a. Click the back button. To which magnitude scale does the M 5.3 refer?
b. What is the actual moment magnitude of the Duvall quake? So was the actual rupture and energy release more significant, less significant or the same as what was implied by the local shaking?

11. Click the back button to return to the main Duvall earthquake site; scroll down to the Summary of the Public’s Web Responses section, and click on the “contour map” link within that paragraph.

You should see a contour map of “magnitudes” compiled from the responses from people all over the Puget Sound area.

a. The explanation below the map takes great pains to point out that the numbers on the map “should not be confused with earthquake magnitude.” Then what are they? Hint: look at the explanation for what the different numbers mean.

b. In fact, the numbers here represent a version of the modified Mercalli intensity scale, a different way to measure shaking. Suggest a reason why the numbers get smaller away from the quake epicenter (the red star).

Not a question, but note that people living in the Mercer Slough area in Bellevue and along the Montlake Cut in Seattle felt the shaking more than their neighbors to the north and south (it’s the little bow-tie shaped 4.8 contour). Weird, huh?

12. Click back to the list of notable quakes, and click on the “Wednesday, February 28, 2001” Nisqually earthquake (this is the big one that some of you may have been around for). Click on the “Community Internet Intensity Map”.

a. Note that the colors refer to the Roman numeral chart below; this is traditionally how the modified Mercalli scale has been represented. What is the maximum intensity shaking (number) felt during this quake?

b. Using your textbook, write what human effects that number corresponds to.

c. Was the largest Mercalli intensity number at the epicenter?

d. Click on the “Statistics” link. How far away did people claim they feel this quake?
In fact, you can report earthquakes and their effect on you at

13. Go back and click the “Peak Ground Acceleration Map”.
   a. What does the little “g” in the acceleration measurements refer to?

   b. If there was a lot of vertical motion during a quake, how would this map symbolize that?

   c. Note that there are a couple of spots on Mercer Island and in the Duwamish River valley that have huge E-W accelerations (even bigger than the E-W accelerations near the epicenter – the red star). Suggest a reason for this (this will also be the reason that the Mercer Slough and Montlake folks felt the Duvall quake more).


   Recalling what “g” means, where is the least shaken part of Seattle predicted to be? Where is the most shaken part of Seattle predicted to be?

15. On the east wall of the classroom, find the map of Seismic History of the Pacific Northwest 1872-1993. Note that earthquake epicenters are plotted on this map, and that the size of the earthquakes are shown by the circles of differing size.

   a. How can you determine from this map that there is a subduction zone off the coast of Oregon and Washington?

   b. Note that there are two highly localized clusters of earthquakes. Describe their geographic location and suggest a cause of such repeated seismicity for each.
16. The following information is taken in part from figure A-4 in Noson, Qamar and Thorsen, *Washington State Earthquake Hazards*, Washington Division of Geology and Earth Resources Information Circular 85 (1988), which lists the largest earthquakes in the Puget Sound region since 1896.

<table>
<thead>
<tr>
<th>Year</th>
<th>North latitude</th>
<th>West longitude</th>
<th>Depth (km)</th>
<th>Mag. (felt)</th>
<th>Mag. (inst.)</th>
<th>Area (km²)</th>
<th>Location</th>
</tr>
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<tbody>
<tr>
<td>1896</td>
<td>48.5000</td>
<td>122.8000</td>
<td>?</td>
<td>5.7</td>
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<td>?</td>
<td>Puget Sound</td>
</tr>
<tr>
<td>1909</td>
<td>48.7000</td>
<td>122.8000</td>
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<td>6.0</td>
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<td>150,000</td>
<td>Puget Sound</td>
</tr>
<tr>
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<td>48.6000</td>
<td>123.0000</td>
<td>?</td>
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<td>70,000</td>
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<tr>
<td>1939</td>
<td>47.4000</td>
<td>122.6000</td>
<td>deep</td>
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<td>122.9000</td>
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<td>122.7000</td>
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<td>63</td>
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a. Considering only those quakes with a felt magnitude equal or greater than 6.0 (the level for significant damage to occur to human structures), what is the average recurrence interval between these large quakes?

b. Based on this average recurrence interval, when are (or were) we due for the next >6.0 magnitude quake? Are we overdue?

17. The Duvall quake had a revised moment magnitude of 5.1; the 1949 Seatac quake had a magnitude of 7.1. How many times more severe was the amplitude of ground motion (shaking) in the Seatac quake compared to the Duvall quake? How many times more energy did the Seatac quake release compared to the Duvall quake (which explains why it was felt so much farther away)? Hint: look this up in the textbook and the two numerical answers should not be the same.
18. Look at the photo from *Washington State Earthquake Hazards*; it is of a “ghost forest” near a tidal flat in Willapa Bay. All of the dead trees died at the same time about 300 years ago. How does it show evidence of a huge (>8.0 magnitude) earthquake in the past? (In fact, the earthquake occurred roughly 300 years ago; the numerical age was obtained by radiocarbon dating.)

![ghost forest photo]


19. Go to the NEIC site above and click on the World map. The map plots the epicenter of the most recent earthquakes.

a. What do the colors of the epicenter symbols signify? What do the sizes of the squares representing earthquakes represent?

b. Click on the largest earthquake you find and a data sheet for that quake will appear. What moment magnitude was this quake? When did it occur? How deep was the focus?

c. What kind of plate boundary describes this area? Hint: click on the Maps tab and then on the “Location Maps” link.