Lab 8: Geologic Hazards: Earthquakes and Landslides

Introduction

Most of the geological processes you have been introduced to in this class take place over thousands or millions of years and have very little direct effects on our everyday lives. Other geologic events, such as earthquakes, landslides, volcanic eruptions, and floods, can occur almost instantaneously and have profound effects on the landscape and our lives. These events are common in the Pacific Northwest. In fact, you will probably experience all of these geologic events in your lifetime. (Some you may already be familiar with.)

A. Earthquakes and Faults

Stress and Strain

Tectonic forces move and deform the crust of the Earth. The movements of small or large parts of the Earth's crust create stress. The adjustment of a rock to stress is called strain. In other words, strain is a change in the rock caused by stress. There are basically three types of stress: compression, tension, and shear:

- Compression results in things (i.e., rock units, crustal plates) being pushed together.
- Tension results in things being pulled apart.
- Shear results in things sliding past one another.

In rocks, stress can produce three types of strain or deformation: elastic, plastic, or brittle:

- If the strain is elastic, the deformed body returns to its original shape after the stress is removed. A good example of elasticity is a mattress. When you get out of bed, the mattress springs back to its original shape. A geologic example of elastic strain is glacial rebound. The crust under Hudson's Bay in Canada has been rising since the 3 km-thick Laurentide Ice Sheet melted 10,000 years ago.
- In plastic strain, a body is molded or bent under stress and does not return to its original shape. Plastic strain in the Earth's crust can result in folded rock units.
- Brittle strain produces fracturing. Faults are good examples of brittle deformation in the Earth's crust.

Faults

A fault is a break or fracture in the Earth, along which there has been movement on one side of the fault relative to the other side. Faults are discontinuous structures that are commonly, but not always, planar (like planes).

Components of a fault (Figure 8-1):

- The fault plane is the surface along which movement occurs. It may be vertical, inclined, or horizontal.
- The hanging wall of a fault rests on or lies above the fault plane.
- The foot wall supports the hanging wall and lies underneath the fault plane.
- The upthrown block is the side that moves upward relative to the other side.

- The downthrown block is the side that moves downward relative to the other side.
- The slip is the distance, measured on the fault plane, between two formerly adjacent points on the opposite sides of the fault.

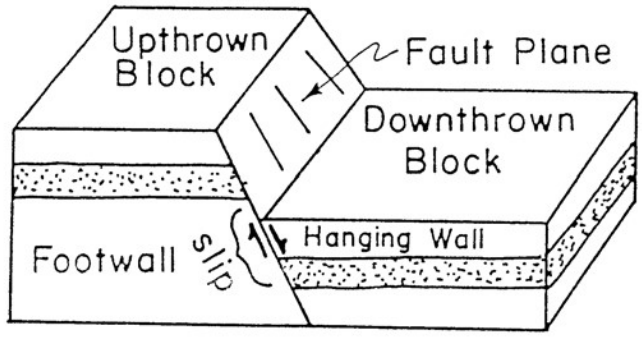

Figure 8-1. Parts of a fault.

Faults are classified according to their movements. Movement can be up or down, and/or right or left. The following faults types have been defined:

- Normal faults are faults in which the hanging wall moves down relative to the footwall (Figure 8-2); these faults often develop as a consequence of tensional forces.
- Reverse faults are faults that had their hanging walls move up relative to the footwalls; such faults often form as a result of compressional forces (Figure 8-2).
- Strike-slip faults commonly have steep dips, and their slip is in the horizontal direction, parallel to the orientation (strike) of the fault plane. A left-lateral strike-slip fault is a fault that has experienced movement as shown in Figure 8-2. A strike-slip fault with right-lateral motion, the motion is opposite (i.e., the block on the other side of the fault, relative to the viewer, will move to the right).

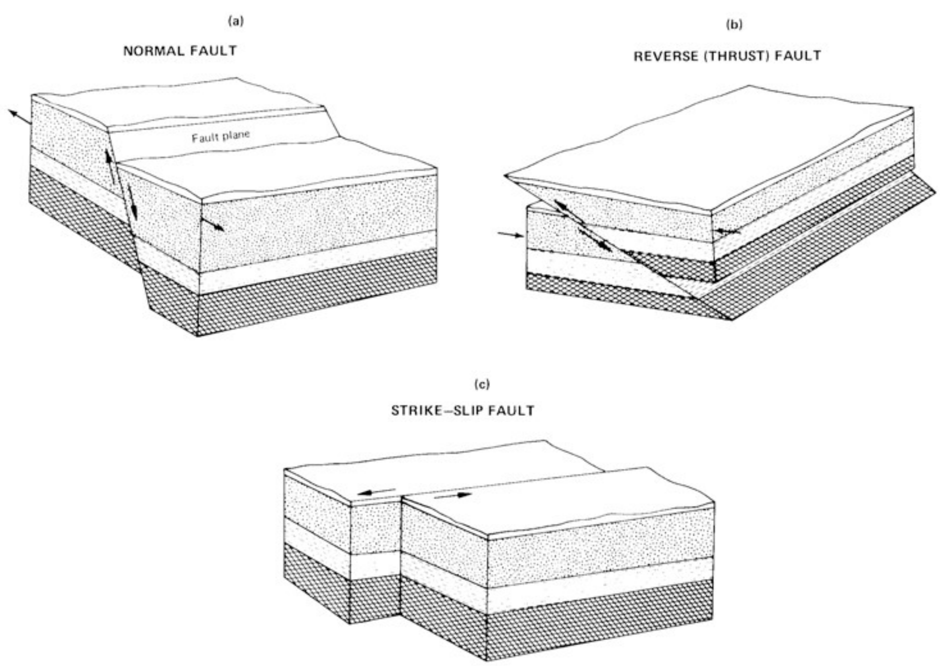

Figure 8-2. Types of faults.

Use the wooden models to answer questions 1 and 2.

1. Push the two portions the block model together from the sides. (You are applying a compressional stress.)

   (a) **Draw an illustration of the fault below**. ***Be sure to label the hanging wall and footwall, and use arrows to indicate the direction of motion***.

   (b) **What is the motion of the <u>hanging wall relative to the footwall</u>**?

   (c) **What type of fault is this?**

   (d) **At what type of plate margin do you think this fault would most likely be found?** (Hint: At which type of plate boundary are compressional forces most common?)

2. Pull the two portions the block model apart from the sides. (You are applying a tensional stress.)

   (a) **Draw an illustration of the fault below**. *Be sure to label the hanging wall and footwall, and use arrows to indicate the direction of motion*.

   (b) **What is the motion of the <u>hanging wall relative to the footwall</u>**?

   (c) **What type of fault is this?**

   (d) **At what type of plate margin do you think this fault would most likely be found?** (Hint: At which type of plate boundary do tensional forces dominate?)

Earthquakes

When the stresses along a fault exceed the strength of the rock, the fault ruptures and releases energy locally, at a place termed the earthquake focus or hypocenter. This sudden release of energy is called an earthquake and what we feel during an "earthquake" is actually vibrations of the solid Earth caused by the passage of seismic waves. These waves are elastic waves, because they do not cause deformation of the rock; the rock is usually not deformed after the waves pass by. Seismic energy propagates in rock as seismic waves move away from the hypocenter in all directions (spherically). Two types of seismic waves are called P-waves and S-waves. The faster wave is called the Primary or P-wave (Figure 8-3a). P-waves are compressional waves. When a P-wave passes through rock, the rock is alternately compressed and dilated in the direction of the propagating wave (like a sound wave). During an earthquake the arrival of P-waves is often described as feeling like a jolt, like what you would feel in a bumper car when you run into another car. The slower body wave is the Secondary, or S-wave (Figure 8-3b). S-waves cause rock to be moved (or sheared) sideways, at right angles to the direction of wave propagation (like ocean waves). S-waves produce a rolling type of motion, like what you would feel in a boat going over waves in a lake.

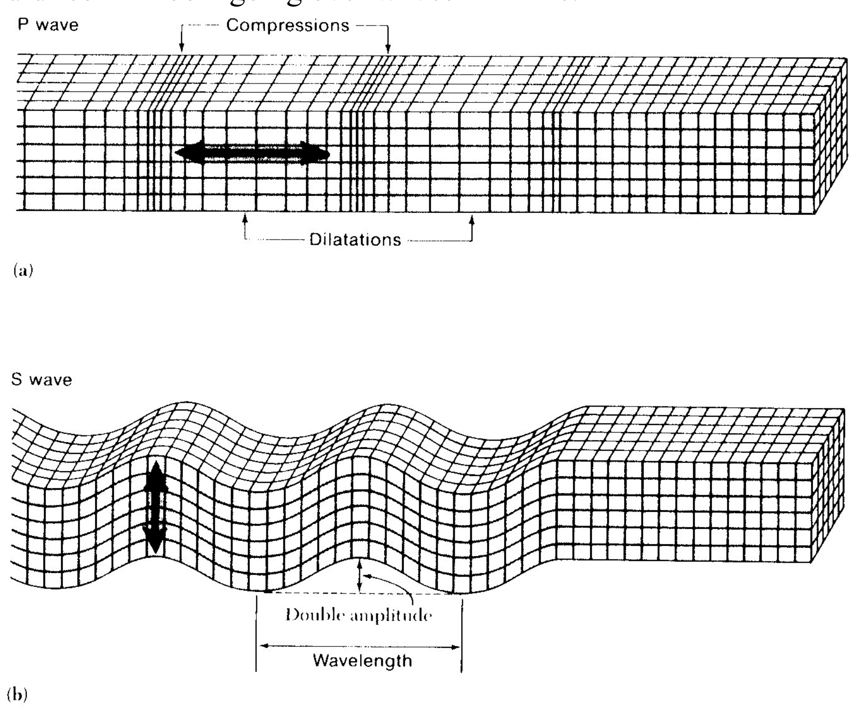

Figure 8-3. Diagram of Earth movements produced by (a) P-waves and (b) S-waves.

3. (a) **Which wave travels faster, P- or S-waves?**

(b) **What do you think would happen to the speed of the P-wave if it traveled through loosely packed material**?

(c) **Given the answer to (b), do you think P-waves travel faster through igneous rocks (very dense) or sedimentary rocks (not as dense)?** Explain your answer.

The actual location of an earthquake is the focus, or hypocenter. It is defined by:

- the epicenter, or position on the surface of the Earth vertically above the hypocenter, in degrees and minutes of latitude and longitude.
- the focal depth, or the distance from the epicenter to the hypocenter.

Seismographs are instruments that record vibrations of the Earth as seismic waves arrive at the seismograph station. Seismograms are the recorded trace of the ground motion at the station, and are the records which seismologists use to study earthquakes.

When an earthquake occurs, seismologists must quickly determine both the magnitude and location of the earthquake. There are several different ways to measure earthquake magnitude (just as there are several ways for measuring the size of a person), including: measuring the duration of shaking at a given point, measuring the maximum amplitude (or height) of seismic waves generated by the earthquake, and measuring the area (length times width) of the fault rupture. These different methods usually yield only slightly different magnitude estimates. All magnitudes display a logarithmic relation to ground motion; in other words, **each unit increase in magnitude represents a 10-fold increase in the duration of shaking and/or the amplitude of ground motion**.

Locating the magnitude 6.8 Nisqually Earthquake of February 28, 2001 (10:54am Pacific Daylight Time)

The epicenter of an earthquake can be determined using triangulation and a map. A seismograph records the exact time when seismic waves reach the seismograph station (the arrival time). If the time of earthquake occurrence (the origin time) is known, then the time it takes for the seismic waves to travel from epicenter to an individual seismograph station (the travel time) can be calculated as follows:

Travel Time = Arrival Time - Origin Time

The arrival time and origin time of an earthquake is measured with respect to Greenwich Mean Time (GMT).

4. Use the three seismograms (the recorded trace of ground motion) from seismic stations OSD, SEP, and MBW to determine the arrival time of the P-waves at each station. Then use the arrival time and the **origin time** for the Nisqually earthquake (**18:54:25 GMT**) to determine the P-wave travel times to each station. Show your work.

Station	Arrival Time	Travel Time
MBW		
OSD		
SEP		

5. The travel time can be converted into a distance if we know something about how fast P-waves travel through the Earth. For continental plates (which are made largely of granitic rock) the average P-wave velocity in the crust has been determined to be 6.5 km/sec. (This can be thought of as the speed of sound in rock. For reference, the speed of sound in air is about 0.33 km/sec.) Using this information, **calculate the distance from each seismograph station to the epicenter using the following equation**: *Distance = Time * Velocity*

Station	Distance to Epicenter
MBW	
OSD	
SEP	

6. On the map provided (Figure 8-4), **use a compass to draw a circle around each seismograph station, using the distances you calculated above as the radius for each circle**. The epicenter lies at the point where all three circles come closest to intersecting (this process is known as triangulation).
How far from Seattle is the epicenter (in kilometers), and in what direction?

7. For many earthquakes, the arcs you draw do not intersect at a point. **Can you think of at least two possible reasons why?** (One hint: Do all earthquakes occur on the Earth's surface?)

8. Examine the record of aftershocks that occurred after the Nisqually Earthquake.
   (a) **How has the magnitude of the aftershocks changed since the earthquake?**

   (b) **How has the daily number of aftershocks changed since the earthquake?**

   (c) **Are they still occurring? When was the latest aftershock?**

9. Refer to Table 2 on page 22 of the DNR information circular titled <u>Washington State Earthquake Hazards</u>. This table lists the largest known earthquakes felt in Washington State in the last 125 years. Use this information provided to answer the following questions.
   (a) **In the past 100 years, how many earthquakes in the Puget Sound had magnitudes greater than or equal to 6.0** (what we consider a large earthquake)? ***Don't forget to include the 2001 Nisqually Earthquake***.

   (b) **On average how often does Puget Sound experience large earthquakes?** This is called the <u>recurrence interval</u> for large earthquakes. *Use the time between the first and last earthquake counted above and divide it by the number of earthquakes during that period. Show your work.*

   (c) **When did the last large earthquake occur in Puget Sound (M>6.0)?**

   (d) **Based on the recurrence interval you calculated in (b) when are we due another large earthquake in Puget Sound?**

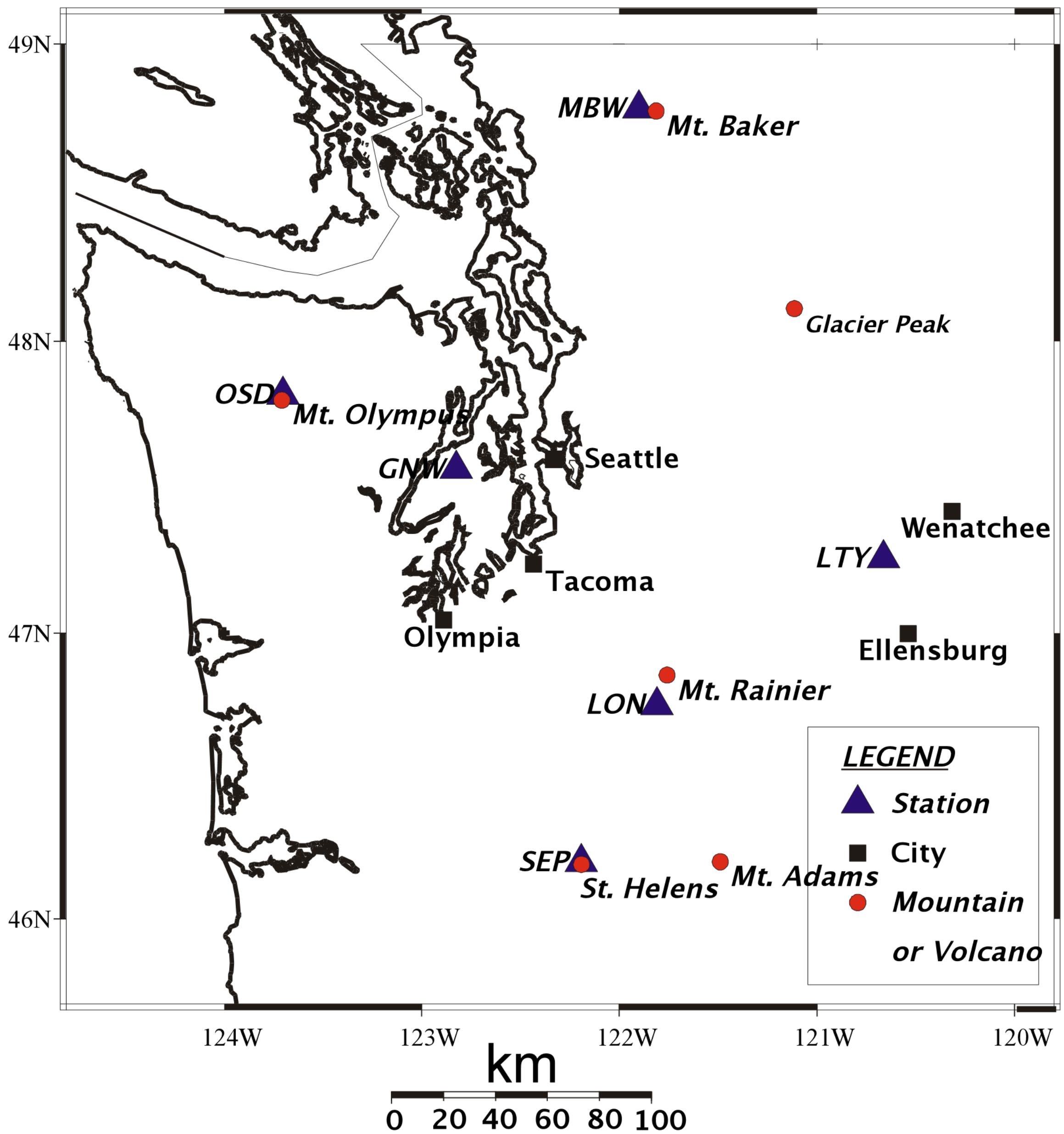

Figure 8-4. Map of the Seattle area showing seismic stations GMW, GSM, and JCW.

10. The Pacific Northwest may experience enormous earthquakes (Magnitude 8.0 to 9.0) about every 300 to 500 years. Unlike the Nisqually earthquake, which occurred in the subducting plate, very large earthquakes commonly occur along the contact between the Juan de Fuca Plate and the North American Plate. The last really big earthquake in the Northwest probably occurred in 1700 A.D. **What type of evidence might we look for in the Pacific Northwest to see evidence for this earthquake?**

11. The hypocenter for the Nisqually earthquake was over 50km below the surface. Deep earthquakes can be devastating, but shallow quakes are generally more destructive. The Seattle Fault, which runs through downtown Seattle and follows I-90 to the east and *surfaces* on Bainbridge Island, is believed to have ruptured about 1100 years ago. This earthquake uplifted south Puget Sound 6 meters above sea level, and generated a tsunami (a seismic sea wave) that washed up Puget Sound. **If the earthquake along the Seattle Fault had a magnitude of 8.8, how much greater than the Nisqually earthquake (M=6.8) would the amplitude of ground motion have been in around Seattle?**

B. Landslides

Mass wasting is defined as the downslope movement of earth materials under the influence of gravity. Common examples include landslides, mudflows, and soil creep. The classification of mass wasting is based on the type of movement (slide, fall, flow) and the composition of the moving mass (debris, mud, rock). Slope failure is caused by specific pre-existing conditions (e.g. bedrock geology, structures) in conjunction with some event (or trigger).

Substrate geology is one of the most important pre-existing conditions. Some rock types are inherently weak and are referred to as incompetent roc. Some common examples of rocks that behave incompetently include shale, siltstone, mudstone, schist, and volcanic tuffs. The structure of the rock units also affects the stability of slopes. Slopes can fail where there are planes of weakness in the rock (e.g. faults, fractures, bedding planes, and foliation surfaces). The plane along which the slope fails is commonly a zone of weakness in the rock. Differences in porosity between rock units can also make a slope more susceptible to failure.

Landslides are triggered when the forces acting to pull material down a slope overcome the forces holding that slope in place. The forces acting to pull material down the slope increase as;

(a) the slope steepens (e.g. it is undercut by wave or stream erosion),
(b) the thickness (weight) of the material on the slope increases (e.g. due to sedimentation or construction), or
(c) the density of the material on the slope increases (e.g. heavy rains fill the pore space with water).

A landslide also becomes *more likely* if the forces holding the material in place decreases. This occurs if:

(d) the cohesion of the material decreases, such that it doesn't stick together very well (e.g. due to shaking from an earthquake),
(e) internal friction decreases making it easier for grains to start sliding past one another (e.g. water builds up along a plane of weakness), or
(f) the pore water pressure increases (increased water in the pore spaces pushes grains apart).

12. **Where would you expect most landslides to occur in the Seattle area? Why?**

13. **What time of year do you expect most landslides to occur in the Seattle area? Why?**

14. A number of landslides in the Seattle area occur at the boundary between the Esperance Sand and the Lawton Clay units; the Esperance Sands tend to slide off of the Lawton Clay. **Based on what you know about the physical properties of the two sediment units and the occurrence of landslides propose a theory to explain this phenomena.**

15. 1965 was a particularly dry year, however, there was a higher than average number of landslides in the Seattle area. **What is another possible trigger for these landslides?**

16. Stratovolcanos are prone to large mudflows (called lahars). **List at least *three* physical characteristics of stratovolcanos that can lead to large mudflows.**

17. Look at Figure 8-5 which shows the path taken by the Osceola mudflow on Mt. Rainier.
   (a) **How far did that mudflow travel**?

   (b) The average flow rate for mudflows is 40 km/hr. **At this rate, how long would it take a mudflow to reach the town of Greenwater? What about Auburn?** *You should have two answers for this question.*

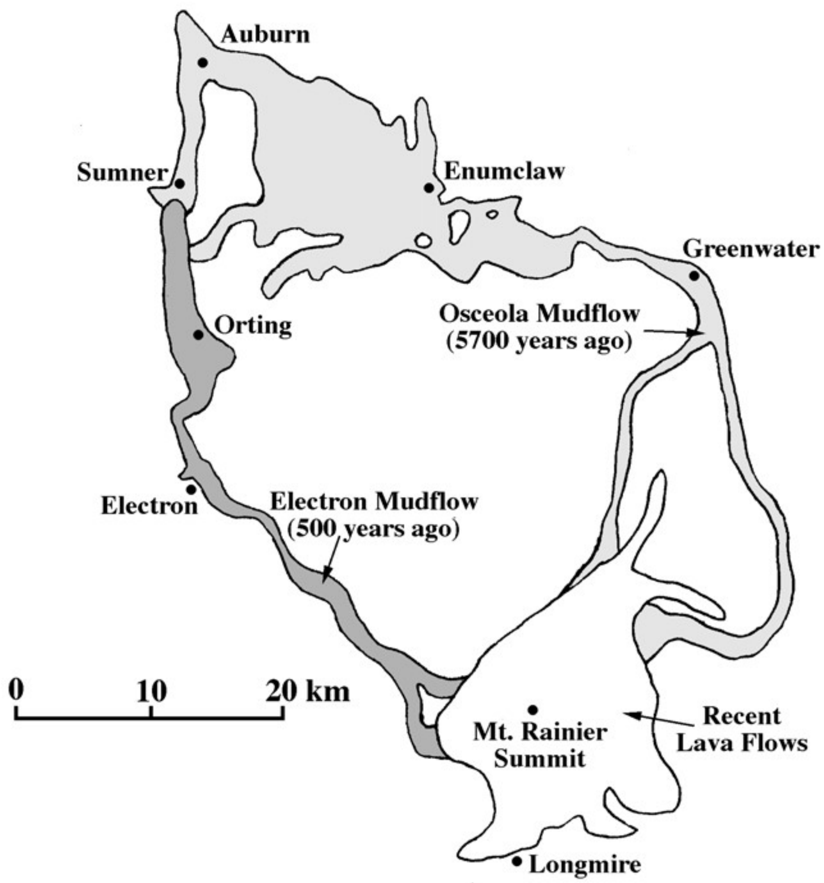

Figure 8-5. Path of the Osceola Mudflow and the Electron Mudflow. Both mudflows originated on Mt. Rainier.

18. If you where buying a house in the Seattle area what geologic factors should you investigate in order to prevent losing your investment to a natural disaster?