PUGET SOUND DISASTERS: LANDSLIDES OF SEATTLE FIELD TRIP

Use all resources at your disposal to prepare for this trip. Some good resources include (but are not limited to) those listed on the course syllabus (Pre-Trip Questions sheet) and the course website (http://scidiv.bcc.ctc.edu/gj/HCCgeo152.html). Use your resources and your learning from the Pre-Trip Questions as guides as you prepare your Field Trip Summary Article. (Remember, all work must be fully sourced.) During the trip, we will hear student presentations, each 5-10 minutes in length. The itinerary and stops described here may be amended.

### STUDENT PRESENTATION TOPIC

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### Background Information and Some Questions to Ponder

Landslides cause millions of dollars of damage in the Seattle area during an average year. The slides are a result of a combination of geologic, climatic, and human factors. Landslides are numerous during particularly wet winters, and are most common after heavy rains. In addition, landslides may be triggered by earthquakes. Waves and streams speed up the erosion process and increase the risk of landslides.

Human factors that often contribute to landsliding include the diversion of drainage water onto a hillslope; excavations on a hillslope; and inadequate planning, construction, or maintenance of houses, retaining walls, and other structures. This field trip will acquaint you with some examples of landslides in the Seattle area.

Much of the Seattle area is built on thick layers of sediment deposited by a huge glacier during the most recent "ice age" (glacial maximum about 14,000 to 17,000 years ago). From the surface down, these layers may include glacial till (hardpan), sand, clay, and silt. Because these layers are loose sediment rather than hard rock, they are relatively easy to erode and thus prone to landslides. Evidence of earlier glaciations exist throughout the Puget Lowland.

The assigned readings (and others!) give more information on the factors and processes of landsliding.

### STOP #1 (Carkeek Park) - restrooms available

Look north up the shoreline at the recent landslides. Estimate the height of the bluff, based on the height of the houses on the bluff. Then estimate how large each slide is, in terms of length, thickness, and height. Multiply these numbers together to get a rough idea of the volume of material that slid (volume = length \( \times \) thickness \( \times \) height). Notice that huge trees are tilted sideways or even toppled, due to the slides. Take notes and make sketches.

Next look southward, and if the weather permits, walk up close to another recent landslide on the bluff. What kind of material does the bluff seem to be made of (solid rock, loose sediment, ...)? How old do you think this landslide might be? What are some clues from the vegetation on the slide material? Take notes and make sketches.

### STOP #2 (Sunset Hill Viewpoint Park)

Now we're on top of a bluff, a bit south of Carkeek Park. Why does the bluff edge appear "scalloped" from above? Some large slides occurred here in 1996-97 (why?). Do you see any clues in and around the sidewalk for these events? How about for sliding that's taken place since then, that is even going on today? How many landslides can you see on the slope itself? Can you estimate their age? How close are the houses to the park's sidewalk (near the fence)? Take notes and make sketches.

Look southward to Magnolia, the next "spit of land" beyond the Ship Canal. Notice the large grey vertical cliff.
It's made of glacial sediments, which we'll see up close (tides permitting) at the next stop. Why is this cliff so steep? How close are the surrounding houses (above and below) to the cliff? Take notes and make sketches.

STOP #3 (Discovery Park) - restrooms available

Here we'll get an up-close look at the glacial sediments that Seattle and much of Puget Sound is built on.

* The bottom layer is called the Olympia (or Kitsap) Formation. It was deposited by rivers before the most recent "ice age", when the climate was similar to today's.

* The next layer up is the Lawton Clay. It was deposited here when the huge continental glacier, flowing down from Canada blocked Puget Sound, making it a huge lake.

* The layer above is called the Esperance Sand. It was deposited by glacial rivers, when the ice sheet got closer to Discovery Park.

* The top layer is the Vashon Till. Till is deposited directly by glacial ice. It is a mix of all sizes of sediment, from clay to boulders. The fact that we have till at Discovery Park means that the glacier made it at least this far south during the last "ice age". (In fact, it made it to the southern end of Puget Sound.)

What do you see in terms of old landslides? Is there evidence of recent landslide activity here? How does the arrangement of glacial sediments increase sliding in Puget Sound? Take notes and make sketches. Make a stratigraphic section, to scale as best you can.

Look at the rocks (pebbles and sand) in the sediment on the modern beach itself. Identify the dominant rock types (from among the attached igneous, sedimentary, and metamorphic ROCK ID. CHARTS). Also identify some of the less-common ones. Hypothesize as to the possible sources of the rocks in the modern beach sediment. Take notes and make sketches.

"The treatment plant sits on an archaeological site showing evidence of tsunami and fault subsidence. The West Point spit accreted over the past 5000 yr, building outward with longshore drift and upward with sea-level rise. Prior to 1000 yr ago, beach berms protected a back beach tidal marsh. Native Americans occupied dry ground around the marsh and used the land as a seasonal shellfish processing area. The major earthquake on the Seattle Fault, 1000 yr ago, caused 1 m of subsidence and deposited a tsunami sand layer. Rapid sedimentation buried the tsunami sand until excavation for the treatment plant in the early 1990s exposed the layer." (Troost et al., 2003 GSA "Quaternary Geology of Seattle" field trip).

STOP #4 (Perkins Lane)

Perkins Lane is famous for its view homes...and for its big, expensive landslides. Some people have lived here for many years, whereas others are just building their dream homes on this street. As we drive along, look for evidence of landslides, old and new. Also look for ways people have tried to prevent (or lessen the impact of) landslides here. At least one house slid enough that its owners moved it across the street (toward the water). Another is falling down and apparently being rebuilt. What locations on Perkins Lane do you think are the safest? The least safe? Why? If you were a scientist (or potential homeowner), how would you go about finding out? Take notes and make sketches.

"The most prominent landsliding here has involved the uppermost unit, Vashon Till, that has detached in large blocks from the upper scarp. At this site, the till has numerous lenses of sand and joints that locally transmit groundwater quite effectively, and that have created zones of weakness through the otherwise strong material. This site also lies at the edge of an older, larger rotational landslide that has involved not only the failed material at the foot of the slope by also several lots to the northwest." (Troost et al., 2003 GSA "Quaternary Geology of Seattle" field trip).

STOP #5 (Magnolia Boulevard Viewpoint Park)

Walk south (toward downtown) along the fence. When the path dips and the bluff cuts in a bit, go just a bit farther
and then look back and down to the waterline. Look at all the wrecked houses, and the big mass of slide material. Take notes and make sketches.

What is the height of this mass movement, in feet? Its depth? Its length? Multiply these three numbers together, to get the total volume of this mass movement, in cubic feet. 100 cubic feet equals about 5 tons. How many tons was this mass movement? Have waves played any role in the development of this mass movement? How? Take notes and make sketches.

The citizens of the city of Seattle were sued by the owners of the wrecked homes, because this mass movement involved a public, city-owned cliff, and the city did not prevent this mass movement of the public property, which pushed their property into Puget Sound. The case was dismissed in the city's favor. Are there any signs of damage to Magnolia Boulevard West behind you? Take notes and make sketches.

Look ahead as we drive east across the Magnolia Bridge...Notice the landslide restoration project on the slope (Garfield Street Emergency Slide Restoration). Also notice the houses around it. This has been an expensive project. Imagine you're in charge of this project. What things do you see that seem to be done well? And not so well? Take notes and make sketches (we may be doing this while moving, so be alert).

STOP #6 (Smith Cove Marina)

These sites are instructive because of several different examples of mitigation strategies, trying to slow down mass movement, or lessen their impacts, or stop them altogether. The most prominent strategy here is the use of "shotcrete": concrete sprayed from hoses onto the slopes (with or without forms). People who use shotcrete are trying to prevent rainsplash erosion of bare ground created by a mass movement such as an earthflow. Normally one waits until the ground is stripped bare by mass movements; in some really warped scenarios, the slope is devegetated by hand, and then sprayed with shotcrete. Some people incorrectly believe that shotcrete has the muscle to hold slopes in place. But what negative effects might the shotcrete produce? Take notes and make sketches.

On the site to the right/south, is there any evidence of very recent movement below the shotcrete? On the site to the left/north, we find a very impressive mass movement, that surges forward every rainy season. Old concrete power poles have been placed at the toe of the mass movement to protect the roadway. Is this strategy successful? The rockery to the right was built for exactly the same purpose. Take notes and make sketches.

Examine the topography of the hillside, both the bare and vegetated parts. Is the slope smooth and even, or is it lumpy and bumpy? Estimate how vertical the bluff itself is, and the tilt of the trees on the slope. Give a simple interpretation of the topography you see. Take notes and make sketches.

To the left and right of the large mass movement, there are small pipes sticking into the hillside. These are drainage pipes sticking into the hillside like perforated soda straws, trying to keep groundwater from building up. A drumlin is a long, steep-sided ridge made out of glacial materials (till, sand, clay) and molded into a torpedo shape by the passage of the glacier over the glacial materials. Think about the geology of the Magnolia drumlin. What's the best place to insert these drainage pipes? Usually there's water coming down the long black plastic pipe, and water coming out of a large buried pipe that's emptying into the storm drain. More are needed. Take notes and make sketches.

As we leave the marina area, notice the seismic retrofitting that's been done to the underside of Magnolia Bridge.

STOP #7 (Condominiums above Westlake Ave) - if time permits

A number of condominiums and apartment houses sit at various levels along the extremely steep east side of the Queen Anne drumlin. With the incredible east-facing views of Lake Union and the morning sun, these condos and apartments do not come cheap. However, many are at serious risk for destruction or damage by mass movement, because of bad earth materials and steep slopes. Earthquakes will not be kind to these buildings, either!

How high is the cliff? What would be an appropriate setback, the distance back from the cliff that buildings
should be situated? Is this slope smooth and even, or is it lumpy and bumpy? How wide is a typical mass movement along this hillslope? Is the typical mass movement here gouging deep into the hillside, or is it just sloughing off the upper foot or two of soil, etc.? Take notes and make sketches.

The large building has decaying "christo" (like shotcrete) from January 1997. The plastic tarp prevents revegetation of the bare slope; plants can't grow under the plastic. Is this good, bad, or indifferent? Why? What "pioneer plants" are naturally revegetating the scars from 1997 and earlier? Parts of the slope are semi-stable; they have not moved for 40 or 50 years. How can you tell? Take notes and make sketches.

**STOP #8 (Newly Bulldozed Townhouses on Lakeview Blvd) - if time permits**

The city of Seattle acquired the steep bluff leading up to St. Mark's Cathedral, to establish the St. Mark's Greenbelt. Greenbelts are often established on steep slopes that are unfit for development. However, the acquisition of steep, landslide-prone terrain then puts the city at risk for lawsuits, if the city's cliff moves and damages private property (either above or below). Three townhomes, built within the last 10 years or so, were located at 1515, 1517 and 1519 Lakeview Boulevard East. Damage increases to the north, but all 3 townhomes were condemned in January 1997 and sat abandoned until bulldozed in early 2004. The townhomes were built solidly, both to keep out freeway noise and to prevent earthquake damage. What's the lesson here? Take notes and make sketches.

A bit north on Lakeview Boulevard (just before the freeway overpass) is a steep slope with a staircase running up it. This slope moved on New Years, 1997, partially blocking Lakeview Blvd E for a couple of days. The slope varies from 35° in angle at the bottom to 60° at the top. A green rental home with a black plastic drain pipe is perched precariously. The wooden staircase is new, there was none before the mass movement. The staircase has been built right on the fresh scar. You can argue that this is the best place for the staircase along this slope. Why put the staircase on the scar? Take notes and make sketches.

There are some red alders (*Alnus rubra*) on the south end of the scar, colonizing the scar (plant pioneers). They are 7 years old. How tall are they, on average? How tall will they be in 13 more years, when they are 20 years old? Older broad leafed maple (*Acer macrophyllum*) trees are found to the north and south of the scar. The north ones are leaning out from the slope, and have curving tree trunks. Slow downslope movement of the soil can cause this kind of tilt and curvature. But there is another cause of plants leaning out from a slope, that is not related to slope movement. What is the other cause? Take notes and make sketches.

Across the street is a very large boulder, about 3 feet in diameter, made of some kind of granite. The boulder weighs 3-4 tons. When Lakeview Blvd was built 85 years ago, they pushed this boulder out of the middle of the roadway. How did it get here? (Think about what you saw at Discovery Park.) Take notes and make sketches.

**STOP #9 (St. Mark's Cathedral) - if time permits**

Now we're looking down on the Lakeview Boulevard townhouse site... What do you see? How far back is the cathedral set from the cliff? How far back is the edge of its parking lot? How old might the last major slide be? What evidence do you see for recent movement on this bluff? What do you think about using plastic sheeting on the slope? Take notes and make sketches.

**STOP #10 (California Way SW / Ferry Ave SW Slide) - restrooms at boat launch on Alki SW**

"Shannon & Wilson was retained by the Seattle Engineering Department (SED) to stabilize a landslide that occurred during the historic February 1996 rainfall. The landslide was located along the 1300 block of California Way SW in Seattle and the street was closed for over nine months. The slide was approximately 80 feet wide at the top and 200 feet wide at the street. The vertical height of the slide was approximately 100 feet. ... The soils on the bench consisted of loose and soft silts and sands that had accumulated over many years as a result of local sliding and slumping of the upper slope. After the heavy rains, the colluvium on the bench became saturated and slid over the lower slope and onto the street. Simultaneously, the springs within the transition zone became exposed resulting in additional erosion,
piping, and sliding, ultimately replacing the debris that existed on the bench prior to the landslide. ... Innovative solutions included the first Seattle use of geosynthetic reinforced slopes and uniquely designed spring head drains." (2001 PNW-NAGT field trip guide, "Landslides in the West Seattle Area", led by William D. Nashem, Geologist, Shannon & Wilson, Inc.)

How stable does this slope appear to be? What evidence do you see, in the stabilization structure and the surrounding slope? Take notes and make sketches.

As we continue up the hill, look at the houses we pass (including the overhanging decks).

**STOP #11 (Hamilton Viewpoint Park)**

This location provides a sweeping view of Magnolia and downtown Seattle, across Elliott Bay. We should be able to see several of our other field trip stops from here. Note the height of the Space Needle - The glacier that covered Seattle during the most recent glaciation was 5 times higher (thicker) than the Space Needle! Coincidentally, the ferry routes approximately follow the trace of the main strand of the Seattle Fault (which continues along under I-90). We’ll stop here to hear some student presentations.

"The flat, industrial area surrounding Safeco Field is an extensive fill deposit that rests on soft tideflat deposits. Much of the fill was derived from regrading projects in the early 1900s and dredging of Elliott Bay. In places the fill is as much as 15 m thick, resting on 15 m of soft and loose native deposits. ... Where fill overlies tideflats, extensive liquefaction occurred from the Nisqually earthquake on February 28, 2001." (Troost et al., 2003 GSA "Quaternary Geology of Seattle" field trip).

**STOP #12 ("The Alki" Condominiums Landslide, 1564 Alki Ave SW)**

"The slide occurred along a bench formed on the contact between Esperance Sand and Lawton Clay. ... Prior to completion of this [remediation] project, the face of this slope was always wet from seepage. ... After a critical thickness of sediment on the bench) is reached an unusually heavy winter causes the groundwater table to rise and the sand slides off the bench and onto the face of the bluff and the property at the toe of the bluff. The process then repeats itself. ... SPU [Seattle Public Utilities] requested and received $1.3 M in funding from FEMA (Federal Emergency Management Agency) on this project. The City of Seattle estimated the overall cost of the project to be $2 M. The project is unique in that the remainder of the money needed was provided via a "challenge grant". The "challenge grant" is similar to a ULID (utility local improvement district) except that prior to starting the project, approval of the majority of the people who are being asked to pay for the improvements (properties adjoining the site and who are assumed to receive some benefit) was required. The remaining $700 K was split up 50/50 between SPU and the public. This is the first time the city has used this type of program. ... A major consideration for the project were safety concerns related to constructing a deep trench in close proximity (within about 30 feet at some locations) to the crest of a 100 feet high bluff. ... Remediation at this site included construction of a subsurface cutoff trench, and installation of horizontal drains. The cutoff trench is generally about 25 feet deep and extend roughly 1200 feet along the slope. Horizontal drains consist of 1-1/2-inch-diameter slotted PVC pipes that are drilled back into the slope on the bench. A total of 36 horizontal drains ranging in length between 100 and 300 feet (approximately 7500 lineal feet) were installed." (2001 PNW-NAGT field trip guide, "Landslides in the West Seattle Area", led by William D. Nashem, Geologist, Shannon & Wilson, Inc.)

What are the pros and cons of major remediation projects like this? Describe at least 5 pros and 5 cons. Be specific and detailed, and explain your reasoning.

**STOP #13 (55th Ave SW / 1300 Alki Ave SW Debris Flows) - restrooms opposite 63rd SW**

"The Alki Avenue area of West Seattle has the highest density of debris flows in the City of Seattle. ... Debris flows include not only mud but also wood debris and other objects that can act as projectiles that may cause structural damage to structures in their path. Structures situated at the toe of the slope along
Alki Avenue are susceptible to this type of landslide because of their close proximity to the steep slope. During field reconnaissance performed for the Seattle Landslide Study, several debris flow hazard areas were identified. The 55th Avenue SW area was not initially identified as a debris flow hazard area until several geomorphic [landform] features, indicative of debris flow deposits, were identified during the reconnaissance. Residential structures are built atop historic debris flow deposits. (2001 PNW-NAGT field trip guide, "Landslides in the West Seattle Area", led by William D. Nashem, Geologist, Shannon & Wilson, Inc.)

What information should residents at this site be given, when they consider moving here and/or as geologists and engineers learn more? Compare and contrast the geological causes and potential hazards associated with debris flows vs. other types of mass movements in Seattle.

STOP #14 (Alki Point)

Notice how the topography changes as we approach the top of Alki: It's a flatter lowland, but still above current sea level. Keep a sharp eye out for a hill with houses and a big madrona tree at the eastern (inland) side of the road immediately before (and as) we round the bend at Alki Point. Some very old rock juts up at the tip of Alki, as a built-up hill and some great tide flats. This is the ~40 million year old Blakeley Formation, which consists primarily of sandstones and siltstones,

"representative of a nearshore marine sandy shelf environment [about 40 million years ago]. The bedrock at the south end of the exposure is sheared, suggestive of fault movement some time in the past. Just north of this exposure is one of the traces of the Seattle Fault, which has uplifted this block of Earth's crust several kilometers relative to the block just north of Alki Point over the past several million years (and by an additional 7 m in the year 980 AD)." (Troost et al., 2003 GSA "Quaternary Geology of Seattle" field trip)

This bedrock "may be correlative with the raised marine platform at Restoration Point, on Bainbridge Island, directly across Puget Sound from Alki Point." (Galster et al., 1994 GSA "Engineering Geology of Seattle and Vicinity" field trip)

What are some of the pros and cons of building right here, vs. at our earlier stops? Also, why is there great tidepooling here at Alki Point (think uplifted bedrock)?

STOP #15 (Beach Drive SW)

Keep watching the topography change as we drive along Beach Drive SW. Where are the houses built? Where are the trees? What evidence of mass movements do you see?

At Me Kwa Mooks / Emma Schmitz parks, very low tides expose folded (deformed) layers of highly compressed peat and silt, carbon-14 dated to be about 28,000 years old, thus from the same interglacial interval as the Olympia (Kitsap) layer we saw at the base of the cliff at Discovery Park. Why might this layer be folded here, but not folded at Discovery Park?

If we were to continue on Beach Drive SW rather than turning up SW Jacobsen Road, we'd cross a very subtle fault scarp. Hmmm. How might that happen?

As we loop up SW Jacobsen Road, notice the huge trees tilting rakishly toward the road.

And back to HCC campus!
Driving Directions

From HCC campus to STOP #1 (Carkeek Park - 950 NW Carkeek Park Rd, Seattle) - Directions from the Seattle City Parks website: Take I-5 North. "Taking Exit 173 to Northgate Way and turning west. After crossing Meridian, Northgate Way becomes NW 105th Street and crosses Aurora Ave N (Highway 99). Turn right on Greenwood Ave N and left on NW 110th Street (look for the crosswalk lights above the street). After 6 blocks, NW 110th Street becomes NW Carkeek Park Road and winds down into the valley for 1/2 mile to the park entrance. Watch for the "rainbow-colored" Department of Parks sign on your left." Take left into park. Continue straight (road soon becomes one-way loop). We will park in playground parking lot.

To STOP #2 (Sunset Hill Viewpoint Park) - Loop back through park, make right onto 3rd Ave NW. Take right turn onto Holman. At NW 85th St make right (west). Go left onto 32nd Ave NW. Take right onto NW 77th St, then left (south) onto 34th Ave NW. Park on road.

To STOP #3 (Discovery Park) - Continue south on 34th Ave NW, to NW 75th St. Go left on NW 75th St, then right onto 32nd Ave NW. Continue on 32nd Ave NW to end. Turn left onto NW 54th St (road becomes NW Market St). At 15th Ave NW, turn right. Drive over Ballard Bridge, and follow sign for Fisherman's Terminal / Elliott Ave. You'll take first right after Ballard Bridge, onto W Emerson St. Go past Fisherman's Terminal, then turn right onto Gilman Ave W (sign "To Fort Lawton") (road becomes Government Way). Continue into Discovery Park. Park in visitor center parking lot (on left). (Good stop for lunch and rest rooms.) We'll get special permission to park our van near the lighthouse.

To STOP #4 (Perkins Lane) - Drive back out of Discovery Park, and back onto Government Way. Take right onto 34th Ave W. At first light, make right onto W Emerson St. Go almost to the end of the road, taking left onto Perkins Lane. This is a very narrow road, with few places to park. Please respect the privacy of the residents by not parking in their private spaces. If possible, park and walk to end (past "Dead End" sign), or drive to end and turn around without parking.

To STOP #5 (Magnolia Blvd Viewpoint Park) - Returning from the end of Perkins Lane, take your first right, uphill onto Raye. At the top of Raye, make a right (south) onto Magnolia Blvd. (You can park along the road and walk down staircase to Perkins Lane to see STOP #4 locations.) Continue on Magnolia Blvd to the parking lot for the viewpoint park.

To STOP #6 (Smith Cove Marina) - Continue south on Magnolia Blvd. Take right onto Howe, then right onto Magnolia Blvd again (road becomes Galer). To get to the marina, you have to drive east across Magnolia Bridge, then loop back and drive west across Magnolia Bridge. (To do that, take right on 15th and immediately merge left and turn left immediately onto Galer. Stop and wait, watch the very fast traffic. Turn left onto the bridge.) Stay right on the bridge, and near far (west) end of bridge, take right exit. Go left under bridge toward Smith Cove Marina. Park in parking lot.

To OPTIONAL STOP #7 (Condominiums above Westlake Ave) - Retrace path under and onto Magnolia Bridge (east). At far (east) end of bridge, take left onto 15th Ave W. Turn right at the "Emerson / Nickerson" exit, following the left (Nickerson) branch. Drive past Seattle Pacific University, and under the Aurora Bridge (road becomes Westlake Ave). Continue straight on Westlake Ave. At about the 2400 block, make left turn into Gove's Cove parking lot (beware potholes).

To OPTIONAL STOP #8 (Newly Bulldozed Townhouses on Lakeview Blvd) - Continue on Westlake Ave to Roy St. Make left on Roy St. Bear left (onto Fairview Ave N; road will become Eastlake Ave). Turn right on East Lynn. Take right onto Boylston, bear left (= Newton) under I-5, then follow road (becomes Lakeview Blvd) to the 1500 block, just before Egan House. Park on side street to right.
To **OPTIONAL STOP #9** (St. Mark's Cathedral) - Double back on Lakeview Blvd. Instead of bearing left under I-5, take Harvard Ave E up **steep** hill. Make right onto E Miller St, then right onto 10th Ave E. Turn right into St. Mark's parking lot or park on side street.

To **STOP #10** (California Way SW / Ferry Ave SW Slide):

(A) From **STOP #6** - From St. Mark's parking lot, take left onto 10th Ave E. Continue to "T" at Roanoake. Take left at Roanoake, into far left-hand lane. Cross over I-5, staying in left-hand lane. Turn left onto Boylston, go through traffic light, and merge onto the I-5 South entrance ramp just before the road bends left under I-5. Take I-5 South to the West Seattle Bridge (exit 163A). Bear right as you exit I-5, and follow signs to the West Seattle Bridge. Take the bridge to the Harbor Ave SW exit (**not** Harbor Island!). At end of exit ramp, take right and follow Harbor Ave SW (slowly). Take left onto California Way SW, then immediate hard left onto Ferry Ave SW. The landslide is at this junction.

(B) From **STOP #9** - Travel back across the Magnolia Bridge. Take a right at the end of the bridge, onto 15th Ave W (which becomes Elliott Ave W). Stay in the right-hand lane, and follow 15th/Elliott toward Rte 99 South (**not** left-hand branch to Western Ave W). Keep following the 99 South signs, and take the Alaskan Way viaduct (99 South). Exit to the right at the West Seattle Bridge exit. Take the bridge to the Harbor Ave SW exit (**not** Harbor Island!). At end of exit ramp, take right and follow Harbor Ave SW (slowly). Take left onto California Way SW, then immediate hard left onto Ferry Ave SW. The landslide is at this junction.

To **STOP #11** (Hamilton Viewpoint Park) - Continue up hill via Ferry Ave SW. Follow this road as it loops and branches, bearing right most of the way. The first major intersection is California Ave SW again - Take a right onto California Ave SW and follow it to Hamilton Viewpoint Park. Take a right into the park's parking lot (be careful, it's two-way).

To **STOP #12** ("The Alki" Condominiums Landslide, 1564 Alki Ave SW) - Turn right out of the Hamilton Viewpoint Park parking lot, and continue on California Ave SW as it loops back downhill and becomes California Way SW. Finish the loop at the landslide stabilization structure of STOP #10. Take a left there, then left onto Harbor Ave SW (which becomes Alki Ave SW around the first bend). Keep an eye out for "The Alki" condos (yellow-tan with brick first floor, just before about ten older houses).

To **STOP #13** (55th Ave SW / 1300 Alki Ave SW Debris Flows) - Continue on Alki Ave SW. Take left onto 55th Ave SW. Follow it slowly as it bends to the right. Take a right onto 56th Ave SW, then a left back onto Alki Ave SW.

To **STOP #14** (Alki Point) - Continue on Alki Ave SW. As we round Alki Point (at the lighthouse), the road becomes Beach Drive SW. Park on the right immediately after rounding the point. If the tides permit, we will walk down to the intertidal zone (great tidepools!). For an up-close look at the bedrock "knob", take a left onto 64th, then left onto Admiral (which dead-ends abruptly, so park in the Bar-S Playground lot and walk uphill), turn around, right onto 64th, left onto Beach Ave SW.

To **STOP #15** (Beach Drive SW) - Continue on Beach Drive SW. Pull over at Me Kwa Mooks / Emma Schmitz parks - If tides permit, we'll get out and look at the intertidal zone exposures.

**Back to HCC** - Just past the parks, take a left onto SW Jacobsen Road. Loop up the hill. SW Jacobsen Road becomes SW Hudson. Turn left onto 49th Ave SW. Turn right onto SW Alaska St. SW Alaska crosses SW California Ave in the "heart" of West Seattle. Continue on SW Alaska St, then take left onto SW Fauntleroy Way. Follow the signs to the West Seattle Bridge (the signs will be for I-5 South). Take I-5 South to campus.
Igneous, Sedimentary, and Metamorphic Rock ID Charts

### Some Common Rock-Forming Minerals

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<th>Harder or Softer Than Glass?</th>
<th>Cleavage? (breaks along planes?)</th>
<th>Color</th>
<th>Other Properties</th>
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<td>No</td>
<td>red to brown</td>
<td>twelve-sided or spherical common; glassy luster</td>
<td>GARNET</td>
</tr>
<tr>
<td>Harder (Yes)</td>
<td>pistachio green</td>
<td>surface coatings, or massive</td>
<td>EPIDOTE</td>
<td></td>
</tr>
<tr>
<td>Similar</td>
<td>Yes</td>
<td>peach/pink to white</td>
<td>glassy luster; banding; 2 cleavages at 90° (also called potassium feldspar)</td>
<td>ORTHOCLASE (Pink Feldspar)</td>
</tr>
<tr>
<td>Similar</td>
<td>Yes</td>
<td>white to gray</td>
<td>glassy luster; 2 cleavages at 90°; striations (grooves) possible on cleavage faces (white= sodium-rich, dark= calcium-rich)</td>
<td>PLAGIOCLASE (White to Dark Grey Feldspar)</td>
</tr>
<tr>
<td>Similar</td>
<td>Yes</td>
<td>dark green to black</td>
<td>glassy to dull luster; 2 poor cleavages at 90°</td>
<td>PYROXENE</td>
</tr>
<tr>
<td>Similar</td>
<td>Yes</td>
<td>black to dark green</td>
<td>glassy luster; splinterly appearance; 2 cleavages at 120° and 60°</td>
<td>AMPHIBOLE</td>
</tr>
<tr>
<td>Similar</td>
<td>No</td>
<td>brassy to gold</td>
<td>cubic crystals (with striations [grooves]) common</td>
<td>PYRITE (&quot;fool's gold&quot;)</td>
</tr>
<tr>
<td>Softer</td>
<td>Yes</td>
<td>clear to light yellow</td>
<td>glassy luster; perfect cleavage in 1 dir.; forms flexible, transparent, thin sheets</td>
<td>MUSCOVITE (clear mica)</td>
</tr>
<tr>
<td>Softer</td>
<td>Yes</td>
<td>brown to black</td>
<td>glassy luster; perfect cleavage in 1 direction; forms flexible thin sheets</td>
<td>BIOTITE (black mica)</td>
</tr>
<tr>
<td>Softer</td>
<td>Yes</td>
<td>white to clear (darker if massive)</td>
<td>reacts with hydrochloric acid (HCl); glassy to dull luster; 3 cleavages not at 90° to each other</td>
<td>CALCITE</td>
</tr>
</tbody>
</table>

**Note:**

- Harder: More resistant to scratches and harder to break than glass.
- Softer: More easily scratched than glass and breaks along cleavages.
- Cleavage: The tendency to break into thin, elongated pieces.

**Muscovite**
- No cleavage
- Reacts with hydrochloric acid
- Transparent
- Forms thin sheets

**Biotite**
- No cleavage
- Reacts with hydrochloric acid
- Black

**Calcite**
- Soft, diaphanous
- Forms thin sheets
- Reacts with hydrochloric acid

**Orthoclase**
- White to pink
- Cleavages at 90°
- Harder than glass

**Plagioclase**
- White to gray
- Cleavages at 90°
- Soft

**Kyanite**
- No cleavage
- Reacts with hydrochloric acid
- Slaty

**Amphibole**
- Black to blue
- Cleavage at 120° and 60°
- Harder than glass

**Quartz**
- Clear to white
- Harder than glass
- Cleavage at 90°

**Garnet**
- Red to brown
- Twelve-sided or spherical
- Harder than glass

**Limestone**
- Soft
- Reacts with hydrochloric acid

**Feldspar**
- White to dark gray
- Cleavage at 90°
- Harder than glass

**Pyrite**
- Black to dark green
- Reactive
- Cleavage at 120° and 60°

**Biotite**
- Black to brown
- Reacts with hydrochloric acid
- Cleavage at 90°

**Muscovite**
- Clear to white
- Reacts with hydrochloric acid
- Cleavage at 90°

**Orthoclase**
- White to pink
- Cleavage at 90°
- Harder than glass

**Plagioclase**
- White to gray
- Cleavage at 90°
- Soft

**Kyanite**
- No cleavage
- Reacts with hydrochloric acid
- Slaty

**Amphibole**
- Black to blue
- Cleavage at 120° and 60°
- Harder than glass

**Quartz**
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**Garnet**
- Red to brown
- Twelve-sided or spherical
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- Reacts with hydrochloric acid

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**Biotite**
- Black to brown
- Reacts with hydrochloric acid
- Cleavage at 90°

**Muscovite**
- Clear to white
- Reacts with hydrochloric acid
- Cleavage at 90°

**Orthoclase**
- White to pink
- Cleavage at 90°
- Harder than glass

**Plagioclase**
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- Reacts with hydrochloric acid

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**Muscovite**
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**Biotite**
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- Cleavage at 90°

**Muscovite**
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- Reacts with hydrochloric acid
- Cleavage at 90°

**Orthoclase**
- White to pink
- Cleavage at 90°
- Harder than glass

**Plagioclase**
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- Harder than glass
- Cleavage at 90°

**Garnet**
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- Twelve-sided or spherical
- Harder than glass

**Limestone**
- Soft
- Reacts with hydrochloric acid

**Feldspar**
- White to dark gray
- Cleavage at 90°
- Harder than glass

**Pyrite**
- Black to dark green
- Reactive
- Cleavage at 120° and 60°

**Biotite**
- Black to brown
- Reacts with hydrochloric acid
- Cleavage at 90°

**Muscovite**
- Clear to white
- Reacts with hydrochloric acid
- Cleavage at 90°

**Orthoclase**
- White to pink
- Cleavage at 90°
- Harder than glass

**Plagioclase**
- White to gray
- Cleavage at 90°
- Soft
### Igneous Rock Names

<table>
<thead>
<tr>
<th>COMPOSITIONS (Minerals Present) are in columns</th>
<th>Felsic</th>
<th>Intermediate</th>
<th>Mafic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quartz</td>
<td>Orthoclase</td>
<td>White plagioclase</td>
<td>Grey plagioclase</td>
</tr>
<tr>
<td>Orthoclase</td>
<td>White plagioclase</td>
<td>Amphibole</td>
<td>Pyroxene</td>
</tr>
<tr>
<td>White plagioclase</td>
<td>Biotite mica</td>
<td>Biotite mica</td>
<td>Olivine</td>
</tr>
<tr>
<td>Biotite mica</td>
<td>Muscovite mica</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>TEXTURES are in rows</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coarse-grained</td>
</tr>
<tr>
<td>Fine-grained</td>
</tr>
<tr>
<td>Porphyritic (both coarse+fine)</td>
</tr>
</tbody>
</table>

### Sedimentary Rock Names

<table>
<thead>
<tr>
<th>GRAIN SIZE</th>
<th>OTHER PROPERTIES</th>
<th>ROCK NAME</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coarse-grained (pebble/cobble/boulder)</td>
<td>Rounded grains</td>
<td>CONGLOMERATE</td>
</tr>
<tr>
<td>Medium-grained (sand)</td>
<td>&quot;Sand-sized&quot; particles (often of quartz, feldspars, rock fragments)</td>
<td>BRECCIA</td>
</tr>
<tr>
<td>Fine-grained (silt)</td>
<td>Feels gritty on teeth or between fingers</td>
<td>SANDSTONE</td>
</tr>
<tr>
<td>Very fine-grained</td>
<td>Feels smooth, soft, often layered (clay)</td>
<td>SHALE</td>
</tr>
<tr>
<td>Denser, fizzes in dilute acid (calcite)</td>
<td>LIMESTONE</td>
<td></td>
</tr>
<tr>
<td>Very hard, dense, scratches glass (silica)</td>
<td>CHERT</td>
<td></td>
</tr>
</tbody>
</table>

### Metamorphic Rock Names

<table>
<thead>
<tr>
<th>FOLIATED (LAYERED)?</th>
<th>OTHER PROPERTIES</th>
<th>PROTOLITH (used to be this kind of rock)</th>
<th>ROCK NAME</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes—slaty cleavage (breaks into flat plates)</td>
<td>Microscopic to very fine-grained; clay minerals common; cleavage surfaces dull to slightly shiny</td>
<td>Shale</td>
<td>SLATE</td>
</tr>
<tr>
<td>Yes—schistosity (platy foliation of mica grains)</td>
<td>Medium to coarse-grained; mica minerals common; may also contain garnets</td>
<td>Shale, siltstone</td>
<td>SCHIST</td>
</tr>
<tr>
<td>Yes—gneissic (light and dark) banding</td>
<td>Medium to coarse-grained; mostly non-micas; light and dark layers common</td>
<td>Shale, siltstone, granite</td>
<td>GNEISS</td>
</tr>
<tr>
<td>Yes—aggregate of long amphiboles</td>
<td>Dark green to black; also may contain black mica, feldspars, and/or garnets</td>
<td>Basalt, gabbro</td>
<td>AMPHIBOLITE</td>
</tr>
<tr>
<td>No—made of quartz</td>
<td>Fine- to coarse-grained crystalline texture; light-colored; scratches glass</td>
<td>Quartz sandstone</td>
<td>QUARTZITE</td>
</tr>
<tr>
<td>No—made of calcite</td>
<td>Commonly coarsely crystalline; reacts with acid; usually light-colored; softer than glass</td>
<td>Limestone</td>
<td>MARBLE</td>
</tr>
<tr>
<td>No—made of rock fragments</td>
<td>Coarse-grained, sometimes deformed, rock fragments; rock breaks through individual clasts</td>
<td>Conglomerate or Breccia</td>
<td>METACONGLOMERAT or METABRECCIA</td>
</tr>
</tbody>
</table>