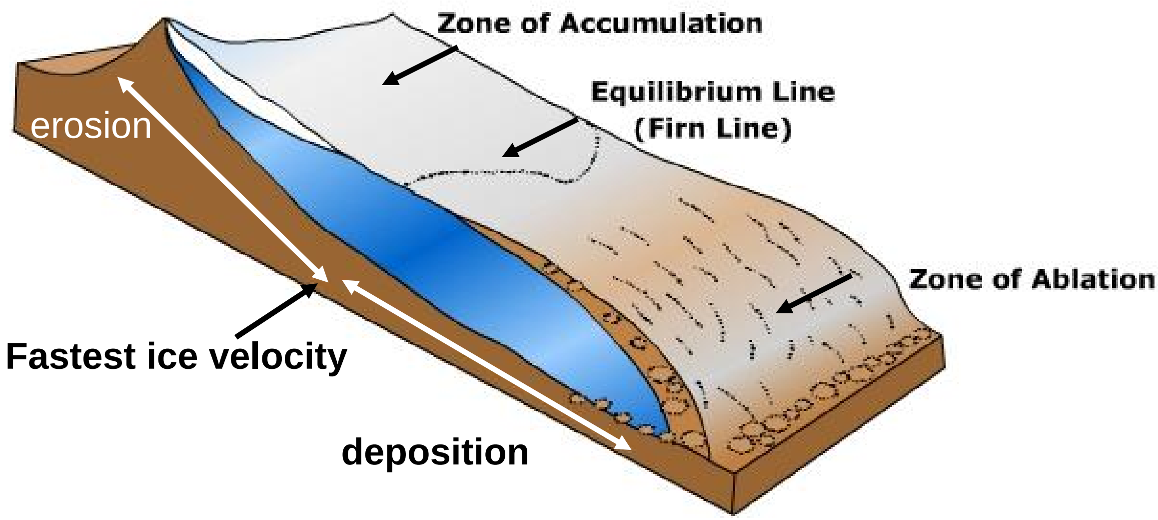
Name: ________________________________

Lab 15: Glacial Processes and Landforms

Glaciers form where more snow accumulates during the winter season than can ablate during the summer season. As years of unmelted snow piles up, the buried snow is compacted and recrystallized into firm. When this ice becomes thick enough it begins to flow under its own weight, becoming a glacier. Glacial ice, when flowing, is always moving downhill. The terminus (end) of the glacier can advance forward like a plow if the accumulation of snow remains greater than the amount removed due to calving, melting, evaporation, or sublimation (these ice-removal processes are referred to collectively as ablation). If less snow accumulates than melts, the terminus of the glacier will retreat (be found at progressively higher elevation); however, the ice itself keeps moving forward. The advance and retreat of glaciers is therefore dependent on factors such as wintertime precipitation in the accumulation zone and summertime temperature.



Ice balance in a glacier

Equilibrium Line Altitude

The equilibrium line altitude (ELA) is the elevation of a glacier above which ice accumulates (overall) and below which ice ablates (overall). Typically, the ice velocity is fastest at the ELA and thus the rate of sub-glacial erosion (a function of ice velocity) is also the fastest at the ELA. Typically, erosional processes dominate in the accumulation and ELA areas, whereas depositional processes dominate in the ablation zone.

The ELA can change through time due to changes in precipitation or temperature. Increased precipitation will cause more accumulation, which can lower the ELA. Colder temperatures will also depress the ELA. The ELA can be estimated using several methods: the average elevation of the glacier is typically near the ELA, and the late-summer snowline (the line that separates where the ice did and did not melt) is often near the ELA.

Alpine vs. Continental Glaciers
Glaciers are divided into two general types based on their size and shape. **Valley**, or **alpine glaciers** are laterally restricted, flowing within valleys in mountainous terrain. These glaciers are typically relatively small. **Continental glaciers** are large ice sheets that overwhelm the landscape and are not restricted to valleys (though they do flow in depressions). The ice caps on Greenland and Antarctica, and the great Pleistocene ice sheets are continental glaciers. Continental glaciers flow outward from their center, like pouring pancake batter on a griddle.

A reconstruction of the Laurentide and Greenland Ice Sheets during a glacial interstadial.

Alpine/valley glacier **Continental glacier**

Glacial Erosion
Like rivers, glaciers shape the landscape through erosion of bedrock and deposition of sediment. Moving glacial ice can erode bedrock as well as pick up sediment and carry it to new locations. Generally, the rate of bedrock erosion scales with ice velocity. Glacial ice can erode the underlying bedrock by the following processes:

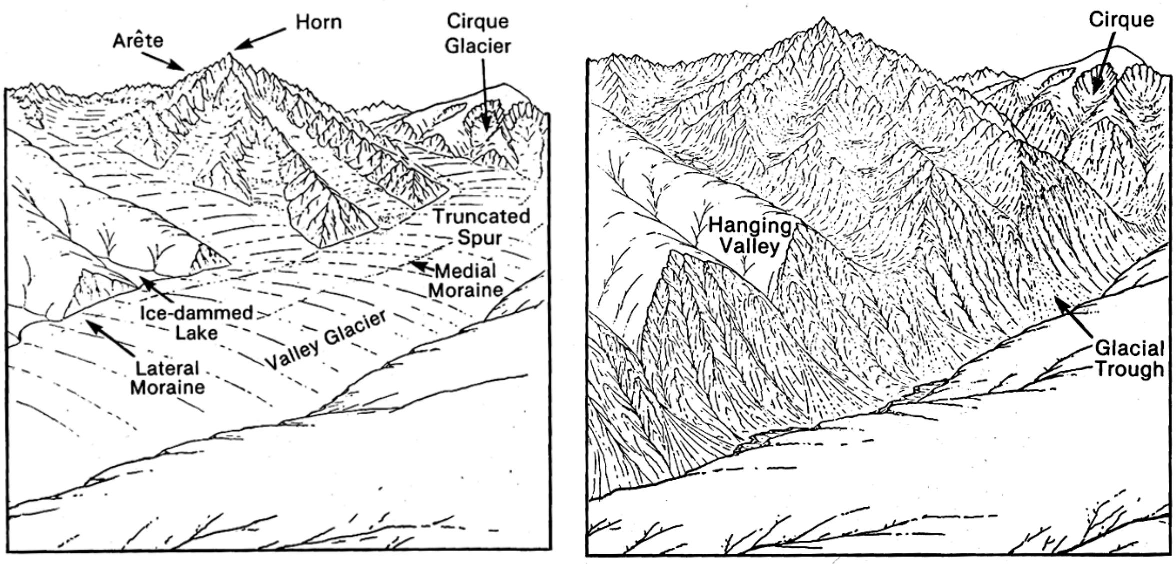
1. **Abrasion.** Dirty glacial ice dragged over bedrock can act like sandpaper. Abrasion produces fine glacial flour (very fine sediment) that gives pro-glacial lakes their stunning turquoise color.
2. **Plucking.** Moving ice (with some help from melting and freezing) can rip chunks of bedrock out of the ground. Plucking produces building-sized erratics.
3. **Dissolution**. The water found at the base of temperate (wet-based) glaciers can dissolve rock.

Additionally, liquid water beneath the glacier can form highly pressurized and erosive sub-glacial streams. In some areas, subglacial rivers produce more erosion than does the ice itself.

Erosional Features Created by Alpine Glaciers

Alpine glaciers can greatly modify mountainous terrain. Glaciers widen valley bottoms from original fluvial V-shapes to broader U-shapes, scoop out bowl-shaped depressions (cirques), and can create sharp peaks and ridges.

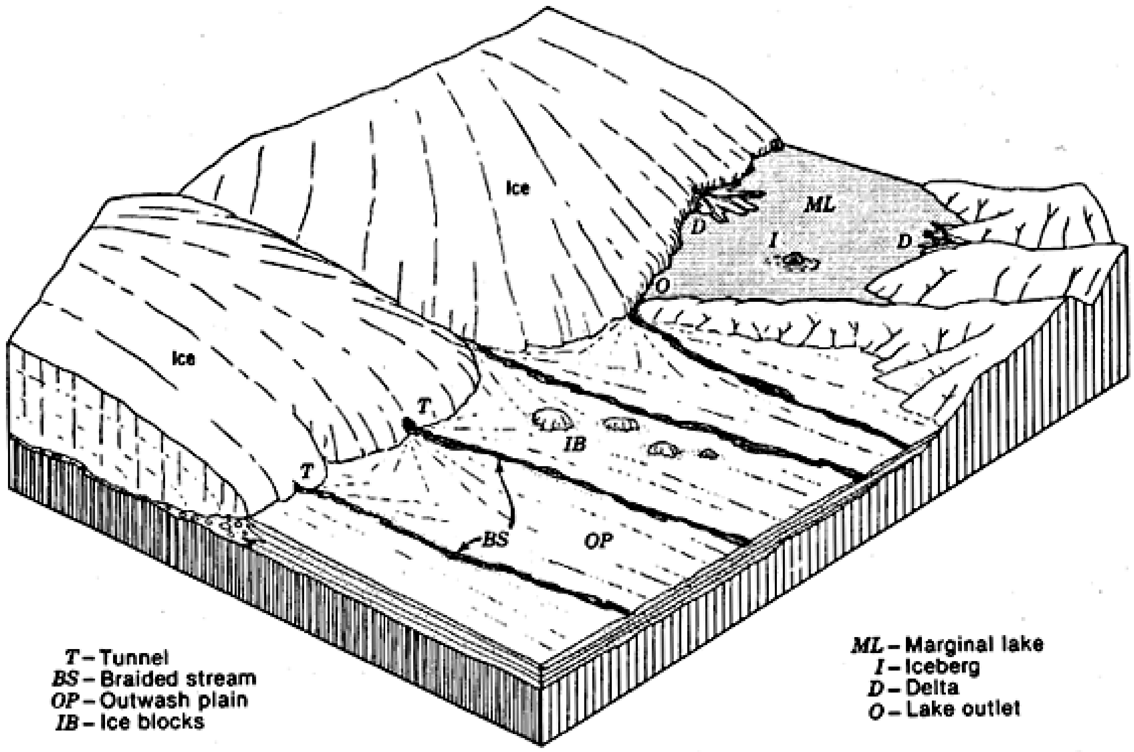
- **Glacial valleys and arêtes**. Valley glaciers widen the their valleys, creating broad U-shaped valleys and narrow ridge-shaped divides between valleys called arêtes.
- **Hanging valleys.** Smaller valley glaciers often flow into larger glaciers as tributaries. The tributary valleys are often elevated above the main valleys (smaller glaciers are less erosive), and enter the larger valley high on its wall.
- **Cirques, horns, and cols.** Valley glaciers, like streams, often erode headward as they grow. This creates bowl-shaped depressions called cirques at the upper end of a valley. If several glaciers flow down from a common summit, the cirques surrounding the peak serve to carve it into a sharp, steep landform called a horn. Neighboring horns may be joined by narrow ridges called cols.

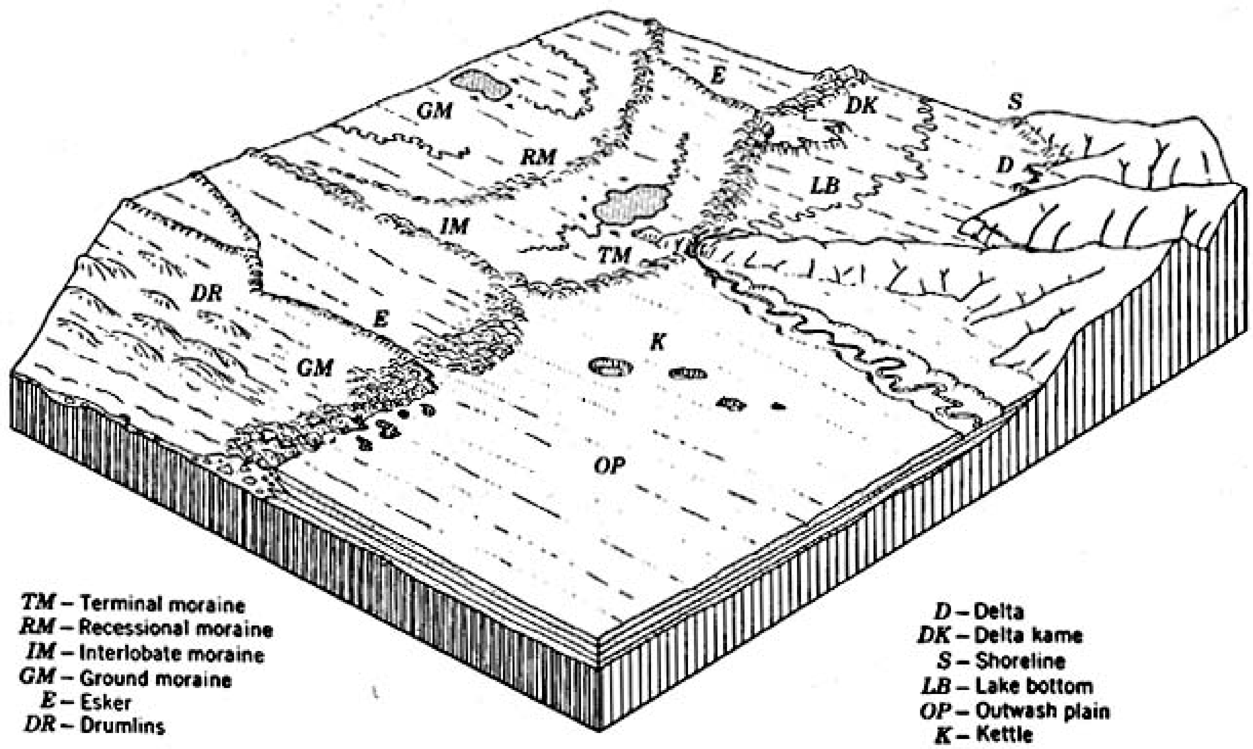


Landforms associated with alpine glacial erosion

Erosional Features Created by Continental Glaciers

Continental glaciers are not restricted to valleys and can erode and move sediment over vast areas. They typically smooth, rather than roughen, pre-existing topography, and thus do not create the striking erosional landforms associated with alpine glaciers. Many of their distinctive features are instead associated with the deposition of sediments.



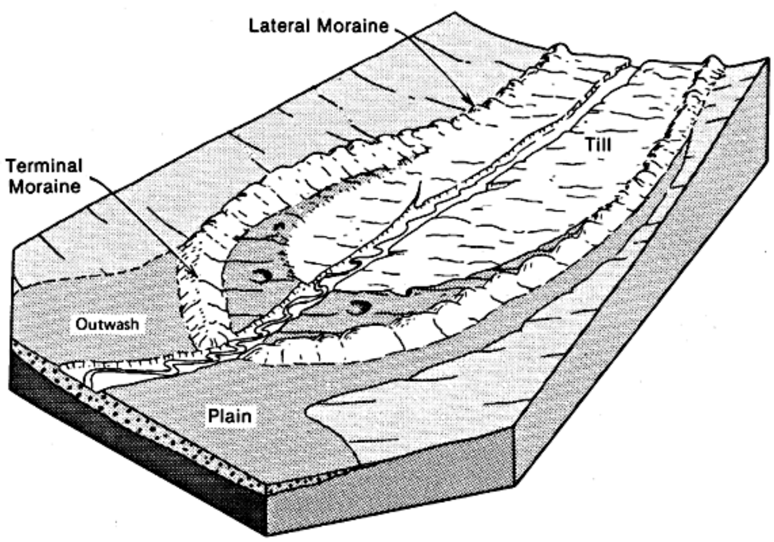


Landforms and deposits associated with continental glaciers

Depositional Landforms

As ice melts it leaves behind the sediment carried within it. This sediment can be piled around the edges or beneath a glacier as it melts, or the sediment can be directly deposited beneath active, moving ice. Subsequent advances of a glacier can rework and destroy landforms created by previous advances. Glacial depositional features include:

- **Moraines.** The debris deposited directly from the glacial ice is called moraine. Terminal moraines are deposited at the leading edge of a glacier, lateral moraines are deposited at the sides of a glacier, and ground moraine is deposited beneath the glacial ice. Medial moraines may form where two glaciers flow together, sandwiching their lateral moraines within the new, combined glacier.
- **Drumlins**. Streamlined hills formed in sediment or bedrock that form beneath glaciers. Drumlins are elongated in the direction of ice motion with steep faces pointed uphill.
- **Outwash plains.** Much of the finer sediment may be washed away from a glacier by meltwater. The meltwater deposits this sediment over a broad outwash plain.
- **Kettles.** Blocks of ice may be isolated from the main glacier as it recedes and become surrounded and covered with moraine or outwash sediment. As the block melts, the overlying sediments collapse, leaving a depression called a kettle.
- **Eskers.** Streams flowing on, within, or below glaciers can deposit ribbons of channel sediment just like those flowing in channels within bedrock. When the ice melts, these ribbons of sediment are left behind as ridges called eskers.

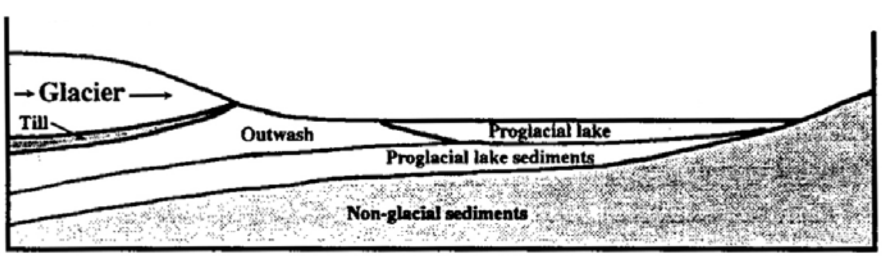


Alpine deposits and depositional landforms

Glacial Sediments
Sedimentary deposits left by glaciers are highly variable in terms of their sorting and grain size. Common deposits found in glacial and near-glacial environments include:

- **Till.** This is sediment deposited directly from the ice. Moraines consist of till. Till is typically very poorly sorted and has angular grains. There is typically no bedding in tills. Often, continental tills have a bimodal grain size, with a fine-grained matrix and larger clasts. (The non-genetic term for bimodal sediment is diamict.)
- **Stratified drift.** This is a catch-all term for glacial sediments that have been somewhat reworked by water. This kind of deposit is common along ice margins where sediment is released from the ice and moved by meltwater. It is often poorly sorted with pockets or lenses of well-sorted sand.
- **Glaciofluvial deposits (outwash).** Meltwater streams can re-work sediment deposited by the glacier. These streams are often steep, have very high sediment loads, and are braided instead of meandering. Outwash deposits are typically better sorted than tills, as the finest grains have been washed away, leaving cross-bedded sub-rounded to well-rounded sand, gravel, and cobble-sized clasts. Outwash develops in front of advancing and retreating glaciers. The size of the sediment can be a function of the proximity of the glacier, with larger clasts remaining closer to the glacier.
- **Glaciolacustrine deposits.** Glaciers can block streams and create pro-glacial lakes. Sediment carried into these lakes settles on the bottom. Typically, the coarse-grained sediment settles near the edges, where streams enter the lake. Fine-grained sediment (silt and clay) can be carried out to the middle of the lake, where it can form very thin layers called laminations. Sometimes, sediment-rich icebergs can carry larger clasts out to the middle of a lake, melt, and drop them into the finer-grained sediment. These large clasts found within finer-grained lake sediments are called dropstones.

Glacial Stratigraphy
The history of glacial advances and retreats are unraveled through their deposits. Because glacial ice advances and retreats, the type of sediment deposited in a glacial environment is highly dependent upon where the ice is through time. For example, an outwash plain in front of a glacier may get overridden by that glacier, resulting in a layer of outwash capped by a layer of till. Similarly, till left by a retreating glacier may become covered by outwash as the ice retreats. However, because glaciers and the associated streams are very erosive and deposition is often irregular, deposits can have irregular (non-horizontal) contacts and entire layers may be missing.



Example of a sequence of glacial sediments from the advance of a glacier

Part I. Ice Distribution and Snowline Altitudes

Use the Mt. Rainier topographic maps and aerial photographs to answer the following:

1. Mt. Rainier is covered with more glacial ice than any other mountain in the continental United States– more, in fact, than all the other Cascade volcanoes combined. On which side of the mountain (N/S/E/W) are glaciers the most abundant and voluminous?

2. Carbon Glacier is on the northwest side of Mt. Rainier. Using both the photos and the topographic map, what is the elevation of the snowline (lower limit of persistent fresh snow)?

3. Assuming that the photos were taken at the very end of summer, just before snow starts falling again in autumn, sketch a map view of Carbon Glacier. Indicate the direction of ice flow and mark the position of the snowline. Locate and label the following on your sketch:
   a. Area of net accumulation
   b. Area of net ablation
   c. Zone of fastest erosion
   d. Deposition (and type) of moraines

4. How would the elevation of the ELA change if the local mean annual temperature decreased? How would this change in temperature be expressed at the glacial terminus?

5. How would the elevation of the ELA change if there were a severe, multi-year drought? What would be the effect on the terminus?

Part II. Glacial Landforms

Alpine glacial landforms

Use the map of Glacier National Park to answer the following questions:

6. What kind of feature is Clements Mountain?

7. What kind of feature is Goat Lake?

8. How many glaciers were responsible for carving Citadel Mountain? And how do you know?

Continental glacial landforms

Use the color shaded relief map of Puget Sound for the following questions:

9. Use the streamlined topography to approximate greatest extent of the Puget Lobe (the tongue of ice that extended into Puget Sound during the last ice age). Draw and label this limit on the map. You do not need to include the valley glaciers in the Olympics or Cascades.

10. Draw at least fifteen small arrows on the map in the directions of flow in different areas.

11. Did the Puget Lobe cover what is now Seattle?

12. Another way to find glacier limits is to map the deposits left by the ice. Compare your ice limit to the extent of Quaternary glacial sediments (Qg) on the Geologic Map of Washington. Is your glacial extent, mapped using landforms alone, reasonably consistent with the extent of glacial deposits?

Part III. Glacial Sediments

When a lobe of ice like the Puget lobe advances across a landscape, it deposits a series of sediments. The type of sediment deposited at any particular time or location depends largely on the position of the ice. As the ice advances and retreats, different sediments will be deposited. In this section you will interpret the glacial sediments found at Discovery Park. Below is a typical section of Seattle glacial stratigraphy; you will observe these layers in the bluffs at Discovery Park during the next lab period.

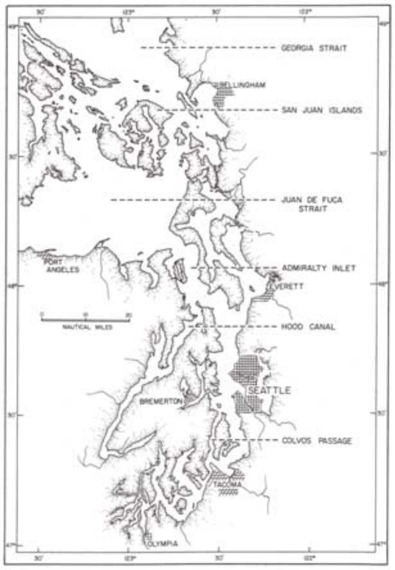
13. For each deposit, consider what processes were involved in the deposition of each unit; was it direct deposition by ice, deposition into a glacial lake, deposition from pro-glacial streams, or deposition from rivers during a non-glacial time? Add this to the right column of the chart below.

Stratigraphy of Discovery Park, Seattle

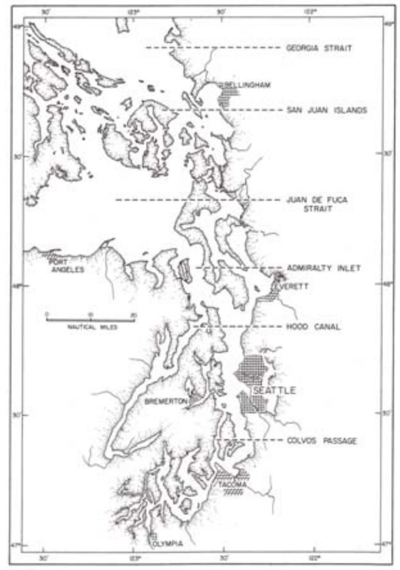
Name and Description	Depositional Process
Vashon Till: Compact diamict of sand, silt, and sub-rounded to well-rounded gravel. Very dense. Radiocarbon age: ~14,000 yr BP	
Esperance Sand: Well-sorted, cross-bedded sand. Little organic matter.	
Lawton Clay: Stiff to hard laminated silt, clayey silt, and silty clay. Radiocarbon age: ~15,000 yr BP	
Olympia Formation: Sand, silt, and gravel, in places well sorted. This unit contains abundant peat and other organic material. Plant and animal types suggest warm climate. Radiocarbon age: >20,000 yr BP	

14. On the series of maps below, draw the approximate location of the ice margin of the Puget Lobe during the time of deposition for each formation listed above. Next to or below each map, briefly describe the environment at Discovery Park during that time.

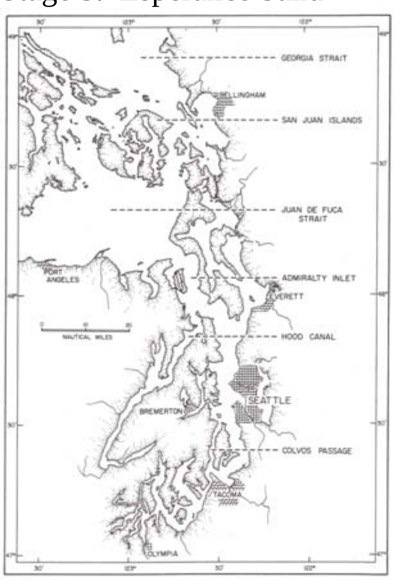
Stage 1. Olympia Formation



Stage 2. Lawton Clay



Stage 3. Esperance Sand



Stage 4. Vashon Till