This guide is the work of Dr. Terry W. Swanson, University of Washington. Adaptations have made to fit our field trip.
Swanson, T. W., 2003, *Late Pleistocene Glacial History of Whidbey Island, Washington*; Geological Society of America Field Trip #14

Introduction

During the Pleistocene Epoch (2.0 million to 10,000 years before present), large continental ice masses advanced into the Puget Sound Lowland during glacial periods and then retreated during interglacial periods. These massive ice sheets and warmer periods left behind glacial and interglacial deposits that overlay the Tertiary basement rocks in the Puget Lowland. In the Southern part of the Puget Sound, evidence indicates that the area was glaciated at least six times during the Pleistocene. (Hagstrom, et. al, 2004).

Vashon Stade of the Frasier Glaciation

During the last glacial period, the margin of the Cordilleran Ice Sheet (CIS) expanded into northwestern Washington. As the CIS reached the Olympic Mountains, it divided into two lobes, one flowed west through the Strait of Juan de Fuca out onto the now-submerged continental shelf, while the second (Puget Lobe) flowed south into the Puget Lowland between the Olympic Mountains and the Cascade Range. (Fig. 1)

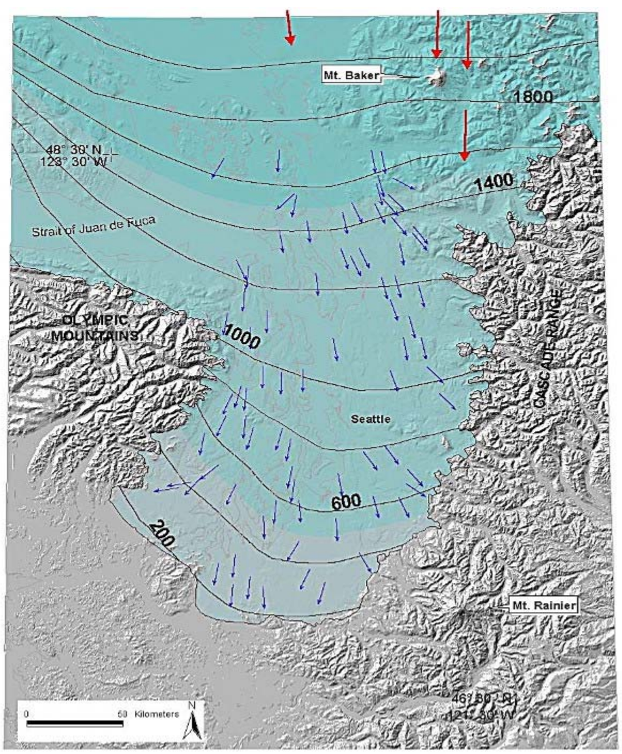


Figure 1. Thickness distribution of the Puget Lobe of the Cordilleran Ice Sheet. Glacial maximum: roughly 15,000 years ago.

The chronology of the advance and retreat history of the Puget Lobe during the Vashon Stade of the Fraser Glaciation (Armstrong, et al., 1965) is based on a suite of conventional and accelerator mass-spectrometer radiocarbon ages lying above and below the respective drift units. Porter and Swanson (1988) inferred that the Puget Lobe advanced south of Seattle shortly after 14,600 ± 90 ^{14}C yr B.P. (≈17,500 calendar years) based on dating the outermost rings of spruce logs collected from the topset beds of a proglacial delta near Issaquah, Washington. Limiting dates for glacier recession indicate that the Puget Lobe had retreated north of Seattle sometime before 13,610 ± 80 ^{14}C yr B.P.

The general stratigraphy of bluff exposures around the central Puget Lowland is typically comprised of non-glacial alluvial units overlain by the advance glacial units, including the Lawton Clay, Esperance Outwash, and Vashon Till capping upland surfaces. The glacial retreat record is not as well preserved in the bluff stratigraphy in the central Puget Lowland, as most of retreat sediment was deposited in topographically low basins, which have been submerged by rising sea level or buried with Holocene sediment. A brief overview with Puget Lowland glacial history/stratigraphy is provided below.

Between 25,000 and 18,000 years ago global sea level was about 420 feet lower than modern times due to continental ice build up during the last glaciation. During the Olympia Interglacial Period, Puget Lowland streams flowed from the Cascade and Olympic mountains toward the central Puget Lowland and then northerly along a gently sloping alluvial (river) flood plain towards the Strait of Juan de Fuca. Sandy layers within this alluvium represent point bar, channel deposits and tend to be discontinuous over horizontal distances. Inter-layered alluvial silts likely represent slack-water deposits that accumulated along the floodplain.

Approximately 18,000 years ago, the Cordilleran Ice Sheet reached the Fraser Lowland in British Columbia and a lobe flowed west into the Strait of Juan de Fuca and south into the Puget Lowland (Puget Lobe). As the Puget Lobe dammed the north flowing streams with the lowland, a system of proglacial lakes developed in the structural low topography within the area. Glacial lacustrine (lake) sediment was deposited in these proglacial lakes and is locally defined as the Lawton Formation. The Lawton Formation consists of laminated clays, with sporadic ice-rafted dropstones present, and has a very low permeability and porosity. Above this impermeable layer, subsurface water becomes perched and reaches the surface as seepage springs along many of the upper bluff slopes. Many of these seepage springs are observed within the upper bluff of South Whidbey. The thickness of the Lawton clay can vary depending on the pre-depositional topography and location on pro-glacial lake basins.

Sediment comprising the Kitsap and Lawton formations retains relatively steep slope angles because they are compacted, fine-grained, and damp (high cohesion) throughout most of the year. Despite the high competence of these lower units, most of the debris- and mud-slide activity along the bluffs on south Whidbey Island is concentrated within these two units. Because loosely consolidated colluvium commonly overlies these impermeable units, the colluvial cover often becomes saturated during excessively wet winters, greatly increasing the likelihood of landslides.

As the Puget Lobe continued to advance south, outwash deltas were pro-graded into marine embayments and proglacial lakes after the Strait of Juan de Fuca was dammed. This advance outwash unit, locally called the Esperance Formation, consists of well-sorted, stratified sands and its local elevation was dependent upon the pre-existing topography and forms the upper slopes of many high bluffs. Slopes comprised of advance outwash sands trend to maintain an angle of repose of about 30-35º. Because of the high permeability of the outwash sands, surface runoff is low on slopes comprised of this unit. Most of the water within this unit reaches the bluff slope as seepage springs perched on the Lawton Clays or compacted alluvial silts within the non-glacial alluvial units.

As the Puget Lobe advanced south to its terminal position near Olympia, Washington, the Vashon till was deposited over much of the pre-existing landscape throughout the lowland. Pre-glacial topography played an important role as to whether glacial erosion or deposition processes dominated the landscape. In pre-existing structural lows, (i.e. lineal topographic troughs), where ice convergence occurs, glacial erosion processes dominate, and the interglacial and advance units were eroded and the Vashon till was deposited unconformably over such erosional surfaces. Sub-glacial melt water also played a significant role in erosion. Where pre-existing topographic highs exited (i.e. land over 300 feet high on Whidbey Island) ice-flow tended to diverge around these topographic highs and till was deposited. Pressure differences beneath the ice resulted in glacially streamlined topography that parallels ice flow direction. This glacially streamlined topography is evident on the LIDAR image show below (Fig. 2)

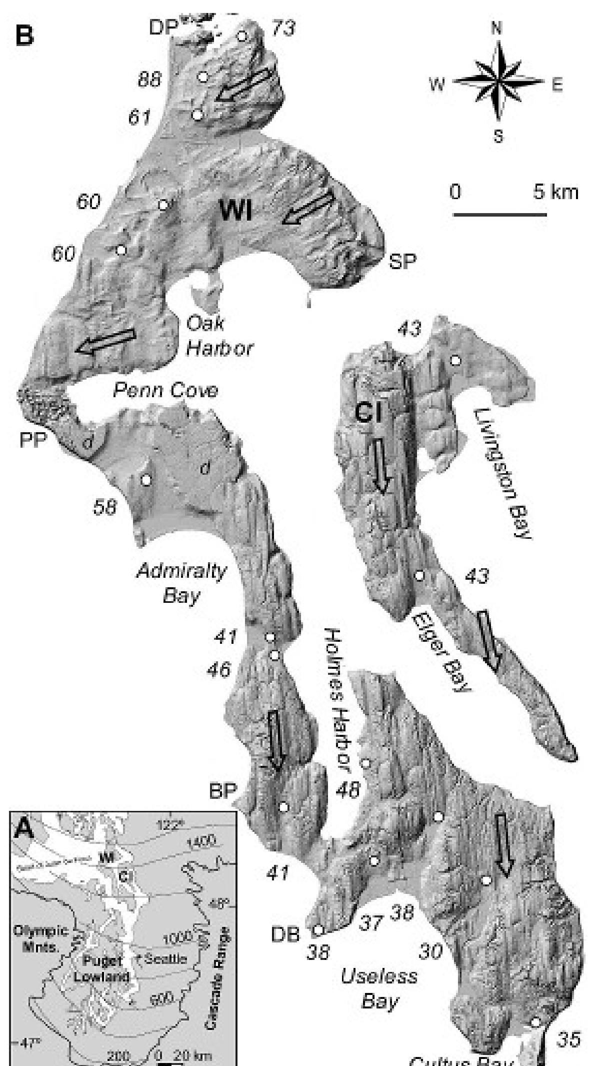


Figure. 2. LIDAR image of Whidbey Island. Notice the parallel streamlined topography that resulted from ice flow. Pressure differences beneath the ice caused sediments to form into drumlins and drumlinoids.

Retreat of the Puget Lobe ice sheet from the Puget Lowland was characterized by both rapid calving in lake and marine embayments, as well as ablation of grounded ice from the upland surfaces. Following deglaciation, Whidbey Island was isostatically depressed during the time of the marine incursion into the Puget Lowland. Consequently, relative sea level on South Whidbey Island was about 140 feet higher than modern sea level during this post-glacial marine high stand and progressively higher to the north. Initially, the rate of isostatic uplift was greater than eustatic sea level rise, which resulted in the formation of a series of post-glacial terraces incised into the pre-existing substrate. These terraces are clearly defined around the ferry terminal near

Clinton, Sandy Hood, and Langley communities, as well as many other coastal locations where post-glacial bluff retreat is low, low rate of slope retreat for the easterly bluffs on the lee side of South Whidbey Island.

It is also evident from the LIDAR image that remnant ice existed on the upland surfaces of South Whidbey and that meltwater channels were incised into the pre-existing stratigraphy during retreat. These relict channels became inactive following disintegration of the remnant ice.

Similar to much of the landscape of the Puget Lowland, Whidbey Island's topography and underlying stratigraphy is strongly imprinted by the advance and retreat history during the last glaciation.

Previous Advances of the Puget Lobe

To the south and north of the Puget Sound lowlands, earlier glacial and interglacial units have been identified. (See Fig. 3). In the Puyallup River valley, pre-Vashon glacial and interglacial deposits are exposed. They consist of drift and outwash of the Orting, Stuck, and Salmon Springs glaciations (Crandell et al, 1958). All of these glacial materials and their inter-bedded interglacial deposits have ages grater than ~ 780,000 years before present (Easterbrook et al, 1998). To the north on Whidbey Island, the upper section of Pleistocene deposits consists of the Double Bluff, Possession, and Vashon glacial deposits and intervening nonglacial deposits (Easterbrook, et al, 1967). No deposits between the Double Bluff and Salmon Springs glaciations have been identified in the Puget Lowland.

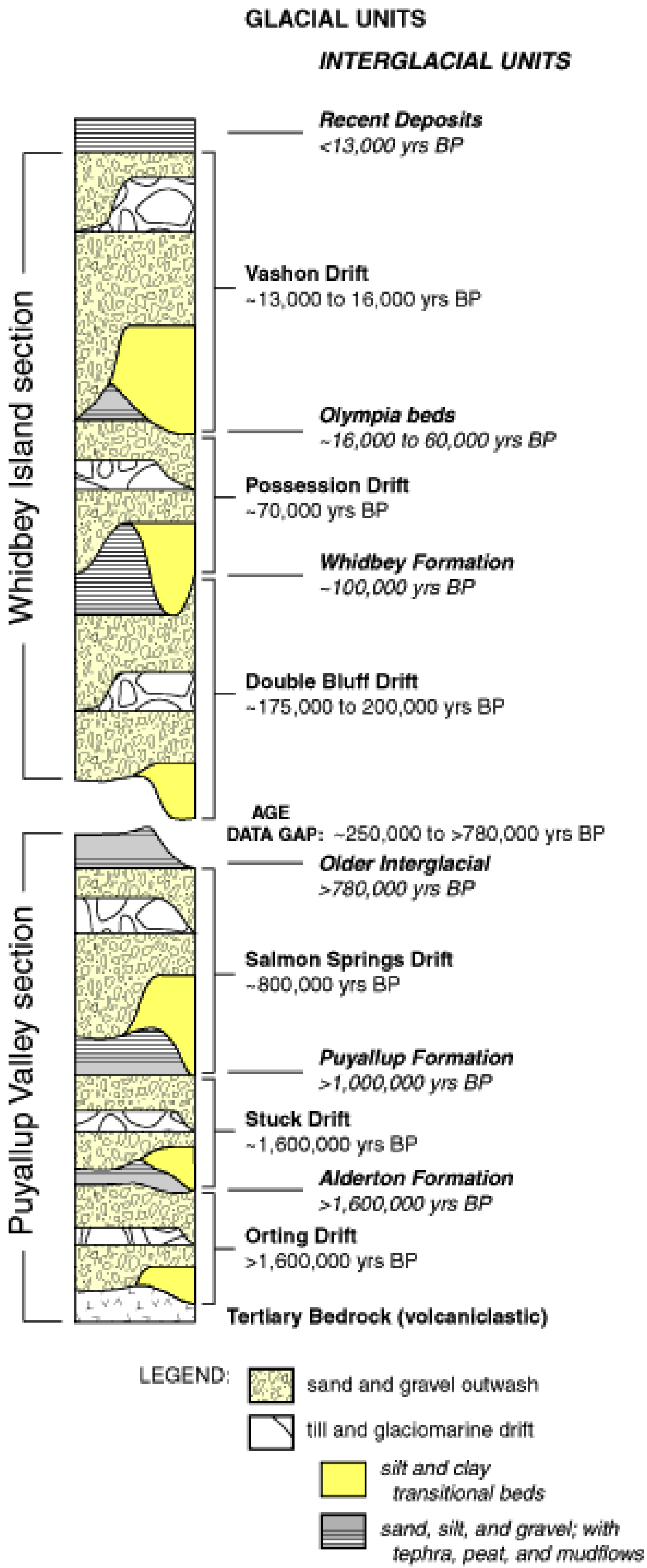
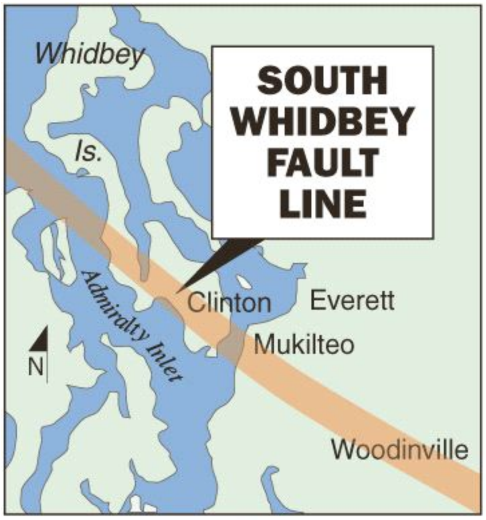


Figure 3. Glacial and non-glacial units of the Pleistocene Epoch, as found in locations within the Puget Sound. (Hagstrum, J.T., 2004).

South Whidbey Island Fault



JUDY STANLEY / The Herald

Figure 4. Map showing South Whidbey Island Fault Zone as it passes through the Sound.

In addition to the better known Seattle and Tacoma faults, Whidbey Island has a fault of its own. The South Whidbey Island Fault Zone starts on Vancouver Island, crosses the Sound, sweeps across the southern part of Whidbey Island and continues on toward Woodinville (see Fig. 4 and Fig. 5).

Researchers have shown that there have been about 3 major earthquakes from this fault in the past 3000 years (Kelsey, et al, 2004). One occurring right about 3000 years ago is estimated to have been a M 7.0. The South Whidbey Island Fault, like all faults crosses the Sound, have the potential to generate tsunamis.

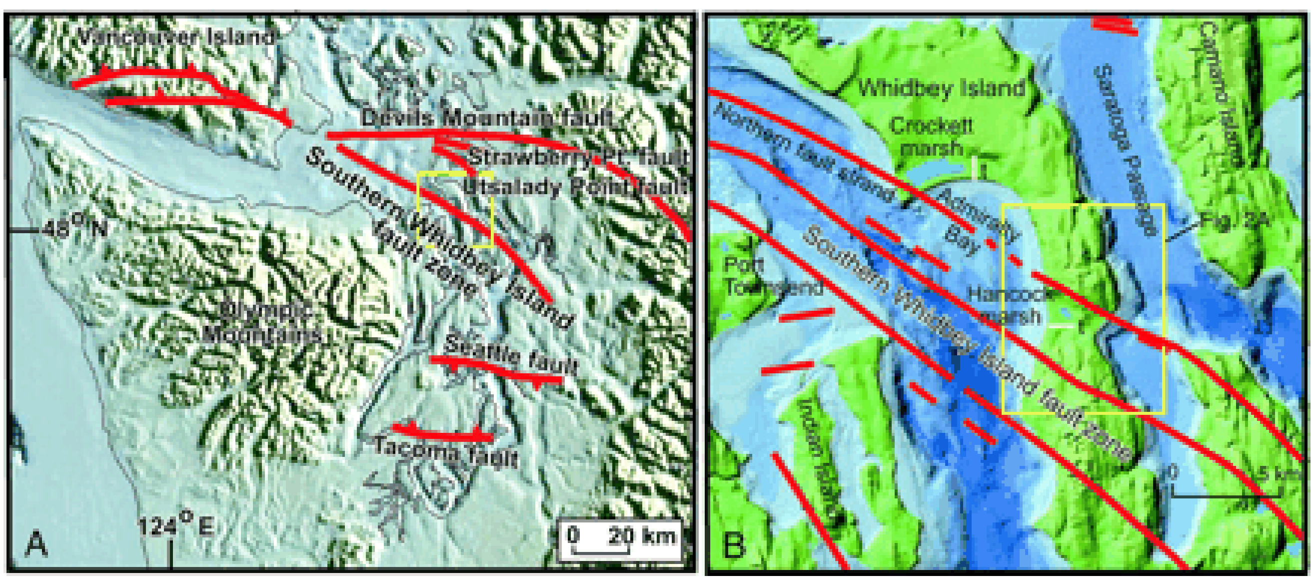


Figure 5. South Whidbey Island Fault Zone. Notice that the southern splay of this fault passes close by Double Bluff Beach, one of our stops.

ROAD LOG

To Stop 0 - Directions from Highline Community College to Mukilteo Ferry Terminal to Clinton Ferry Terminal

We will depart HCC and travel to Mukilteo ferry terminal via 1-5 north. Take I-5 until exit 189 (WA-526). Exit the freeway taking the Mukilteo-Whidbey Island exit heading west. Continue west along WA-526 past the Boeing Airlines assembly plant. Follow WA-526, keeping to the right and following the traffic signs to the Mukilteo Ferry and Washington State Route 525. Turn right (north) onto WA-525 and follow signs directing to the Mukilteo Ferry. We will load the vans onto the ferry.

Observations along the way:

As we leave the city of Seattle traveling north, many north-south trending flutes (drumlinoid structures) and troughs are clearly visible. All have been modified. In fact, “the seven hills” of Seattle define this ice-molded topography. Much of the upland surfaces are veneered with Vashon Till, while the lowland surfaces are alluvium deposits.

On the ferry, it is an excellent time to notice the glacial/non-glacial stratigraphy of the Puget Sound bluffs that are well-exposed inn recent landslide scarps on both the mainland and southern Whidbey Island. Seepage springs are perched above the impermeable glacial-lacustrine (lake) and older silty alluvial (river) units. The Vashon till and its advance outwash can be observed near the top of the section of the higher bluffs. We will look at these two units at our second stop near the Clinton Water Tower.

Most of the landslides exposed along the bluffs of southern Whidbey Island are shallow debris slides that are initiated during excessively wet winters or high magnitude precipitation events. Southerly-facing bluffs have the additional problem of being undermined by wave action during the winter storm season.

As we travel across Possession Sound toward the Clinton ferry terminal a series of post-glacial marine terraces are observed inland from the ferry terminal. These terraces are clearly seen on the LIDAR map (Fig. 2). Similar terraces are observed along coastal areas in other locations of Whidbey Island. The elevation of the highest post-glacial terrace is $\approx$ 140 feet above sea level and is inferred to represent the marine high stand following deglaciation. The postglacial terraces were created where wave cutting has incised minor platforms paralleling the post-glacial coastline. The interplay of postglacial isostatic uplift and eustatic sea level rise likely gave rise to periods of stability where the more prominent terraces were incised.

To Stop 1 – Driving Directions to the Clinton Erratic

0.0 mi As you leave the Clinton ferry terminal set your odometer to 0.0 miles at the traffic lights by the toll both and merge toward the left lane. Travel north along WA-525.

0.20 mi Turn left (west) onto Humphrey Road. You are driving along one of the post-glacial terraces discussed above.

0.40 mi Turn left (southeast) onto Berg Road.

0.50 mi Turn right (south) onto Conrad Street

0.60 mi Park along the right side of the road near the large boulder exposed near the drainage ditch on the west side of the road.

The Clinton Erratic

This greenstone boulder was deposited within lodgement till (basally) during the most recent advance of the Puget Lobe (Vashon Stade). The long axis of the boulder trends north-south, paralleling the ice-flow direction at this location. Faint grooves also trending north-south indicate that ice flow continued for a period of time while this boulder was emplaced. Much of the exposed relief of the boulder was likely exhumed by wave incision during post-glacial isostatic recovery. The lithology of the boulder indicates that it was likely transported from ophiolite rocks found inherent to Fidalgo Island.

To Stop 2 – Driving Directions to the Clinton Water Tower

Return to the vehicles and retrace the route back to WA-525.

0.65 mi Turn left onto Berg Rd.

0.80 mi Turn right onto Humphrey Rd.

1.05 mi Turn right onto WA-525

As we leave the town of Clinton, WA-525 enters a post-glacial outwash channel, which was incised into the pre-existing topography as remnant ice melted from the upland surface. The radial pattern of these channels is well defined on the LIDAR image (Fig. 2).

1.80 mi Turn right onto Forgotten Lane and park to the right (northwest) of the wooden water tower.

Clinton Water Tower

The bluff exposed to the southeast of the water tower provides an opportunity to observe the advance sequence of the Vashon Till and its underlying outwash unit. The outwash pro-graded into proglacial lakes which formed when north-flowing streams were dammed by the advancing ice into the Strait of Juan de Fuca and northern lowland. At this location you will note that the sidewall of a post-glacial channel is exposed in the section. The original channel shape and its post-glacial fill are well exposed on the northwest side of the outcrop.

To Stop 3 – Whidbey Telephone

Return to the vehicles and follow the dirt access road past Dalton Realty to WA-525.

2.0 mi — Turn right onto WA-525 north. Notice the undulating topography as we drive northwest over N-S trending flutes and troughs.

6.75 mi. — Turn right (northeast) onto Bayview Road.

6.90 mi — Turn left onto Marshview Avenue at the 4-way stop.

7.1 mi — Turn left into the Whidbey Telephone parking lot.

Whidbey Telephone (Glaciomarine drift and emergent facies)

In this 2-meter high road cut, you can observe the thin emergent beach lag gravels that cap a stony glacial marine drift (GMD) unit. The GMD has no mollusk fossils present and its origin is inferred mainly by its low elevations (~ 50 ft above sea level) and its stratigraphic relationship to the overlying emergent facies gravels. The retreat record is think over much of the south end of Whidbey Island, except where small fans and deltas were pro-graded into marine embayments from melting ice on upland surfaces.

To Stop 4 – Double Bluff Beach Walk

7.2 mi — Turn right onto WA-525 north. To the left is Useless Bay, which got its name because of its shallowness and problems for larger ships.

9.5 mi — Turn left (southwest) onto Double Bluff Road.

11.0 mi — Park in the Country Park parking lot. This will be a 1.5 to 2.0 mile beach walk (tide permitting!). Public restrooms are available here.

Double Bluff

At this stop the complete Vashon advance glacial stratigraphy and older non-glacial units known as the Whidbey Formation can be observed. The Whidbey formation is interpreted to represent deposition during the last interglaciation (Easterbrook, 1992). Glacial till, glaciomarine drift, and outwash from the Double Bluff Glaciation is exposed in the lower bluff 1 mile SW of liquefaction structures. The Double Bluff glaciation has been assigned an age of 180-250 ka based on dating by Easterbrook.

As we walk along the beach, we will be walking in a direction geologists call "down section", meaning the as we walk northward, the sediments we observe at that base of the bluff are older and older. Near the start of the Bluff at the park, Vashon Outwash and Till from the last glacial advance (16,000 – 13,000 years ago) are near the top of the bluff. These are underlain by the non-glacial Whidbey Formation made up mainly of sediments deposited in a delta. Refer to the idealized section in figure 6. Farther down the beach, we will begin to see the Double Bluff Drift (250,000 to 175,000 years before present) exposed below the Whidbey Formation (refer to the idealized section in figure 7).

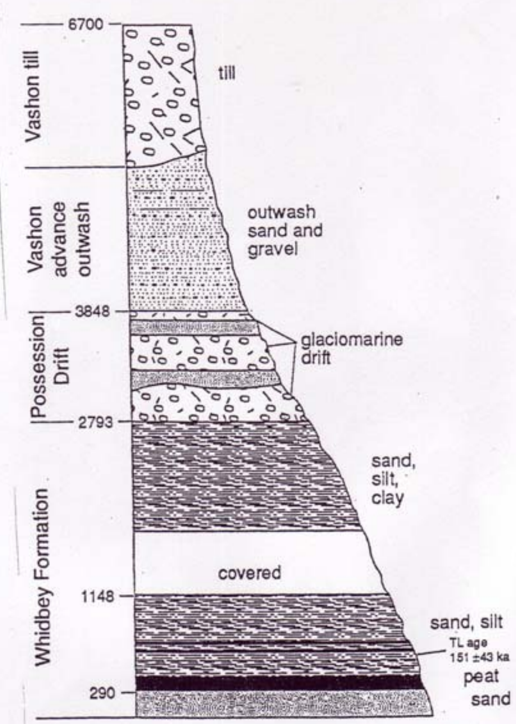


Figure 19. Stratigraphic section at Point Wilson. A TL age of 151 ± 43 ka was measured from clay in Whidbey Formation interbedded sand, silt, clay, and peat near beach level.

Figure 6. Composite section at the type location for the Whidbey Formation. To the south side of Double Bluff Beach, Vashon Drift is seen overlaying Whidbey Formation.

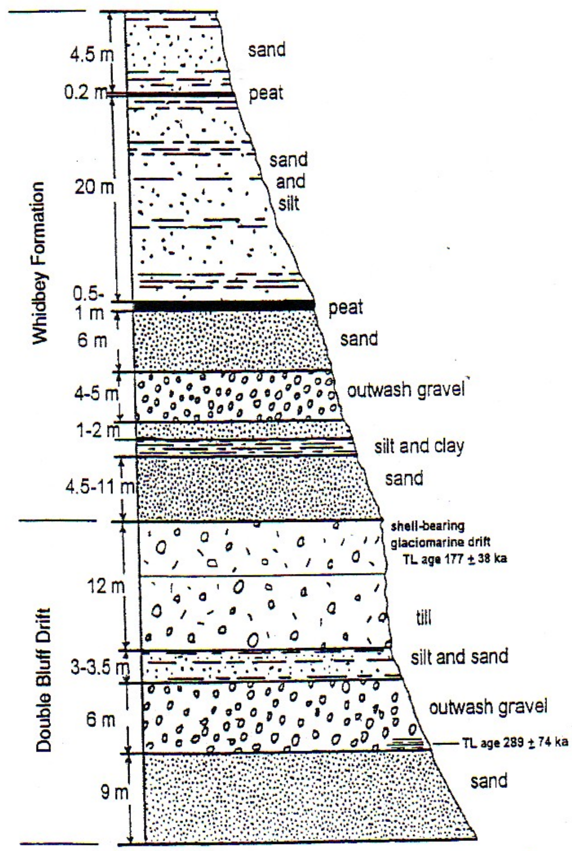


Figure 7. Composite section at the type locality of the Double Bluff Drift. Double Bluff Drift, which dates between 250,000 to 175,000 ybp is seen at the base of the bluff.

One of the objectives of this stop is to compare deformation structures observed in non-glacial fluvial units, which have been inferred to represent liquefaction structures to deformation structures that are clearly glacio-tectonic. Scrambling up the bluffs in this location is optional.

Note the rip-up clasts of organic peat within the fluvial deposits. These peat blocks are similar to continuous peat beds lying to the SW of the fluvial deltaic sequence. It is inferred that the sands in which the "liquefaction" structures exist are younger than the non-glacial portion of the record containing the blocky peat deposits. It is inferred that this delta sequence is deposited in a structural low, which pinches out just beyond the small canyon incised by an upland creek. After we pass the creek canyon, we can climb up the bluff to the glacio-tectonic structures in the Lawton Clay were fold axes trend E-W suggesting N-S ice flow.

Comparative study of two different sequences of deformation structures exposed in the stratigraphic record at Double Bluff beach on South Whidbey Island, WA indicated that their genetic origin is dissimilar (Nelson, et al., 2003). Deformation structures found near the top of the section in the glacial lake clay units have distinct fold patterns with their respective axes aligned east-west and perpendicular to the inferred N-S ice flow direction of the Puget Lobe. These structures are typically found closely beneath the Vashon Till and are though to have a glacio-tectonic origin.

In the lower and middle sections of the exposed stratigraphy at Double Bluff beach, a more extensive sequence of deformation structures are observed for almost 1.5 km in alluvial silty and sandy units mapped as part of the non-glacial Whidbey formation. These deformation structures have been mapped by others as being related to paleoseismicity, but have not been closely studied.

To Stop 5 – The Coupeville Erratic

Retrace your route back to WA-525.

12.9 mi Turn left onto WA-525 north.

Mileage after this point may be slightly off!

26.3 mi WA-525 becomes Highway WA-20.

31.5 mi Turn right into the driveway of the Big Rock Apartments. Drive around the apartments and park on the right side of the parking lot, so as not to block local residents from backing out.

The Coupeville Erratic

This is one of the more famous glacial field boulders on Whibey Island. This greenstone erratic was excavated from Mt. Erie 40 km to the north. It generated a lot of controversy when a local resident filed a building permit to build a coffee shop in front of it.

To Stop 6 – Fort Ebey State Park

Return to the vehicles and retrace the route back to WA-20. Turn left (north) onto WA-20.

36.3 mi Turn left onto Libbey Road heading west towards Partridge Point. Go past West Beach Road.

35.3 mi Turn left onto Hill Valley Drive. Go past Hawk West Drive. Enter Fort Ebey State Park. Restroom facilities are located at the Lake Pondilla parking lot.

Lake Pondilla

We will walk down to the beach to observe a kettle depression that has been dissected by wave-cutting. Collapse structures can be observed on each side of the kettle. We will also walk to Lake Pondilla.

Return to Highline Community College.