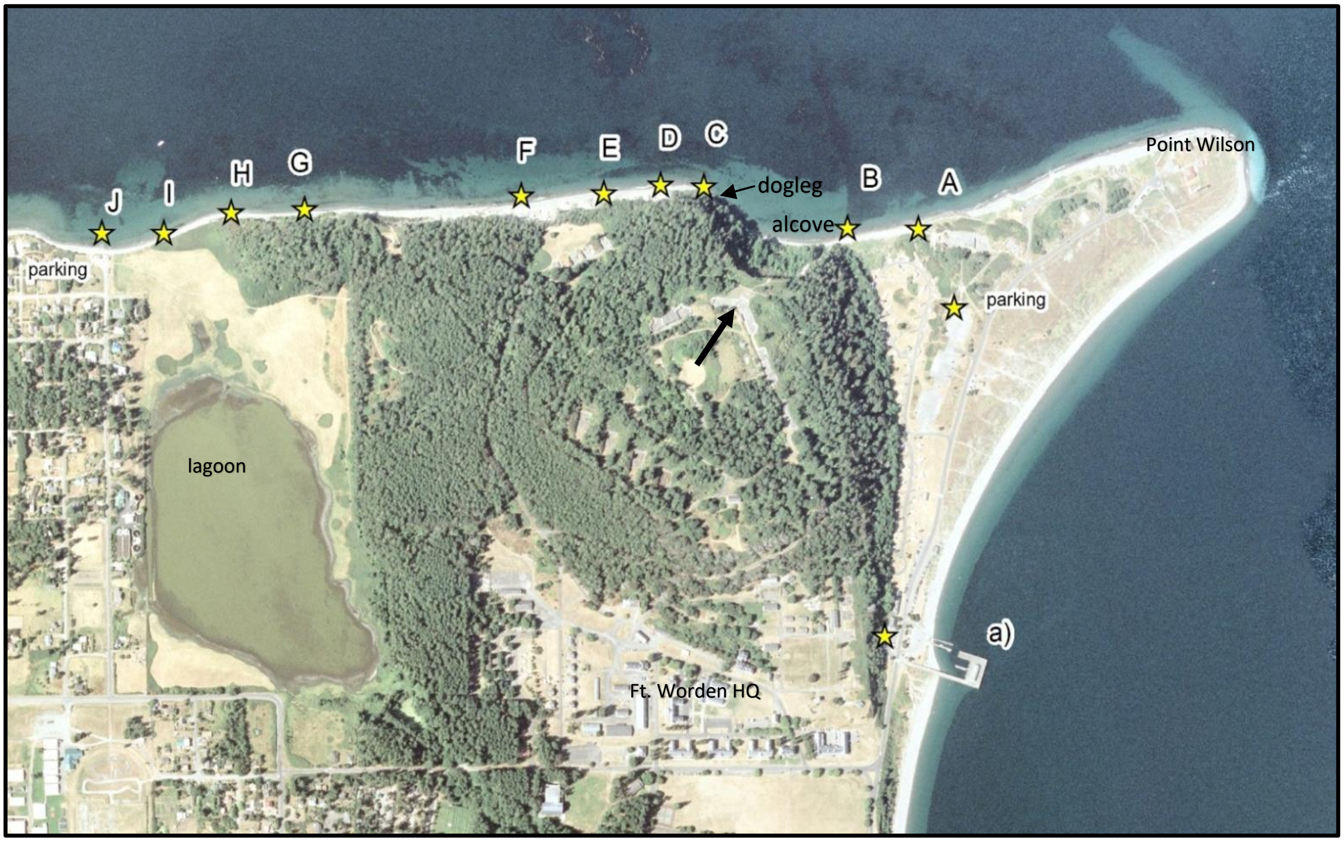
GEOLOGY OF THE BLUFF ALONG NORTH BEACH AT FORT WORDEN



Location	Latitude/Longitude	Description
A	48.1428/-122.7619 (48°08'33.9"/122°45'43.0")	Trail to the beach is to left (west) of Battery Kinzie. This walk (A-J) is about a mile long.
B	48.1428/-122.7637 (48°08'34.0"/122°45'49.3")	Drowned 'forest': buried logs, branches, and roots exposed at low tide. Battery Ash (arrow) is closest to the landslide scarp, the 'alcove'.
C	48.1434/-122.7673 (48°08'36.3"/122°46'02.2")	West side of the 'alcove'; landslide and unstable slope features en route
D	48.1435/-122.7683 (48°08'36.5"/122°46'05.9")	West edge of 'peat' layer in the Whidbey Formation
E	48.1433/-122.7697 (48°08'36.0"122°46'11.0")	Large boulder (erratic) on beach with brass USGS marker; Battery Tolles on the upland between here and Location F
F	48.1433/-122.7718 (48°08'35.9"/-122°46'18.4")	Bluff at west end of Battery Tolles; alluvium with darker sediment high in the bluff; Battery Walker in the small clearing east of Location G.
G	48.1431/-122.7771 (48°08'35.1"/122°46'37.7")	Everson-age delta-like deposit (the diamicton or 'jumble') reaches beach level. Above this is glacio-marine drift (gmd) with an irregular top surface.
H	48.1431/-122.7790 (48°08'35.0"/122°46'44.3")	Large clast of the Whidbey Formation in bluff face
I	48.1427/-122.7806 (48°08'33.8"/122°46'50.2")	The "wandering rock". Bluff face is gmd and diamicton overlain by thin layer of dark loess below vegetation.
J	48.1427/-122.7822 (48°08'33.8"/122°46'55.8")	End of concrete boat ramp at low tide. The county park is directly south.
a)	48.1363/-122.7628 (48°08'10.6"/122°45'46.1")	Marine Science Center parking lot; Olympia beds and Whidbey Formation are exposed by 2016 debris slides at star, but the blackberries are covering the slope again.
parking	48.1415/-122.7611 (48°08'29.4"/122°45'39.9")	The east-most star marks the concrete pad south of Battery Kinzie. This is a good place to leave a car for this walk; it requires a Discovery Pass.
parking	48.1423/-122.7822 (48°08'32.2"/122°46'55.8")	At the star near the west edge of this map (north end of Kuhn Street) is the North Beach County Park day-use parking lot. No pass is needed. [Google Earth image]

Introduction

This guide is for people new to the Port Townsend area or who have little familiarity with the glacial geology here. It describes the geology on the north shore of Fort Worden State Park from Point Wilson west to a county park. The walk is less than a mile one way. The lettered locations on the cover photo are features of interest. A few photos and/or short discussions are offered for each of the lettered locations. Some notes describe features on the south shore of Whidbey Island. The guide's subject is the bluff, not the cobbles and boulders on the beach.

The walk is best done at a minus (low low) tide so as to see the rapidly vanishing remains of the sunken trees at Location B (see cover photo) and to get a glimpse of what is at the water edge of the beach. A low tide enables a wide view of the tall bluff; it's also safer than standing at the edge of the bluff.

Everything exposed in this bluff is of late Pleistocene and Holocene age, from about 120,000 years to 6000 years ago. In this guide, we'll look first at the big picture. The next page lays out the Pleistocene geochronology of the Puget Sound region. The table, page 6, focuses on the northern Quimper Peninsula, offers descriptions of characteristic lithologies, and notes nearby locations of the units present. First, we'll get familiar with Point Wilson's development (page 7), then walk west, up in geologic time, to the county park boat ramp.

The text on the next page also fills out information for the geologic map of Fort Worden (page 4). The map shows where various sediments are exposed (or would be if the surface were bare). The section measured in the alcove north of Battery Ash (see cover photo) shows the order in which the Pleistocene materials were laid down and how thick they were in 2004. (Check out the Washington Geological Survey's home page, https://www.dnr.wa.gov/geology; see also http://lidarportal.dnr.wa.gov. URLs in this guide are not live.)

The map of the Puget Lowland (page 6) illustrates where the Vashon ice lobe was at its maximum extent. In the early 1900s, J Harlen Bretz (of Missoula floods fame) mapped the area covered by this version of the lobe. Results of modern mapping differ from his by about a square mile. He suspected there had been, and found remains of, prior glaciations. Of the seven glaciations identified to date in the Puget Sound area, (probably not all that came through here; see the next page), some occupied more territory, some less, than did the Vashon. Bretz suggested that lobes followed the same paths as their predecessors: south down the low area that is now Puget Sound, as well as out to the Pacific Ocean via the Strait of Juan de Fuca. The deep troughs in Puget Sound were excavated by water under the lobes. Low ground is covered by advance and recessional outwash or ablation till, post-glacial stream deposits, or slumped shoreline slopes.

Because North Beach is an active littoral environment, some features in the photos in this guide have eroded away. Older photos help explain bits of bluff history. The beach changes every day – and so can the bluff!

Some cautionary notes*:* **(1)** Climbing on or digging into the bluff can start a debris flow – fast, voluminous, heavy, and potentially lethal. **(2)** If the 'tide' behaves oddly and/or the earth moves during a beach walk, *get to high ground ASAP*. (Don't wait to figure out where the quake happened. The siren warning won't be heard on this beach.) Climbing the bluff is not an option, so move promptly to where it's possible to get tens of feet above sea level. Join the campground/beach crowd moving to the parade ground level or higher. Or go to the old boat ramp and climb up Artillery Hill, back from the bluff edge. There may be debris flows off the bluff to dodge, scramble over, or wade past when going in either direction. If it is the Big One (or even a not-so-big one) off the Pacific Coast, the good news from state and federal models is that it will take about an hour for tsunami waves to reach the Port Townsend area. And more good news: *preliminary* modeling suggests a quake on the Seattle fault will not create a giant wave(s) here. However, we don't yet know what would happen if a strand of the South Whidbey Island Fault Zone (see page 13) were to rupture. A potential tsunami could arrive quickly from the east.

The Quimper Geological Society welcomes comments on this guide and photos of features on this stretch of beach. Please send them to http://quimpergeology.org/ or to Michael Machette paleoseis@gmail.com.

Puget Sound Pleistocene Glaciations and Interglacial Periods

The Pleistocene (*ca.* 2.6 million years ago to about 11,000 years ago, *aka* the Ice Age) was characterized by periods of irregular slow cooling and rapid warming. The cold periods were, in general, shorter than the warmer ones, and both cold and warm extremes increased in the last 500,000 years.

Below is a list of the Puget Sound area's currently named Pleistocene components and approximate ages. Glaciations are in roman type, interglacial periods in italic type. (See also the table on page 6.) A stade is a temporal sub-unit of a glaciation. Drift is a general term that covers everything transported or deposited by ice, such as outwash and till. "yr BP" means years before present; radiocarbon dating protocol defines present as 1950. Lowercase names are not considered formal. OIS refers to divisions of time defined by $^{18}O/^{16}O$ ratios.

Fraser Glaciation:
- Sumas Stade (11,500 - 10,000 yr BP) – this ice mass advanced just south of the Canadian border
  - *Everson Interstade* (13,000 - 11,500 yr BP)
- Vashon Stade (18,000 - 13,000 yr BP)
  - *Port Moody Interstade* (23,000 - 21,000 yr BP) – not recorded locally
- Coquitlam Stade (30,000 - 25,000 yr BP) – this event may be recorded near Sequim
- *Olympia nonglacial interval* ("Olympia beds") (60,000 - 21,000 yr BP)

Possession Glaciation (Possession Drift) (60,000 - 80,000 yr BP)
- *Whidbey Interglaciation* (Whidbey Formation) (80,000 - 125,000 yr BP)

Double Bluff Glaciation (Double Bluff Drift) – oldest event recorded in local bluffs (125,000 - 185,000 yr BP)
- *Hamm Creek formation* (OIS 7, about 200,000 yr BP) – deposits present farther south and at depth

Defiance glaciation (OIS 8, 255,000+ yr BP) (Defiance drift)

We can expect to detect more glaciations in still older sediment.

……Geomagnetic reversal at 780,000 years ago Bruhnes is the current normal polarity time. Matuyama is the next older, reversed, interval. The Salmon Springs Drift has reversed polarity……….

Salmon Springs Glaciation (OIS 24-28) (Salmon Springs Drift, about 800,000 yr BP)
- *Puyallup interglaciation* (OIS 28-50) (Puyallup Formation)

Stuck Glaciation (OIS 51-59) (Stuck Drift)
- *Alderton interglaciation* (OIS 60++, about 1.6 million yr BP – dating breaks down about here) (Alderton Formation)

Orting Glaciation (about 2 million yr BP) (Orting Drift, Orting Gravel)

Exposed in the North Beach bluff are fine sediments of the Whidbey interglacial unit to Vashon till. Deposits of these units are known from other sites along the strait, but little is known about older deposits in that area.

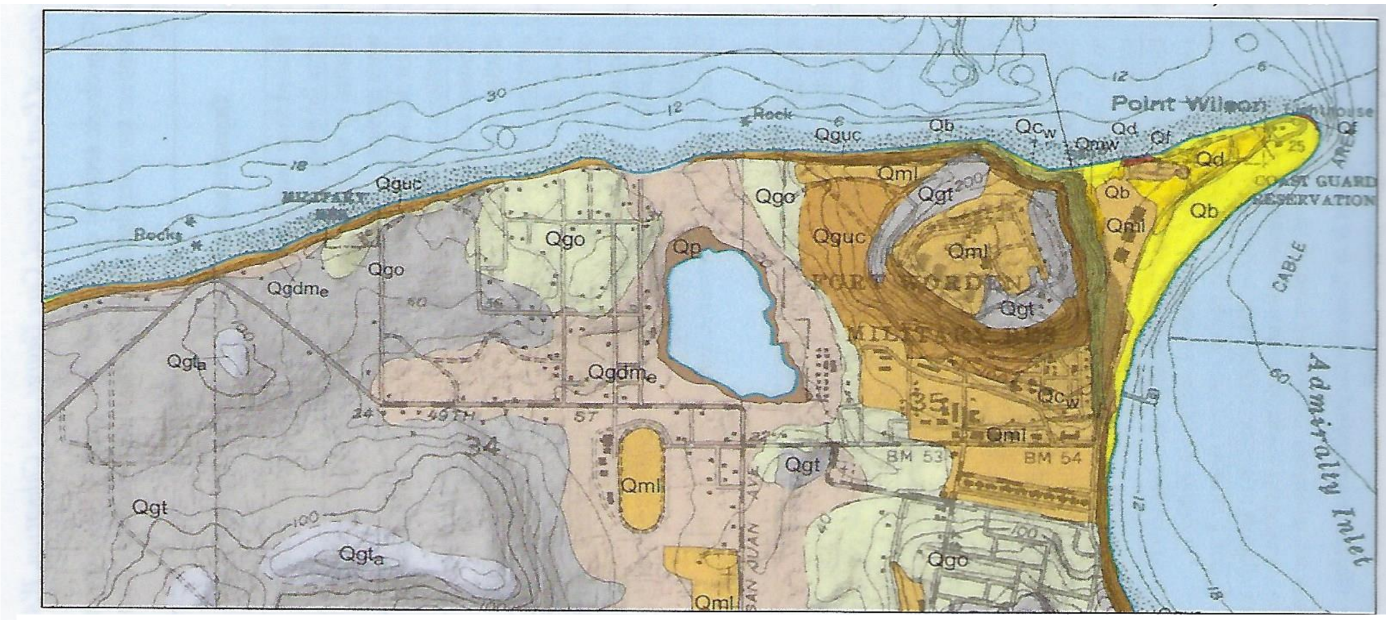
The **geologic map** of the park area on the next page is taken from:

Schasse, H.W., and Slaughter, S.L., 2005, Geologic map of the Port Townsend South and part of the Port Townsend North 7.5-minute quadrangles, Jefferson County, Washington: Washington Division of Geology and Earth Resources Geologic Map GM-57, I sheet, scale 1:24,000. http://www.dnr.wa.gov/Publications/ger_gm57_geol_map_porttownsends_24k.pdf

The **geologic section**, next page (also from Schasse and Slaughter), shows what was exposed in the alcove north of Battery Ash in 2004. These unit thicknesses (numbers on the left of the column) are probably not still visible. The Possession- and Olympia-age units may crop out only in the alcove. It is likely that no oldest or youngest layer of any unit is present.

On page 5 is a diagrammatic cross section that shows how the geologic units are arranged. It does not show the gentle warping that has occurred in the last several million years.

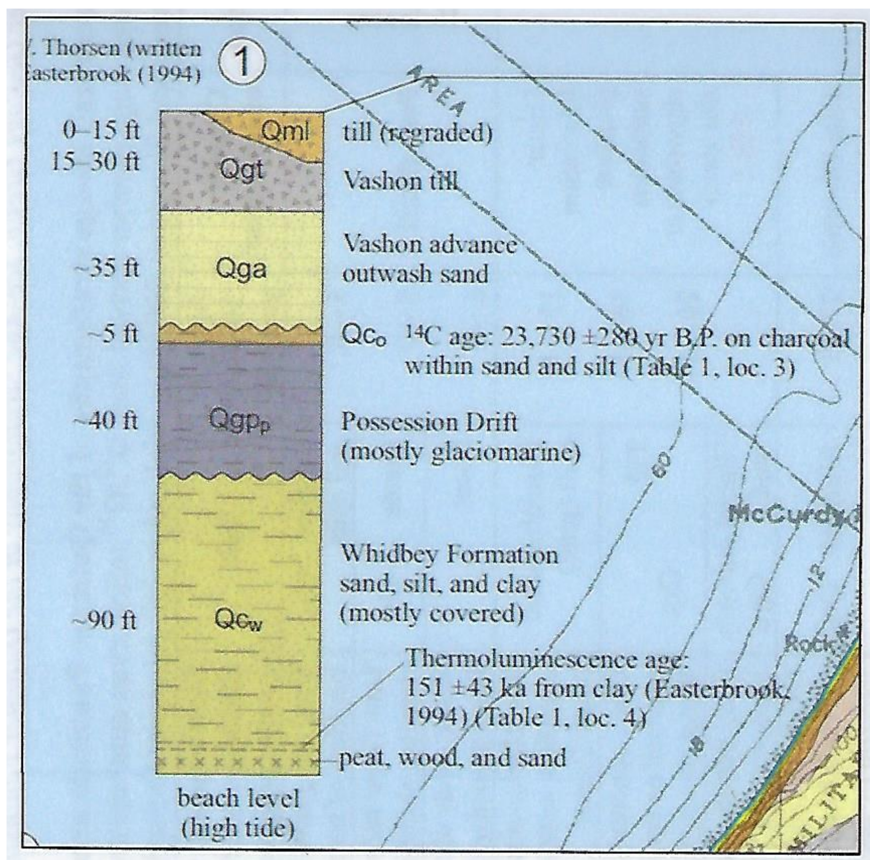
Helpful references are listed at the end of this guide along with end notes.

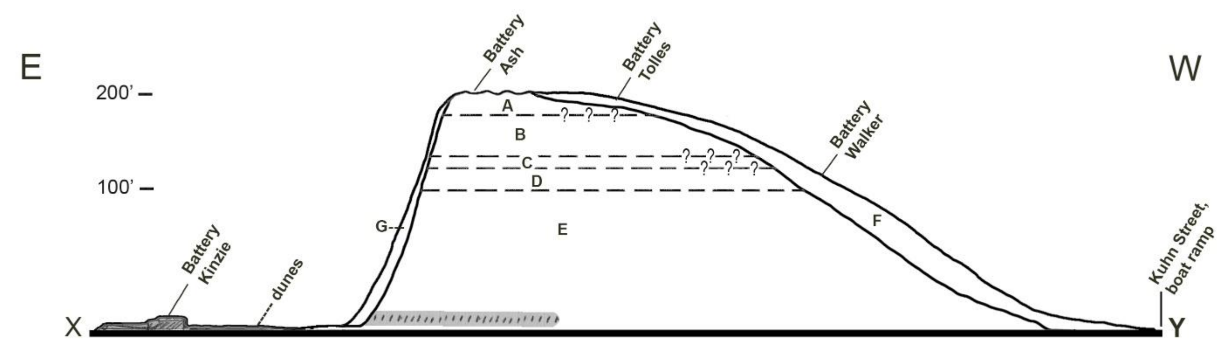


This **geologic map of the northwest part of the Quimper Peninsula, including the Fort Worden area** (mostly in brown tones), is taken from Schasse and Slaughter (2005). Possession Drift and Olympia sediments may be visible in the alcove.

Explanation of unit labels on geologic map and section. By Washington Geological Survey (and, with some exceptions, U.S. Geological Survey) convention: Q, Quaternary (Pleistocene and Holocene; Pleistocene units have a g in them); g, deposits of glacial origin; c, nonmarine (continental) deposits; subscripts indicate unit's name. (Unit chronology and descriptions are in the table on page 6.)

- Qml - land disturbed by the military, county, or city
- Qmw - mass wasting, landslide or colluvial deposits
- Qd - dunes
- Qb - beach deposits
- Qp - peat
- Ql - loess
- $Qgdm_e$ - glacial-marine (or glacio-marine) drift, Everson age (incl. the diamicton/jumble)
- Qgt_a - Vashon ablation till
- Qgt - Vashon lodgment till
- Qgo and Qga - Vashon advance outwash
- Qguc - glacial deposits, undifferentiated, nonmarine
- Qgp_p - Possession Drift
- Qc_o - Olympia beds
- Qc_w - Whidbey Formation





A - Vashon till
B - Vashon advance outwash
C - Olympia-age sediment
D - Possession drift
E - Whidbey Formation
F - Everson recessional outwash: gmd + diamicton
G - modern colluvium
- peat

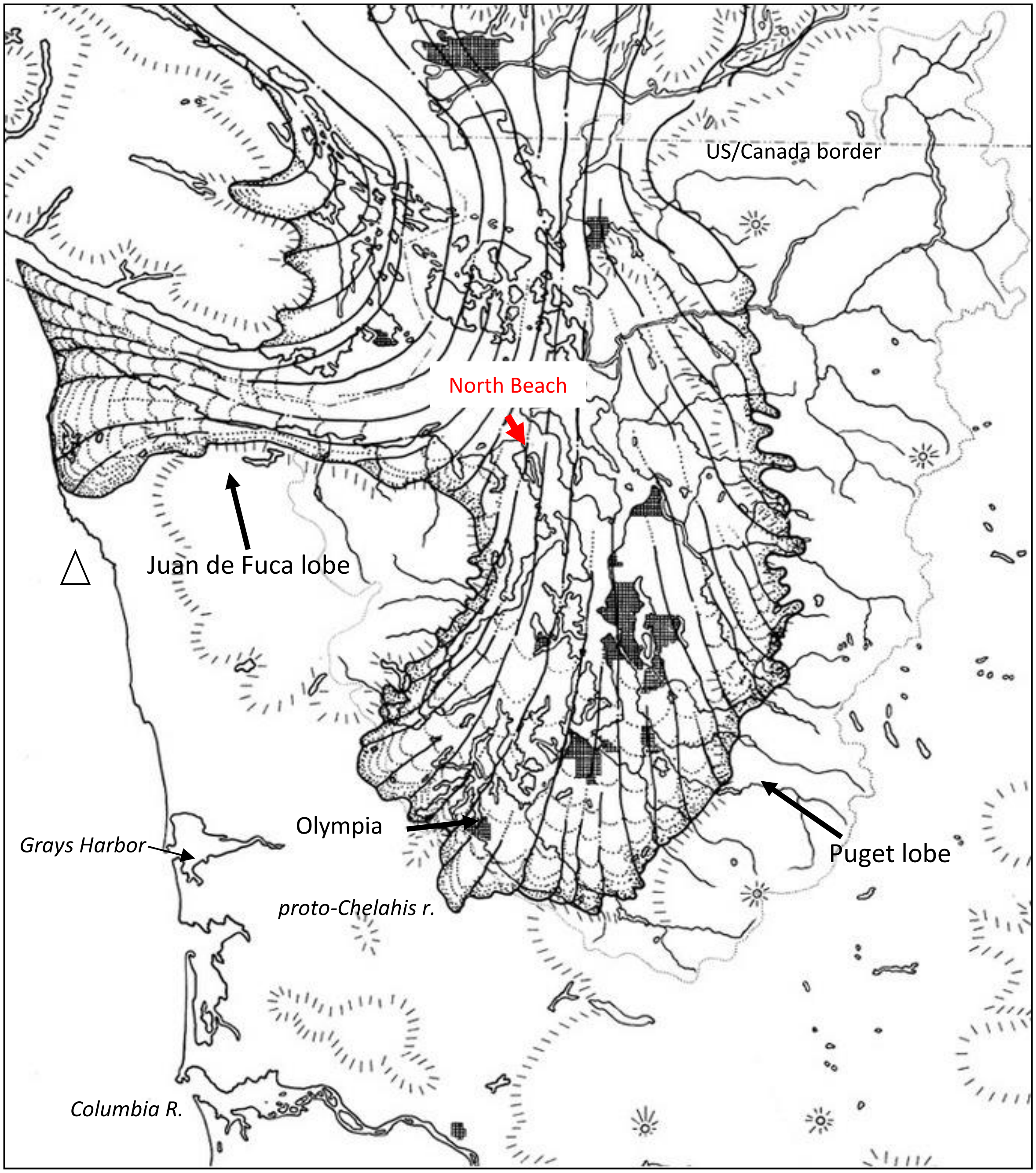
X to Y = approx. 1 mile. Note vertical exaggeration.

Diagrammatic cross section of the geology of North Beach between Battery Kinzie and the county park on Kuhn Street. Vertical exaggeration means that each geologic unit drawn here is thicker than it would be if this were drawn to scale. The dashed lines indicate that the contacts are approximately located. The till has been rearranged by the U.S. Army; bluff erosion is greatest north of each battery. The east limit of unit F is conjectured. (Prepared by Varn Brooks)

Generalized stratigraphy of the Port Townsend area. No local bluff contains all these units. OIS, oxygen isotope stage number derived from O^{18}/O^{16} ratios; even numbers are glacial periods, odd numbers, interglacial.

Period	Climatic environment / age name	Age: KYR BP*	Landform or origin	Unit description (most common appearance or lithology)	Depositional environment (unit is widespread unless locations are given)
Holocene	post-glacial	5 – 0	beaches, bars, and spits	Sand and gravel, locally littered with boulders of northern origin	Fed by erosion of nearby bluffs; boulders (from glacial layers) that are too large for waves to move remain as a lag
		5 – 0	dunes	Low linear hills of fine sand rimming shoreline bluffs	Built and eroded by wind from west-facing sandy bluffs bared by wave erosion
		6+ – 5	loess	Black sandy silt, ±3 ft thick, over latest glacial sediments	Dust deposited by wind; preserved locally by "rain-shadow" microclimate (?)
Pleistocene	interglacial: Everson Interstade	13 – 11	recessional marine deposits; glaciomarine drift (gmd)	Chaotic but partly bedded mix of boulders to sand overlain by and locally mixed with diamicton and blocky-weathering clay	Shallow marine diamicton 'jumble' found under or near ice and near the shore indicate local high pore pressures and rapidly changing conditions during ice melt. Fine glaciomarine drift texture and sparse marine fossils indicate some deposition in quiet water
	glacial: Vashon Stade (*Fraser Glaciation*) OIS 2	18 – 13	till	Gray, concrete-textured, not layered to vaguely layered; as vertical surface in bluffs	Clay- to boulder-size debris smeared at the base of ice onto earlier landscape (*i.e.*, bluff along Water Street in PT); also from in-place melting ice
		20 – 18	glacial advance outwash sand	Gray pebbly sand, angle-of-repose surface within bluffs	Deposited by braided, sand-laden meltwater streams from advancing ice on a vast plain
	non-glacial: late Olympia	25 – 20	alluvium; 'Olympia beds'	Oxidized sand+gravel, peat, with rare terrestrial fossil fragments; locally overlain by lakebed silt	Deposited in and along streams; later covered by a lake (exposed in the Shold pit near Chimacum)
	non-glacial: Olympia beds OIS 3	37 – 25	loess	Yellow-tan silt, as layers in vertical bluffs; little or no stratification	Deposited on land by wind as dust during a period colder than the present; on Whidbey and Protection Is and at Cape George
		60 – 37	paleosol(s) (poorly developed)	Orange-brown sand with rocks and fine carbon, 3 feet thick	Rust coloration due to weathering during long period of no deposition; on Whidbey and Protection Is. May be older
	glacial: Possession Glaciation OIS 4	80 – 60	glacial marine drift	Gray blocky-weathering glacial marine drift (gmd)	Texture and sparse marine fossils indicate deposition as debris from floating ice in shallow water (gmd); rarely exposed
			glacial advance outwash sand	Gray pebbly sand, angle-of-repose slopes	Deposited by braided, sand-laden meltwater streams from advancing ice sheet on a vast plain; Whidbey Is., Protection Is., spotty distribution, poor age control
	interglacial: Whidbey Formation OIS 5	125 – 80	Whidbey Formation	Gray stratified silt, compacted peat, and tan planar and cross-bedded sand and overbank silt/sand	Setting similar to today's Skagit River flood-plain flats (La Conner to Burlington); climate varied from cooler to at times warmer than now
	glacial: Double Bluff Glaciation 'OIS 6'	>180 – 125	Double Bluff drift	Till overlain by gmd in places	Ice-smeared rock debris, clay to boulders, overlain by debris shed from floating ice (gmd). In beach bluffs at Cape George, Ebey's Landing on Whidbey Is., and Protection Is.

* KYR, thousands of years. BP, before present, *i.e.*, 1950. These are *raw date, with no error ranges*. The practical limit of radiocarbon dating is about 45,000 yr, but that can be extended by using ultra-refined samples. The older ages, determined by multiple techniques, are guestimates with possible error of ±10%. In general, the older the sediment, the less precise its age.



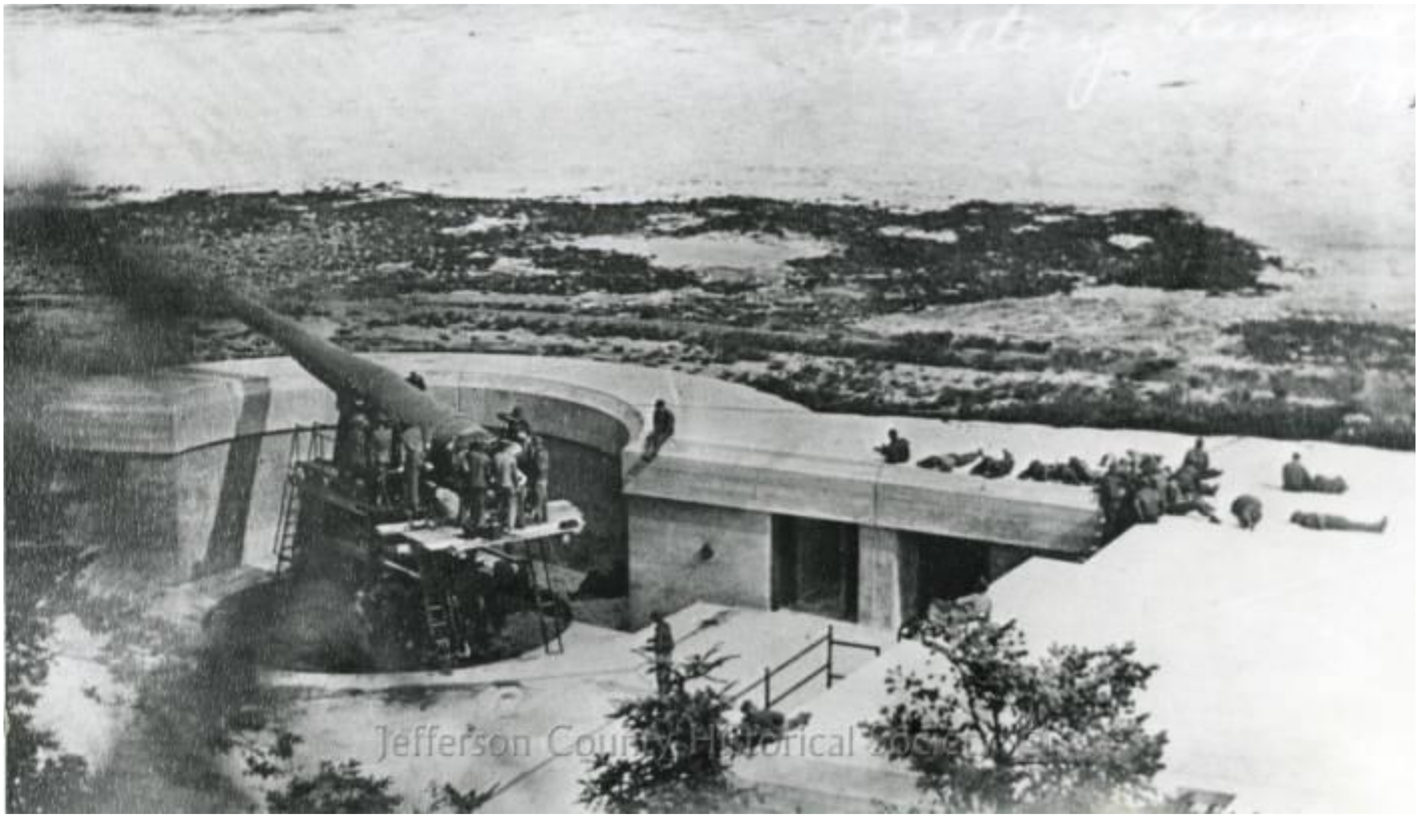
The position of the Vashon ice lobes at their maximum extent, about 14,500 years ago. Thin black lines are ice flow (hence sediment transport) direction. Faint gray lines beyond the ice limit are modern watershed boundaries. Hatch-marked areas are major population centers.

At this time, so much water was locked up as ice that sea level was about 300 feet lower than it is today. Destruction Island (triangle) off Kalaloch is a remnant of land "added" by the drop in sea level. At the same time, the weight of the lobe ice depressed the land surface by 200+ feet. It is hard to distinguish the effects of sea- and land-level changes. The Pacific shoreline drawn here was then actually about 50 miles farther west. The terminus of the Juan de Fuca lobe was close to that shore, not as shown here. A deep canyon was cut south-southwest offshore from it.

At its maximum extent, the Puget lobe's terminus reached about 12 miles south of Olympia. Puget lobe ice filled the Puget Lowland in the center of this map and flowed up and dammed river valleys on its east and west sides. Meltwater drained south along both ice edges. A proto-Chehalis river carried the meltwater to the Pacific Ocean by way of Grays Harbor. A deep channel extends offshore from there.

Ice came south over the Canadian border ∽19,000 years ago. (See end note 1.) It broke up eastward along the Strait of Juan de Fuca starting ∽13,000 years ago. Lowland ice, no longer fed from the north, wasted away over the next few thousand years. (See end note 2.) The Manis mastodon, found near Sequim, was killed ∽12,000 (13,800 calibrated) years ago, showing that people moved rapidly into ice-free vegetated areas.

The Beach Walk



This old photo is on a sign to the west of the trail from the parking pad south of Battery Kinzie to the battery. Note all the “land” beyond the gun installation. What exactly is that at the top of the photo – beach? Fog? Is there a road crossing the area? The first thing one might wonder is when was this photo taken. Records in the fort archives show it was 1912. Did all that land disappear in 110 years?

It turns out that this is a composite photo made to disguise the location of the gun. There was no land area like this to the north. But there have been a lot of changes to the North Beach shoreline since 1912. The fact that riprap has been placed on the north side of Battery Kinzie and at the lighthouse tells us that storm waves are still pummeling those areas. Just in the last decade or so, winter storms added enough moisture to the vegetative cover of the bluff that the ‘skin’ has almost entirely slid off, leaving the north face more vulnerable to erosion (and undercutting). It’s hard to ignore the constant cascade of sand from the bluff north of Battery Tolles or the crumbling low bluff near the boat ramp and the county park.

Erosion is why we know some of the history of the bluff—what happened thousands of years ago and what is happening today. Mysteries have shown up, and there’s much still to be learned. The one date we have for sediment in the bluff is older than the currently accepted age range for the unit sampled. So, how old are any of the units? And we’d like to know how fast the shoreline is shifting south. It is almost impossible to determine an average rate without measuring for a decade or two, and air photos can’t provide the needed precision. At one place, a big storm might remove in a few hours what normally erodes in five years; a short stretch of the bluff elsewhere can collapse, cutting south perhaps ten feet, and then nothing happens for a few years. Perhaps we could define the rate for one spot, but not reliably for a mile of shore. We may eventually turn to lidar and GPS instrumentation to get answers.

So now let’s go look at the bluff and think about processes and time.

LOCATION A. **Development of Point Wilson.** Getting to our starting point at the parking pad (red star) south of Battery Kinzie usually requires passing the Port Townsend Marine Science Center's building on a WWII pier. The lower photo shows a longshore current coming from the south, pushing/dragging sand along the tidal zone there. The pilings in the pier in the upper photo (2006 Wash. Dept. of Ecology [WDOE] aerial oblique) are placed closely enough to impede sand movement. Note that at a low tide, the left (southeast) part of beach is wider than the relatively starved right side. Even the boat ramp has slowed some moving sand. And this is just a small part of the coast picture.

The growth of Point Wilson east from the bluff began ~4000 years ago when sea level had stabilized. In the lower photo, the longer arrow indicates the east-directed longshore current on the north-facing beach. It is stronger than the northeast-directed current (shorter arrow) that passes the pier. This mismatch determines the spit shape. The double-ended arrow represents strong tidal currents that limit the point's eastward growth. Note sand plumes at the point tip.

Riprap (stars in the lower photo) at the Coast Guard facilities and Battery Kinzie will not prevent southward movement of the spit as erosion on this active north-side beach continues. Battery Kinzie's riprap, refreshed once, is collapsing again. Since 2016, permitting agencies have been discussing the cost and consequences of replenishing riprap.

The white arrow in the lower photo indicates Location B (the sunken trees discussed on the next pages). Note the area's straight west edge. What caused the linear features at the curved arrow?

The view in this photo is to the east from where we reach the beach just west of the battery. The white arrow points to one of several boulder groins placed to slow passage of sand. Sand goes right on past, though, not affecting the shore. The riprap boulders in the right foreground still offer some protection to the north side of Battery Kinzie.

> >>> *Before we start our walk: On Whidbey Island (north across the water from here) is Ebey's Landing State Park. The swale above the beach there is a channel that brought water from Penn Cove south to the strait during the last years of the Everson Interstade. The swale has nothing to do with the low area on this side of the strait between the North Beach day-use park and Kah Tai Lagoon near the Safeway store to the south. Native Americans used that low area as a portage route so as to avoid the strong currents off Point Wilson.*

As we start this walk west, we pass the east end of a boulder pile just offshore. In 2014, there was some peat just below the low tide level here, under some of the cobbles and boulders. It resembled a fine bark mulch and was not noticeably compressed; it looked quite fresh. (There is some Holocene peat northeast of the beach parking at Point Hudson near town that looks similar.) No peat remained in 2016. What bog could have been here?

At **Location B** are the sunken trees, previously referred to as the 'drowned forest', but, really, there are not enough trees for that term. At a minus tide these tree remnants stick up out of the boulder field. The log in the foreground of the left photo below is about 10 inches in diameter.

Photos from a 1996 unpublished report by R.B. Forbes, G.W. Thorsen, and S.Y Johnson. The linear feature on the left has not been seen since their work; it parallels the west edge of the boulder/tree field and dips west. The substrate here is firm clay. In the right photo, note the tree remnants that were visible then. The hammer is about 3 feet long. (Right photo copied by V. Brooks)

The tree remnants plunge ESE into the beach; a few are vertical. The larger pieces trend(ed) WNW to W. The late Robert Forbes (former Alaska State Geologist, Port Townsend resident) acquired radiocarbon dates of 2000 to 3000 years on at least two trees here (almost certainly not these). The younger date is from a ?pine ?fir cone and is considered more reliable. Other samples show that some trees are younger (and probably Douglas fir). How did this mix of ages come to be? For how long did branches stick up out of the beach, and why are there no protruding tree remnants like this only 20+ years later?

And why are these tree remnants here, in the middle of a beach? Three and a half explanations for that have been offered. Each has problems. Briefly: **(1)** Forbes believed they were dropped from the bluff along a fault during an earthquake. He proposed a down-to-the-east (normal) fault along the east face of the bluff. This is contrary to what we know about the local faults/regional tectonics: faults in the region are up-to-the-east (reverse) and strike-slip (side-to-side motion). The linear feature in the left photo dips in the wrong direction for a down-to-east fault. He also proposed that sandstone lay beneath the adjacent area in which no boulders were found. As far as we know, the nearest bedrock outcrop is 8 miles south at the bridge to Indian Island, and bedrock is not recorded within more than 400 feet of the surface in local well logs. **(2)** The late Gerald Thorsen (retired, Wash. Geol. Survey) suggested the trees lined a lagoon/pond that was over-run and buried by the beach as the shore moved relentlessly south during sea-level rise; the trees are now revealed in the surf zone. Roots were killed by rising salt water, and the dead trees fell. The beach at Crockett Lake by the Keystone ferry terminal on Whidbey Island is another example of this beach migration. At Fort Worden, there was once a pond between the shore and the campground, and old sketches and photos show large trees near it. Was the (former) peat near the start of this walk related in some way? **(3)** Hugh Shipman (retired WDOE coastal processes specialist) compares these submerged logs to trees brought to beach level in bluff landslides/debris flows. Are the roots we'd expect to see on the west long gone? **(3.5)** Maybe the military shoved the trees and boulders out of the area where the campground is today – or brought boulders in from somewhere. During WWII, much of the spit was leveled to facilitate landing-craft exercises. Was this some special ramp? There is an odd uniformity of boulder size and shape here. For all explanations, the concentration of boulders and the mix of tree ages are a problem.

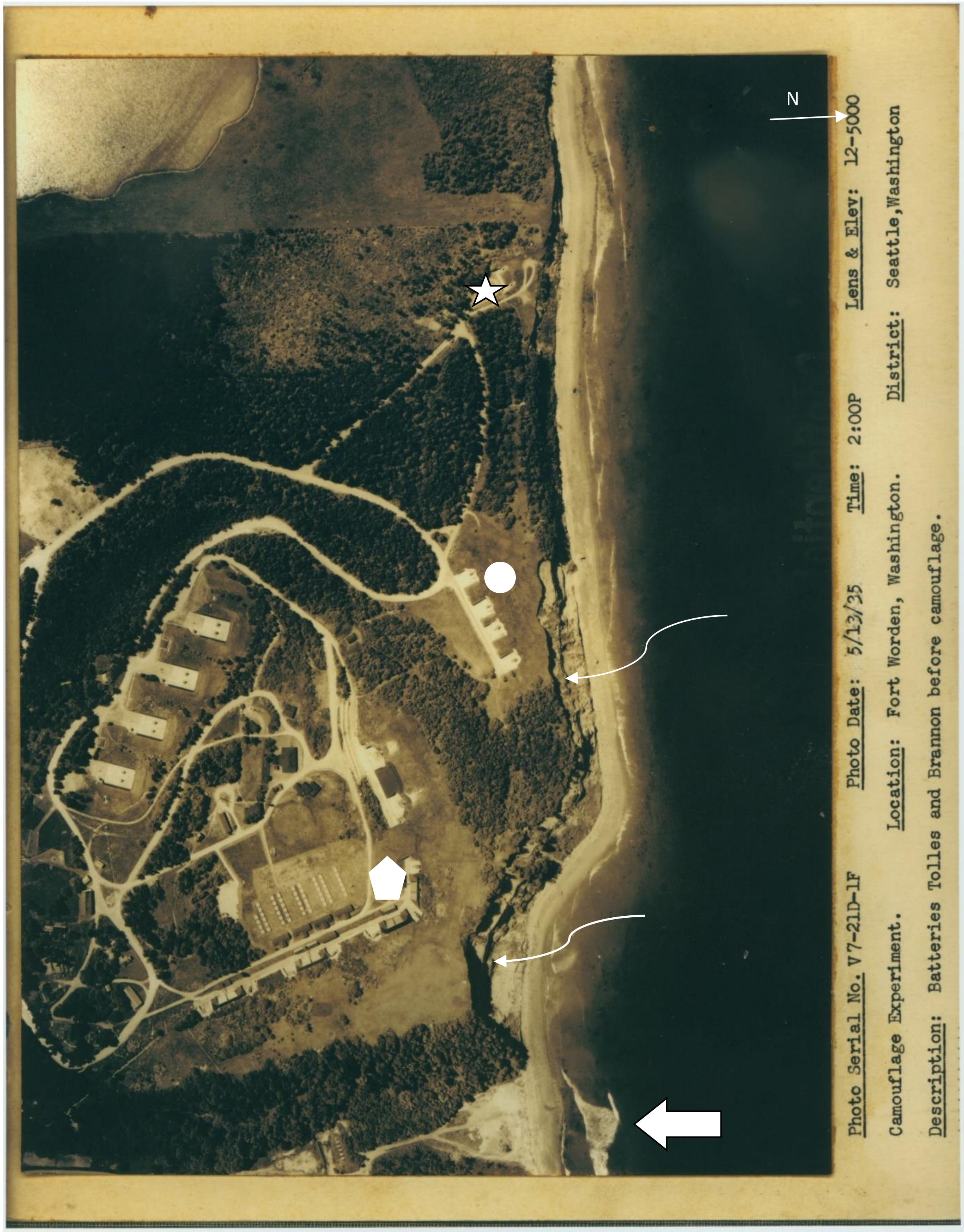
Kelp is growing at the north end of the boulders. Kelp requires a solid substrate (rocks) to attach its holdfast. Are the rocks with kelp attached part of the boulder field?

The sharp west edge of the sunken-tree area *may* reflect the former location of the bluff face. Recall that the shoreline has been moving south for centuries and could have been north of the sunken trees fairly recently. However, there are no boulders in the bluff sediment here. How is it that there is such a concentration right here? (There's some gravel and the occasional boulder in the till at the top of Artillery Hill in the alcove.) During storms, can rocks be pushed east across clay that underlies the cove just to the west? Might they have been progressively trapped by the wood on/in the beach? Apparently not. The west edge appears to be as it is today in Google Earth photos going back decades. Trees that arrive here in storms float to high tide level and are unlikely to be jammed in among the boulders as the sunken trees are. Other explanations of the origins and locations of the boulders and tree remnants are welcome!

LOCATION B (cont'd). Tree remnants, at white arrows, are partly covered by the boulders, shown here at a 2021 minus tide. The sharp west boundary is evident in the upper photo. Note also the pool in the upper photo; it seems to be perched on top of the boulders. What keeps that water from draining to sea level? The boulders in the deposit are larger as we walk west from Battery Kinzie, and there are no really large boulders. Why? And why is this concentration of boulders right here? It would be helpful to know how far into the beach they go (either straight down or to the south). The south edge also seems quite sharp. The boulder field is evident in photos from about the 1940s on. Stay tuned.

Look for light-brown-gray clay exposed at the edge of the upper beach. It extends west under the area north of the alcove and to at least Location C, but is it under the boulder field? Without permission to move the boulders, we can't dig very far. Local geologists have probed the area west of the boulders, and it is not indurated. There are some slabs of old compressed 'peat' (see end note 3) along the west edge of the boulders and on the cove surface north of the landslide. These come from the bluff southwest of the boulders and are light enough to float east with the current.

The next pages lay out the stratigraphy and structure along the beach and in the region. The regional faults have some bearing on Explanation 1 above. There is no fault along the bluff face, but note some odd bathymetry near it (page 16).



1935 U.S. Army vertical aerial photo of Fort Worden. Note the cleared space north of where the campground is. What is the white material offshore at the fat white arrow? Also note the straight landslide scarp and the ledge(s?) near bluff top (curved arrows). The ledges could be contacts (where two units are juxtaposed), but for which geologic units? (See the table, page 6.) Battery Ash is at the pentagon. Battery Tolles is at the circle. Battery Walker (star) has a looped road; look for it in the next photo.

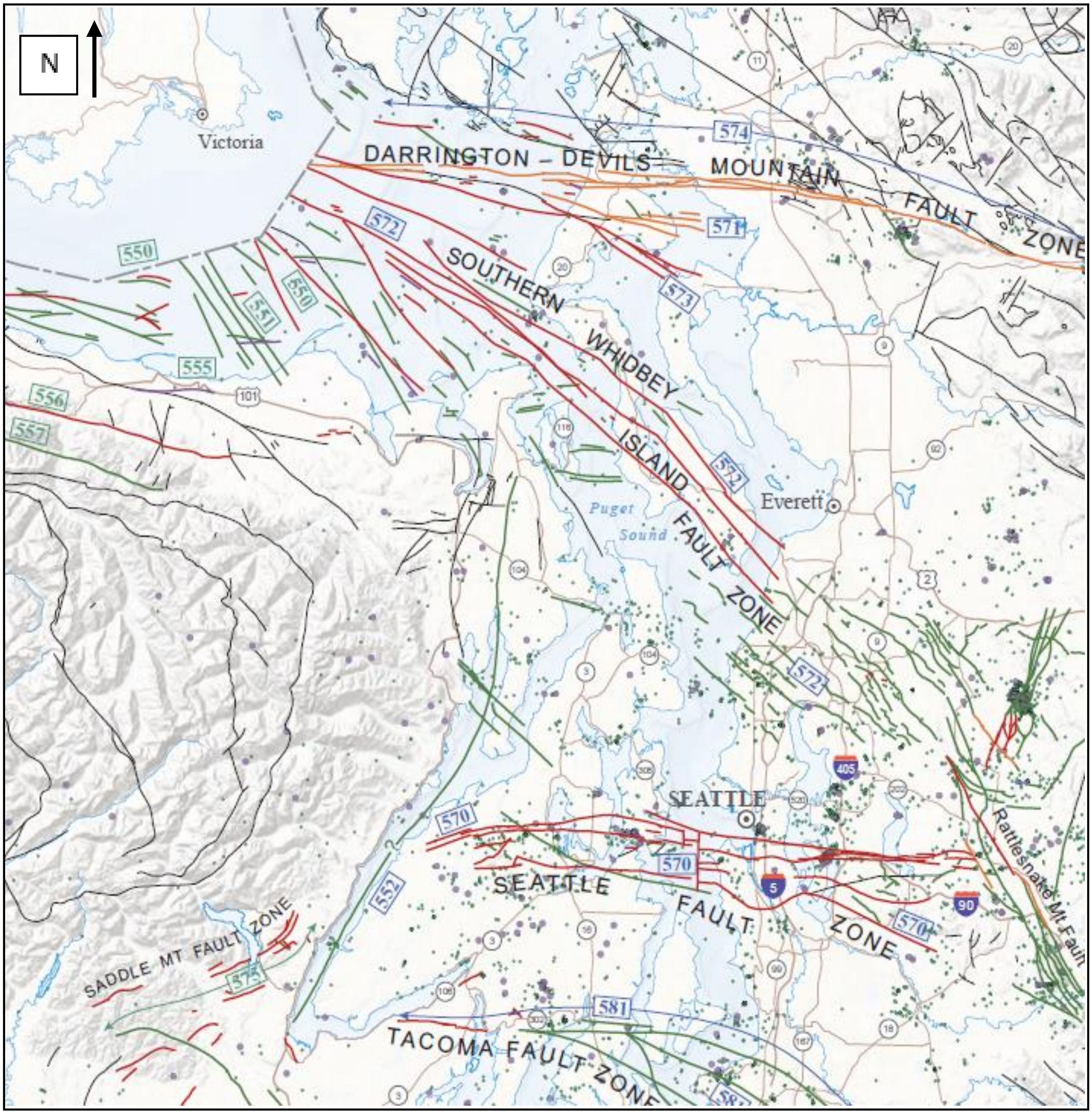
1943 U.S. Army vertical aerial photo of Fort Worden. Compare this to the 1935 photo. Battery Tolles is well hidden. Note how close Battery Walker is to the shore 8 years later than in the previous photo. Also note the pile of something dark at the white arrow, offshore of a cleared area where there was once a pond – and the beach sand(?) passing from the west. What are those bare spots to the east? These also show up in the 2006 WDOE photo on page 9.

The upper-bluff ledges are less well exposed in this photo than in the previous one. Battery Ash is south of the bluff top in the alcove (see the air photos). This is where the fort's largest guns were fired. The vibration of repeated shots was sufficient to disturb the bluff sediment, and the alcove rim has been slowly moving south for years.

Why is there a bend or dogleg in the shoreline at the top edge of this photo? In general, the North Beach shore is linear and soon straightened out after debris slides. The "point" at the dogleg is protected by accumulated boulders, but are they enough to maintain it in the long term? We'll return to this question on page 15.

At the star is the Port Townsend Marine Science Center Marine Exhibit. Note the relatively starved beach east of the pier. (See also page 9.)

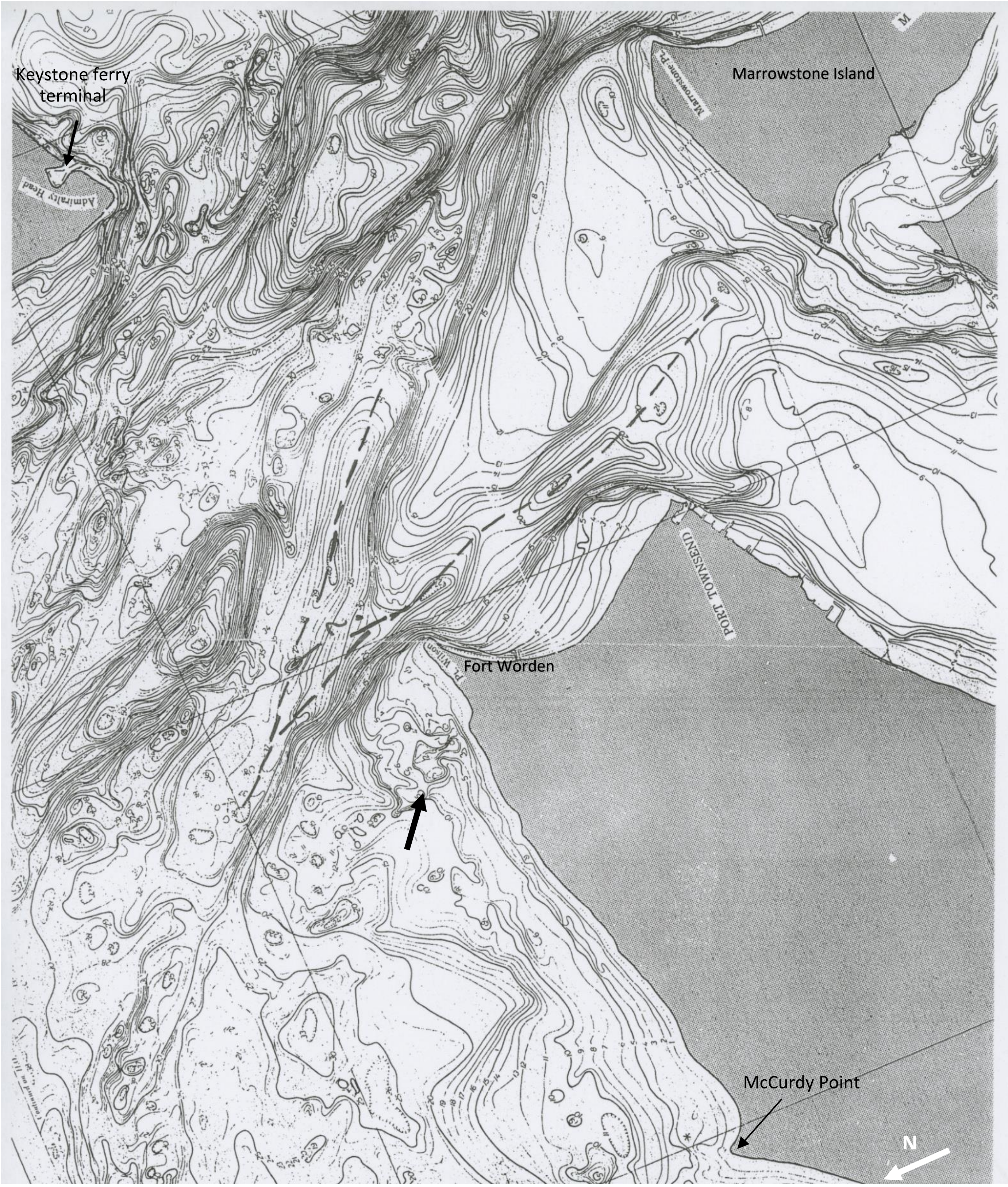
On the next pages are maps that show where the region's faults are. More faults are being found annually, but on the Quimper Peninsula, none (that we know of) breaks the surface where we can see it. Does the seismicity of this part of the peninsula affect the topography? Lidar images (http://lidarportal.dnr.wa.gov) offer a helpful perspective on the area's glacial past and hold a few clues to fault activity.



This map shows **some of the faults** identified in northwest Washington. (Yes, the faults continue into Canada.) The major fault zones are named; many of their constituent faults are shown in red. There is current seismic activity on these zones. The faults shown in black or green help define the structure of the Olympic Mountains. They do not affect the story at North Beach but indicate the complex structure of the area.

The numbers in small rectangles refer to features in the Washington Geological Survey's GIS map layers. The gray dots are earthquake epicenters. The larger the dot, the larger the quake magnitude. (Map prepared by C. Serdar Tepper in 2017.)

Note that the strands of the Southern Whidbey Island Fault Zone (SWIF) are subparallel to the Point Wilson bluff face along the campground. The SWIF is currently mapped as inferred (not yet proven to be where mapped); a western strand crosses Point Wilson.



Part of an old bathymetric map (compiled by the U.S. Coast and Geodetic Survey for the Hydrographic Office, U.S. NAvy, 1st ed. 1953) **of the east part of the Quimper Peninsula**. Land is the gray shading. The dashed lines (drawn by ?) locate possible faults. This map predates mapping on the previous page, but notice that the trace of the west fault branch is subparallel to the east-facing bluff, where the shore is shaped by that longshore current. What is the relation of the bathymetry at the heavy arrow's tip to the bluff orientation? To the east of McCurdy (or Middle) Point, note the hints of a large landslide in the offshore contours there. The deep channels between Point Wilson and Admiralty Head were carved by water under the Vashon Puget lobe ice. (Contour interval is fathoms.)

Approaching LOCATION C. This was the view in September 2015 southwest from the sunken trees of the **North Beach bluff "corner".** The north edge has since lost a few feet. The contact (angled arrow) between the slope debris (colluvium) on the left and the gently west-dipping nonglacial Whidbey Formation (end note 3) is not a fault.

All sediment up the right/west side of this outcrop is Whidbey Formation fluvial sand and overbank deposits. This is the oldest geologic unit along North Beach. Neither its true base nor top is exposed, so we do not know exactly where we are in this thick formation. We also do not know where its north and south edges were. In many places along the bluff there is a gap (erosional and/or non-depositional) of at least 60,000 years between the "top" of the Whidbey Formation and advance outwash of the Vashon Glaciation. (See the section on page 5.)

At beach level up to about 7 feet is dense sandy clay. Over that is silvery gray "peat" (end note 4), flattened by the passage of Possession and Vashon ice (to ∽140 tons/ft^2). Fat arrows point to the base of the peat, which is the remains of a swamp in a wide floodplain. We only see a slice of it, so we do not know its area. Narrow, flat pieces of woody vegetation that stick out of the peat are compressed branches, bull rushes, and other plants. Subfossil (unmineralized) fresh-water snails, ostracods, seeds, and a vole molar found in the bluff near here indicate slow-moving, cool, fresh water and temperatures like those in southern Canada today. Pollen tells us that Douglas fir, hemlock, lodgepole pine, and alder grew here. No doubt it was both warmer and cooler than today during this long interglacial interval.

Location C is at the west end of the alcove. On the way there, we'll see that a lot of sediment is slipping down this usually damp slope. The trees and other vegetation just barely hold the slope's soil skin in place. (Compare this area to the stable, well-vegetated east-facing bluff at the "corner".) Some of what spills onto the beach is swept east by tides, and some covers the bottom of the shallow cove to the north. The cove is underlain by the sandy clay below the peat. The middle portion of the slide covers Possession and Olympia sediments. Anything left by the Possession Glaciation is hard to find/identify, and separating the Whidbey sediment from Olympia beds is difficult because they were deposited by similar agents during interglacial periods. (See the geologic map and section, page 4.) The upper 30± feet of the bluff here stands vertically and has only indistinct layering/bedding; it is likely Vashon till. Till that was at the surface of Artillery Hill has been rearranged by military construction. The slide area is seen best when the deciduous trees are bare.

At the left is the worn bite surface of a fragment of a Columbian mammoth tooth found in 2019 on the beach at the west edge of the alcove. The age of the earliest mammoth in Washington is unknown, but there are reports of mammoth remains from the Whidbey Formation. Which unit did this tooth came out of? (Photo by K. Enright)

Above. Bright blue **vivianite** ($Fe^{2+}{}_3(PO_4)_2 \cdot 8H_2O$) is common in Pleistocene organic material (such as the peat) and weathers to powdery gray dust.

The clay beneath the peat at the “corner” plays an important part in shaping the shoreline here. The peat/clay dips (slopes) west (and north) from the ‘“corner” to beach level. Notice that the peat is closer to beach level at the large white arrow on the right in the photo on page 14. Peat and the clay form the north edge of the landslide, and the clay supports all the sediment above it. Tides chew away on the north edge of the slide, but the clay remains as the margin.

At **LOCATION C**, the peat/clay rises again on the west side of the alcove. The clay surface at the dogleg is littered with boulders. The boulders help protect the dogleg, but they move along, probably sliding off to the north. The clay does the real protecting.

This gentle warp of bedding is a result of the regional east and north tectonic compression and rotation. The warping is recent, a “neotectonic” feature. The dogleg’s upwarp (anticline) and the “corner” will probably continue to look much as they do for a long time but will slowly lose ground on the north side. The dogleg appears in at least one mid-1800s map, suggesting it is not a new feature.

Right. Shiny Whidbey sub-peat clay peeks out among cobbles and boulders (as much as 2 feet in diameter) at the upwarped dogleg in June 2019. The cleaned-off clay is slippery, so it would be surprising to find a boulder in the same place after a week or so. (View is to the northeast.)

Left. This chunk of wood in clay is one of many exposed at low tide below the peat between Locations C and D. Pat Pringle (dendrochronologist) thinks it may be Douglas fir, a tree that was common in this area during Whidbey time. The peat is far more compressible than silt/clay, so the vegetation in the peat is flat, whereas this wood looks modern. The ruler is 6 inches long.

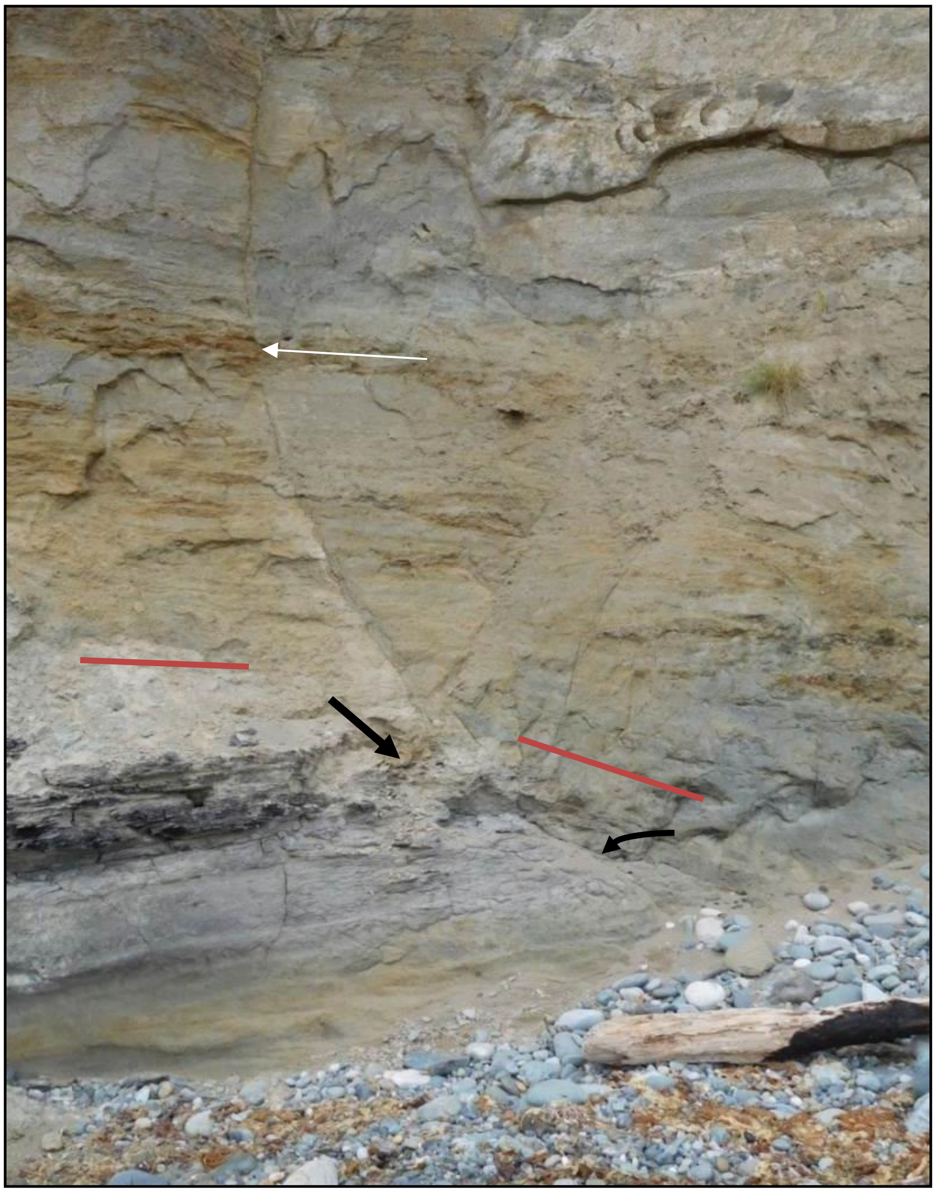
At **LOCATION D**, about 60 feet west of Location C, we see the west end of the peat. How was it cut off here?

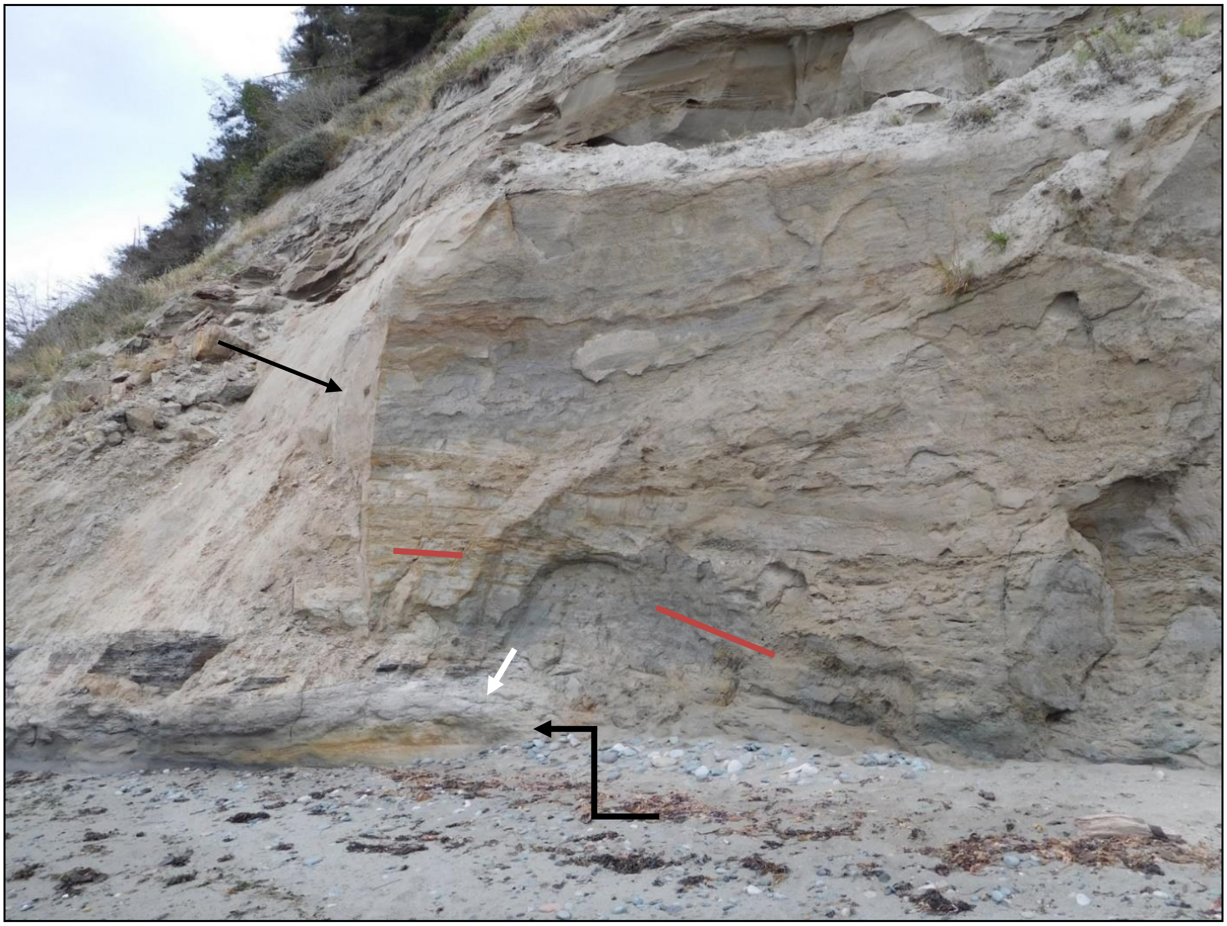
We've called this area "the droop". This photo was taken in 2019, and the features are gradually losing sharpness (see the next page). West is to the right. A crack (white arrow) separates sediment on the north from the bluff. On both sides of the crack is Whidbey Formation. It has been a plane of incipient failure, and, indeed, in 2021, some of the north side fell off. At the curved arrow, the clay above the peat sags down to the west, past the peat, where it is cut off. Indistinct bedding (red bars) crosses the crack there, with progressively less droop toward the upper part of the section. There are bits of flat peat in the lower part of the clay, and scattered pebbles cross the droop.

The black arrow points to the peat's end. The sandy clay below it looks just like the clay at the back at the "corner." The peat and the clay are supporting the bluff. The peat has dried (when?) and cracked. Look for clastic dikes (sediment-filled vertical cracks) in the peat.

What geological process might have cut the peat off here? And what allowed the clay above it to sag and become the beach-level layer? Perhaps an earthquake liquefied the sub-peat sandy clay and forced some of that sediment upward through the peat/clay layers, while at the same time, layers above the peat settled into the space left behind during injection, cutting off the peat and causing some to be eroded and spread off into the sediment accumulating or settling above. How close to the west edge of the "swamp" was that, and how local was the event?

The gray clay (photo E, page 21) to the right of the crack extends under the beach to the north. It also supports the bluff westward.





Here’s the droop area in mid-2021. The plane on the left (black arrow) is where some of the sediment on the north side of the crack slid off. The peat peeks out at the white arrow but is being eroded southward. How is the peat related to the location of the slippage on its west edge (angled arrow)? The east-west dip is a bit clearer in this photo than on the previous page, but notice that it does not continue upward. The gray silt/clay above the peat sags to beach level and continues west. As noted, there are bits of peat and pebbles in it.

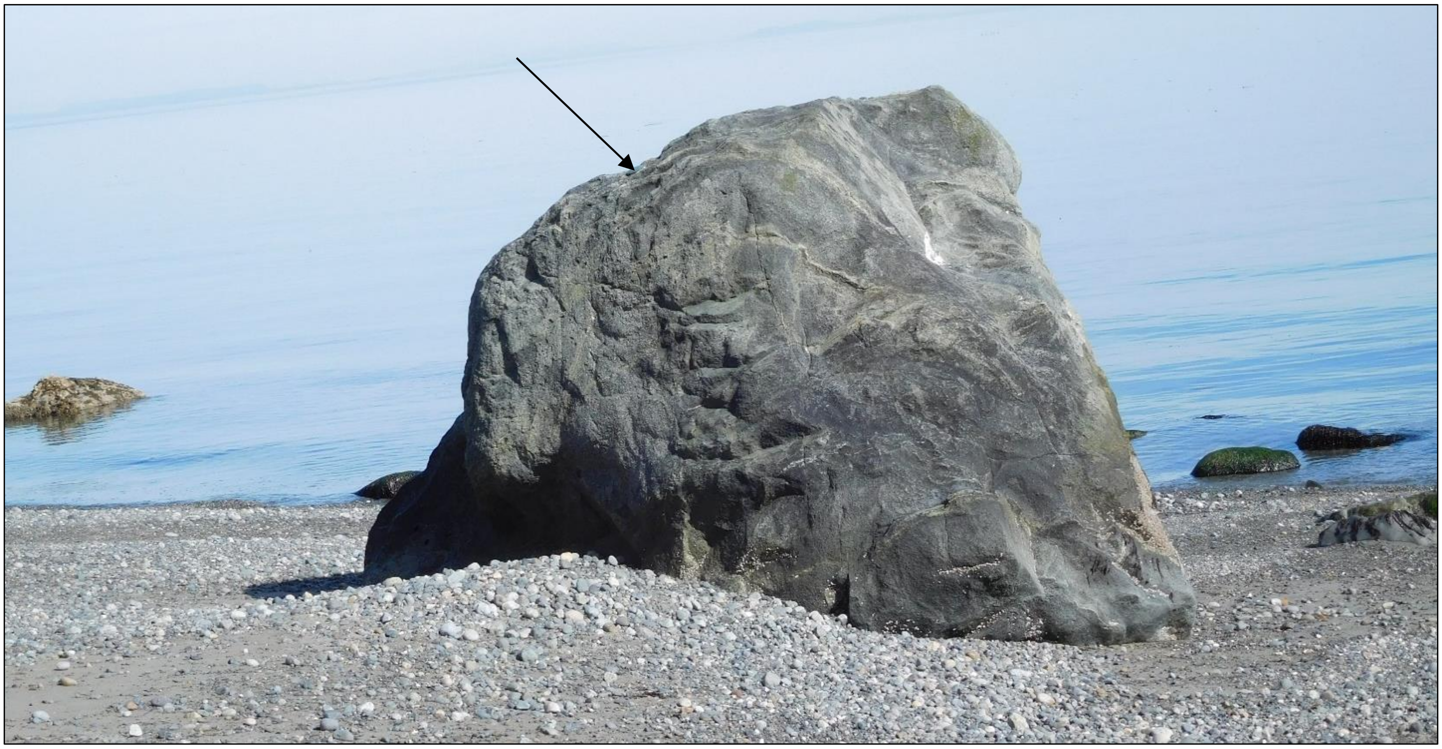
The gray silt/clay above the peat (also shown in photo E on the next page) extends north under the beach and holds up the bluff for perhaps 150 yards farther west. It seems to dip below the beach at that point.

The beach next to the bluff is rarely as clean as in this photograph. When the clay’s face is clean, it’s possible to see some folded beds, like those in photo E on the next page.

Signs of past seismic activity in the Whidbey Formation, west of the dogleg but east of Location D. All but photo **D** are/were at beach level. **A and C**, injection structures. Saturated sediment was liquefied by seismic shaking and forced up through cracks in the peat and into the overlying silty sand. These structures (**C** is double) were within 20 feet of each other, were of similar size, and had similar orientations. No trace of either remained in mid-2021. **B** and **E**, tight folding in sandy silt/clay. The folds in **B** are below the peat and extend ±20 feet west. They have appeared occasionally since at least 2005. How did **B** and **E** form? **E** is in drooped down from above the peat. In **E**, about 4 inches of the tent peg is exposed and is set about 3 inches in front of the folding. **D** is ball and pillow soft-sediment deformation, possibly caused by the sudden addition of heavy sediment atop a saturated bed. This swirling is exposed high in the bluff. In 2021 some was visible just below the possible contact of the Whidbey Formation with Vashon advance outwash.

LOCATION E. This ∽9-foot-high boulder, an **erratic,** is metamorphosed gabbro or basalt. The green color is due to minerals (*e.g*., chlorite, epidote, actinolite) created by the heat and pressure of metamorphism. A likely source for this rock is directly north in Canada, and many of the huge rocks along this beach to the west are of this rock type.

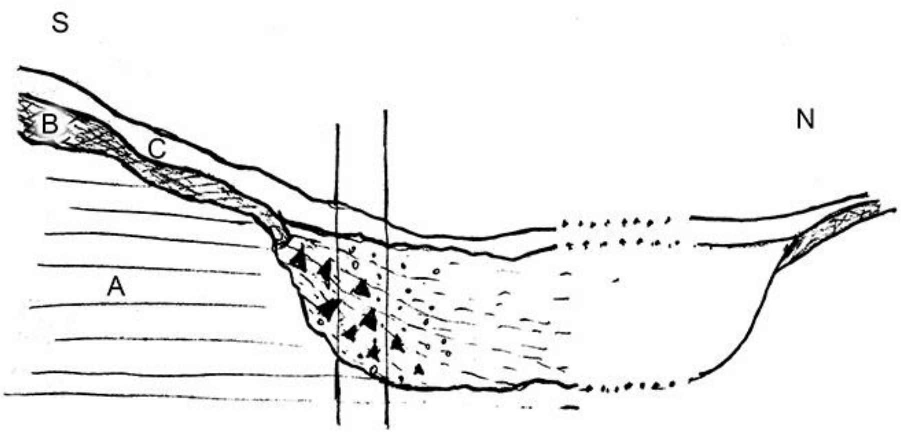
The boulder has a USGS benchmark medal on the top (at arrow and in the photo, right). Note the drilled holes on the lower west part of the boulder facing the bluff; they are in deep shade in this photo. (The view is to the north.)



The beach at this boulder is higher to the west (left) due to longshore sediment transport. Look for a slab of concrete in the gravel to the east; it used to be parked right next to the boulder. (2019 photo)

The USGS marker (or holes) would be a fine starting point for measuring bluff retreat if it were not for the constantly raveling tall bluff face opposite/south. Rarely is any part of the lower 20 feet of the bluff here without piles or a cover of slope debris. Lacking something more than intermittently clean to measure to, we cannot track the retreat rate. However, it's an academic question: No one will be building atop this bluff.

Left. Directly south of the erratic and high in the bluff is this 10-foot- wide clast of Vashon till. The line indicates the orientation of the vague bedding in the till. The clast seems to lie on bedded sediment, probably Vashon advance outwash, which can be seen across the indentation in the bluff to the west. Above and around this clast are smaller light brown chunks in well-bedded gravel. Trace the layer containing this clast and smaller ones to the east and west. This mix, the "jumble," is a diamicton of Everson age and extends from a little east of here all the way to the boat ramp (and far west of that).



Hypothetical section of this bluff from the south, to Whidbey Island on the north. We are walking *into* the diagram, parallel to the bluff (on the left), between the vertical lines. **A** is Whidbey fluvial sand; **B** is Vashon till; and **C** is the jumble (Everson diamicton) and glaciomarine drift. The triangles are clasts of till and Whidbey Formation carried to beach level by an outburst flood that picked them up as it cut across low land from Admiralty Inlet to shallow marine strait water. *No scale implied.* (2016 sketch by J. Dragovich; scanned by V. Brooks.)

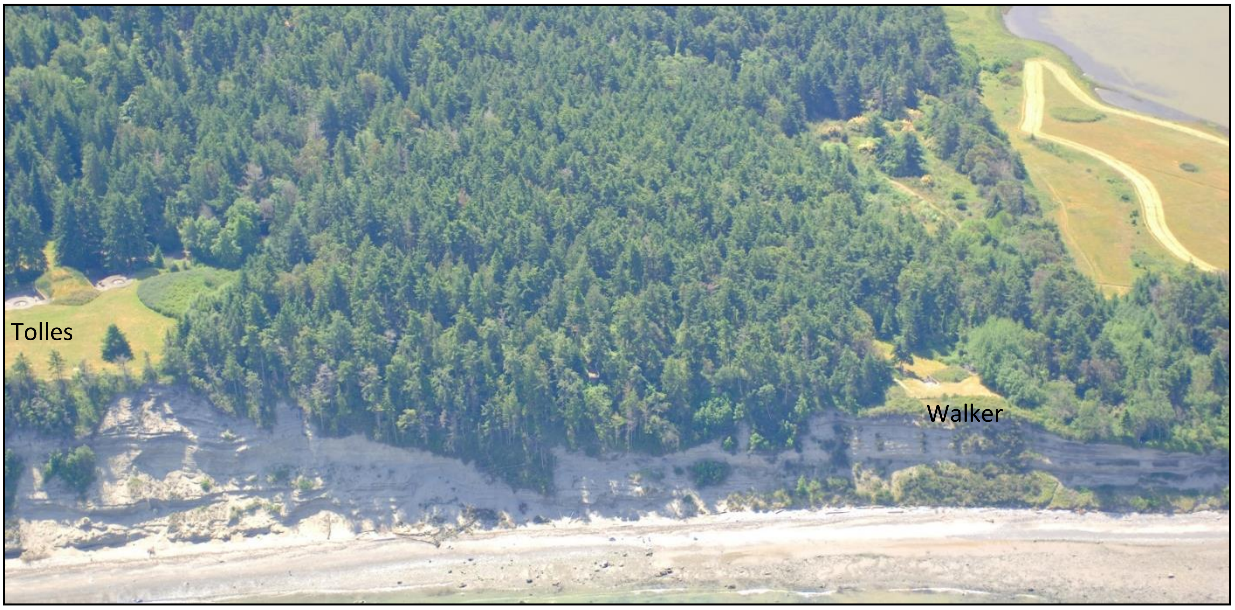
Exposed just west of this clast is brown-gray bedded sand, tentatively identified as Vashon advance outwash, the sediment that preceded the ice as it moved south. It lies below the jumble layer at bluff top and appears to be coarser than the Whidbey Formation below it. The (current) eastmost exposure of Vashon advance outwash on this walk is a little to the east of here.

The photo below left was taken about 40 feet east of the one above. The Vashon outwash outcrop above is at the **V**. Note the bench below it (vertical black arrows). This bench seems to mark the contact between the Whidbey and Vashon units. Is there any Olympia or Possession sediment here? Is this the layer seen in the military aerial photos? The bench is less distinct to the west.

As we walk west, notice the many types of bedding in the fine Whidbey. Below is some cross-bedding, indicating a shift in the current position in the wide flood-plain. The largest pebble is about 3 inches across, so some pulses of water were able to move fairly large rocks.

Above are yesterday's *wind ripples* (west wind) on sand that has slid down to the beach. Crest-to-crest distance is about 2 inches. **Right** is the lower face of a chunk of fine Whidbey sediment fallen to the bluff base. These *water ripple marks* are about 2.5 inches between crests, not as sharp, and about 100,000 years older than the sand ripples.

In **Whidbey Formation alluvium** west of the Vashon outwash outcrop, the layers of sand have cut into one another, showing that the stream channels were actively changing their positions. The arrow indicates rip-up clasts—small, flat chips of silt/clay that were lifted off the bottom of a dry channel when a subsequent current came along and moved them downstream. The whole pile seems to dip gently north as you will see if you stand close to the bluff and look west. Most of the scattered pebbles have fallen out of sand layers to where they are in this photo. Sand with the reddish tint contains oxidized iron. The vertical bar is about 8 inches long. (2015 photo)



This bluff area includes Batteries Tolles and Walker, view south. (**LOCATION F** is nearer Tolles than Walker.) Compare this photo with the 1935 and 1943 vertical aerial photos. In the past decade, the bluff has lost much of its once-extensive vegetative cover. Since this 2006 WDOE photo, the bluff at Walker has retreated closer to the concrete installation. Military records show that large chunks fell off along here, probably helped along by having had the most shells fired at this battery. (Ordinarily, we would expect to see slow raveling and a debris slide now and then.) The Whidbey Formation/Everson jumble contact (photo below) is a little west of this; it is covered in the photos in this WDOE aerial oblique photo series. (See https://apps.ecology.wa.gov/shorephotoviewer/Map/ShorelinePhotoViewer for photos taken in other years.)

LOCATION G. The upper bluff a little west of Battery Walker in 2017. The jumble (diamicton) of Everson age (see the table, page 6) lies against the source for the Whidbey Formation clasts. The force of the water cutting into the silty sand on the left was enough to wedge off large (probably frozen) clasts and fill voids with gravel. The brown chunk at the long arrow was once part of the edge at the short arrow. The jumble appears to be a sort of talus pile accumulated in shallow water. The gravel probably came from Vashon lodgement (basal, smeared) or ablation (accumulated from melting in place) till. The talus/jumble continues *at least* 50 feet north offshore, evidence of southward bluff retreat. As we walk west, try to distinguish clasts of till from Whidbey chunks.

This is the contact area in mid-2021. No clast in the 2017 photo can be identified, but the massive gray sand bed is still at the contact. Note the bedded gravel just under the vegetation. The contact is probably a little east of where it was four years ago; erosion has also removed a few feet from the north face.

Right: The chunks on the left edge of this photo are those in the photo on the top of the next page. The white arrow shows the slope of the ephemeral top of what appears to be a thin brown silty clast/layer. This suggests the overall dip of the jumble diamicton (probably an outburst flood deposit).

Below is a 10-foot-wide slab of brown Whidbey silt/clay, one of several that lay at beach level a little west of Location H after a storm in 2019. It is not yet clear if the flood deposit continues below the beach or if this brown sediment is the local floor of the diamicton jumble. There are several brown layers in the Whidbey that this might have come from, but transport of such a large clast for any distance seems unlikely. This clast eroded away in about 24 hours.

The Whidbey Formation is not indurated – it can easily be carved with a stick. The fact that large and small chunks of the Whidbey remained intact after being moved perhaps hundreds of feet from the contact carved by the outburst flood or from the surface it crossed suggests that they were frozen at the time.

Location H. In the left photo (May 2014), a **Whidbey Formation clast** (~4 ft wide) about 300 feet west of the boat ramp is surrounded by finer diamicton (jumble) fragments and gravel. In 2019 it protruded from the bluff a foot or so. In 2021, the north part broke off and slid beachward (right photo). The arrows on the photos point to the same part of the rectangular clast east of it. The long axis of the round clast seems to have been embedded in the bluff. Its remaining portion is closer to the vertical (broken) chunk on its left. The large round clast obstructed westward flow, and other clasts came to rest upstream of it. The overall dip of the jumble is westward, signaled also by imbrication (overlap) of other clasts. See also the photo at the right margin on the previous page.

Notice that the gravel layers are not continuous along the bluff; some pinch out against others. This suggests more than one pulse of debris came from the east-side source.

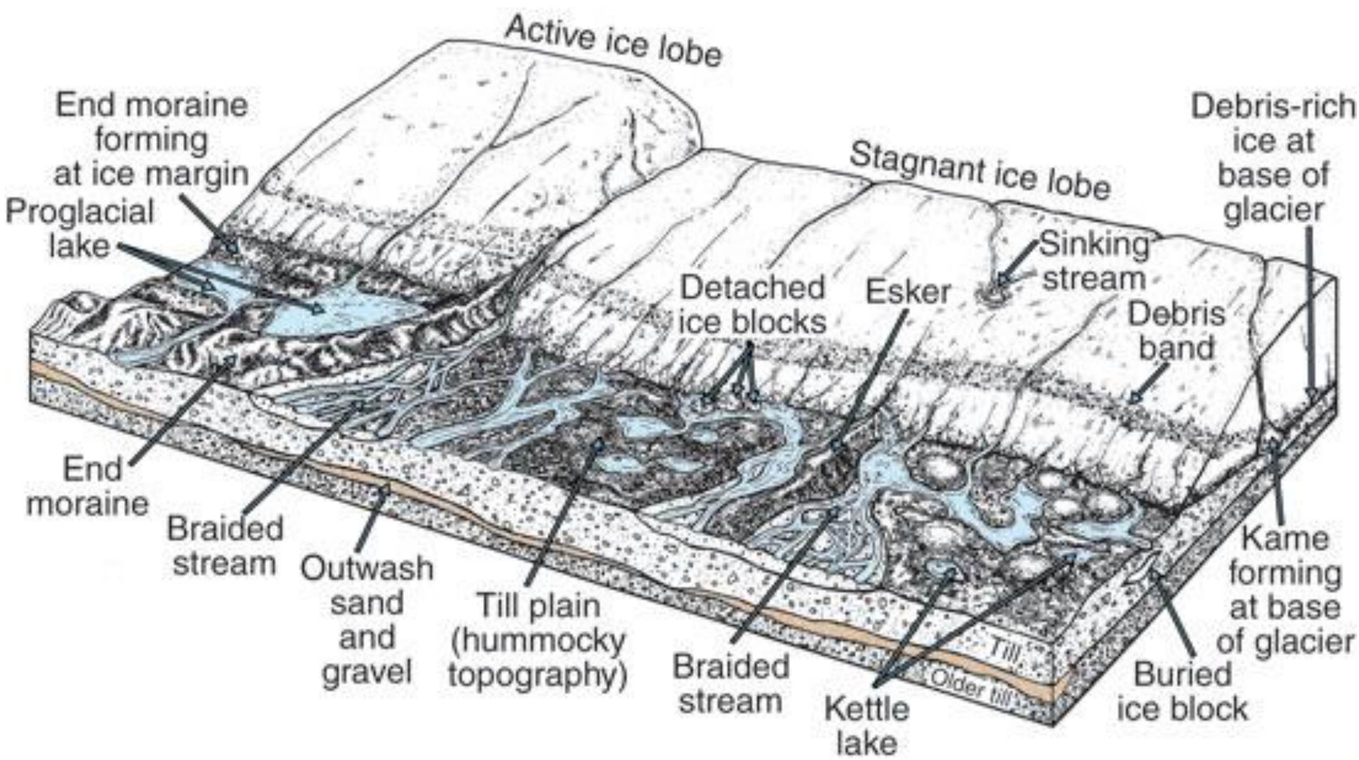
The star is at a layer of glaciomarine drift (gmd). It is fine silt that was deposited in (mostly) quiet water, probably under ice cover. Dropstones occur where icebergs tip over and drop their load of rocks. Because dropstones are rarely found here, the ice cover may have been intact when this gmd was deposited. The gmd is exposed up to and beyond the boat ramp.

Directly under the bluff-top vegetation and thin soil is dark brown Holocene **loess**. (See the table on page 6.) Note the uneven surface on which it rests. There's not enough discrete carbon in the loess to consider radiocarbon dating. Where exposed at the surface, the loess lies over and among cobbles left behind as a lag when the till surface was eroded meltwater from ice stranded ice during/after the Everson Interstade.

This 3-foot-long clast hints at the force of the water (or slurry) carrying it northwest. Gravel was forced into the split at the left edge, and the block was smashed into another clast, shattering the upper corner. The fine Whidbey sediment could not have remained relatively intact under the force of the collision unless it had been frozen. (2016 photo)

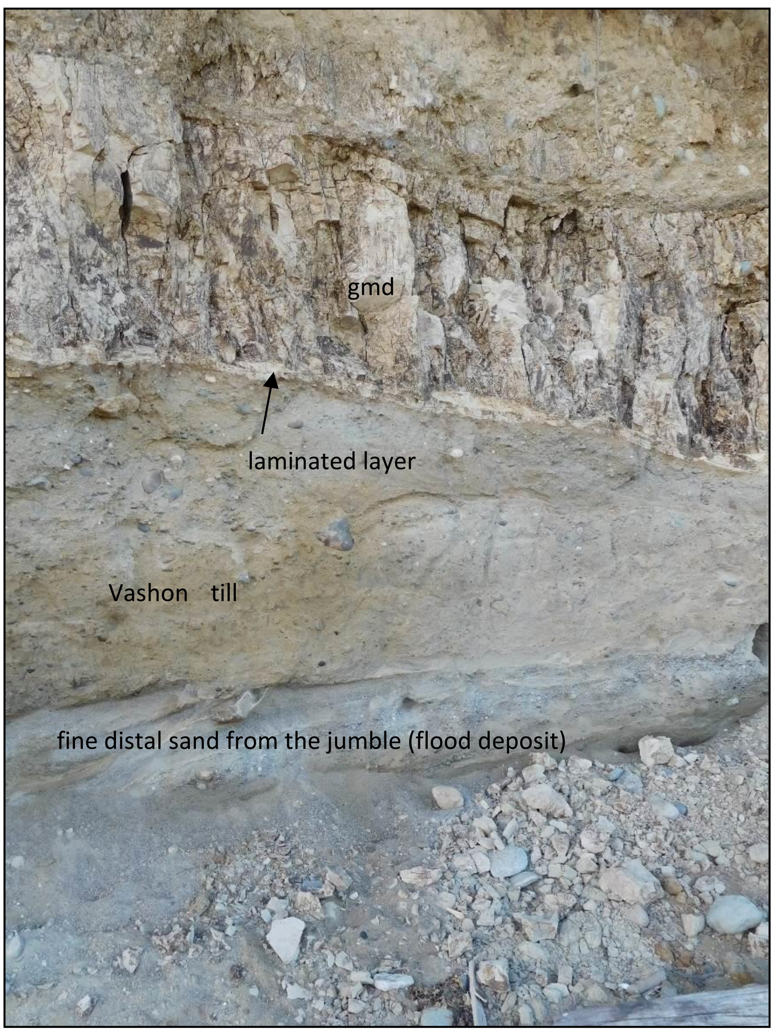
>>>Across the strait, near the west edge of Whidbey Island here, is a breached kettle called Cedar Hollow. It is the large tree-filled dip in the line of the bluff top. A kettle forms when a stranded block of ice slowly melts in place while other sediment accumulates around it and insulates it. Whidbey Island has many kettles here. This may be the site of a late Everson outburst flood from Penn Cove to the strait during which icebergs were grounded. (This event was discussed by Eric Cheney in 2015.) Lidar images of this area can be found at https://lidarportal.dnr.wa.gov/. *The hollows remaining today are partly filled with debris that slumped off their edges. Cedar Hollow is mostly filled by Holocene dune sand (this having been a warmish, dryish time). In 1991, parts of a brown bear skull (10,000 cal yr BP) were found near the bottom of this breached kettle. Amazingly, more parts of that skull/teeth were found there in 1993. (See Mustoes' papers listed in the references.)*

The irregular top of the Whidbey bluff west of Ebey's Landing is Holocene dunes. Sand was blown up the bluff face from the southwest. The dunes buried a forest and are, in turn, being overtaken by trees. This vegetated, stable east part of the bluff is protected by Perego's Lagoon; contrast that area with the eroding bluff face to the west.



Area of **LOCATIONS G and H.** This block diagram illustrates the active **depositional environment** of the Everson Interstade along the shore of the Strait of Juan de Fuca (or what can be seen now in Glacier Bay, Alaska) – it was constantly changing. The area beyond the ice front would have been shallow marine water. Imagine a flood from the left lifting the ice and rushing under it to the shoreline, probably also ice covered. (Accessed in 2017 from the Kansas Geological Survey's website)

While we are not looking at beach rocks on this walk, it's hard to ignore the many varieties and shapes. In these two photos, the results of centuries of sandblasting by the tides are apparent: smooth north sides and overall well-rounded forms. The boulder above is about 3 feet high, and its long axis parallels the bluff. Take time to notice how few large beach rocks are *not* well rounded.



We first paid attention to the gmd near the large Whidbey clasts in gravel (see page 27). The section in this 2021 photo is about 170 feet east of the old boat ramp. The weathering of the gmd makes it look vaguely columnar, a hallmark of gmd along the eastern strait. The geologic term for this is hackly weathering. The gmd here lies below a gray-brown, loose, unsorted but till-like mix (diamicton) that suggests strong currents, perhaps under ice. How is it related to the outburst flood deposit? (See the next page.) Below the gmd is an inch-thick layer of finely laminated silt that indicates deposition in quiet water. It is common at the base of gmd in this area. Below that is Vashon sandy till that contains sparse rounded pebbles. It makes up some of the clasts in the jumble/flood deposit we have been following and tells us that (some part of) the flood happened during the Everson Interstade.

At beach level is sand of the distal edge of a pulse of the jumble, where it ran out of energy and contained only smaller particles. Here, the jumble and gmd are interlayered, so they overlap in time. The relative positions and thicknesses of these units change as the bluff erodes and looks different after each storm.

This hash of small subfossils (no shell material replaced by minerals) is in a swirl of sand and gravel in the midst of gmd. Note the cobble at the white arrow, which might be a dropstone. This outcrop was about 150 feet east of the boat ramp in 2016, but it was entirely washed away in the winter of 2021. The lower photo shows the kinds of shells that were in it. *Mytilus edulis* (blue mussel) shells are at either side. These bivalves attach themselves to rock by byssal threads. (There are still large rocks offshore at a shallow depth.) The top three shells are small *Panomya* (probably *P*. *ampla*; note the characteristic tooth at the hinge). The four elongate shells are *Hiatella arctica. H. artica* has a huge geographic range today, can be found in mussel beds, and attaches to rocks with byssal threads. These species indicate cold water, which we would expect in waning glacial times. The mix hints at turbulence strong enough to have scraped the shells off their substrates.

At **LOCATION I** is the **“wandering rock”** in 2015 (left photo). Thorsen chose this >1-ton granitic rock as a point from which to record bluff retreat at the white arrow. The rock used to sit on the slippery gmd and was occasionally shoved toward and away from the bluff. Thorsen’s photos over the years show that the rock wandered from ∽6 to >40 feet from the bluff. It slid off the gmd onto sandy-pebbly diamicton (or till?) in 2001 and did not move until, in a 2016 storm, it rotated slightly and crept a bit bluff-ward. In 2015, the rock was 43.5 feet from the bluff (white arrow below). In late April 2017, the rock’s “peak” was ∽44 feet from the point indicated. In July 2021 the distance was 47 feet. How far is it today? (Wind plays havoc with keeping a tape straight and level.)

After a February 1999 storm (**right photo**), logs came to rest by the rock, probably having shoved it up/along the beach. During a later storm, other logs bashed the rock and rotated it about 30 degrees while moving it along the beach. Note the position of the sand on the bluff face. The black arrows in the two photos point to the same place on this boulder. Reliable measurements have been possible only since 2001, after the boulder fell off the gmd and stopped wandering.). Logs could still move it…

This is the view east from the county park’s boat ramp of the **gmd beach surface** after an April 2013 mid-tide storm had removed sand and gravel. Note that the remaining coarser beach cover swings away from the bluff to the east. The beach surface there consists of non-slippery sand, mainly jumble diamicton. In the cove at the ramp, gmd extends north (left) under the beach. (Photo by Varn Brooks)

The row of rocks crossing the beach (arrow) cover(ed) the outfall pipe from the water treatment plant (secondary treatment. Only a small area of rocks remained in 2021—at breaks in the pipe that are visible at low tide and where water burbles up. The city plans to replace this outfall at a location west of the boat ramp.

LOCATION J. The old boat ramp acts as a barrier to the longshore current. Sand and gravel pile up on its west side. The east side is starved. In the mid-2010s, the natural transit of beach sand and gravel removed the support of the concrete slab on the east side of the ramp, and some of it collapsed. That process is on-going.

The lowest exposure of the gmd on this walk is in the area of the boat ramp. We know it is a marine deposit because of the presence of marine shells and rare benthic foraminifera. The amount of postglacial land-surface rebound of the land surface can be approximated in the park area by locating the highest exposure of this youngest marine sediment in the messed-up surface of Artillery Hill. There is probably at least 200 feet of rebound, similar to that across the strait on Whidbey Island. The level (sub-dune) top of the high bluff on Whidbey was once the Everson strait seafloor.

On some Whidbey Island hillsides, well-defined shorelines hint at sudden uplifts during rebound. (Check for them on Google Earth.) We can’t see shorelines along at North Beach because several thousand feet of southward erosion, as well as development by both the park and city, have erased such hints of exciting times.

The lagoon south of here is underlain by recent peat (not swamp debris as in the Whidbey Formation) and gmd that defeated a recent attempt to core its bottom so as to find tsunami deposits. The location and configuration of the shore in 1700 when the last Big One occurred is anyone’s guess—certainly, it was farther north then. Today, a tsunami 10 or 12 feet high could flood the lagoon area and leave some traces.

This guide (revised in September 2021) evolved from unpublished information developed by Gerald Thorsen (1933-2009), who spent years walking this beach before the Everson jumble was so fully exposed. This version of the guide reflects contributions from and reviews by area geologists and members/advisors of the Quimper Geological Society. Particular thanks to Hugh Shipman, Pat Pringle, Joe Dragovich, Carol Serdar Tepper (who prepared the cover and provided some of the photographs), Michael Machette, Shelley Jaye, Keith Norlin, Wendy Gerstel, Tim Lawson, Steve Mader, and Varn Brooks. Gail Workman gave this an eagle-eye edit. Alfred Chiswell gave us historical information and access to images from the Fort Worden archives; Kevin Alexander explained effects of the military installations. The guide is not copyrighted, but credit would be appreciated.

End Notes

1. The semi-precise dates given in this guide are based on analyses of carbon isotope ratios. Radiocarbon (^{14}C) dates can be reported in two ways: raw and calibrated. Both have ranges of error that lead to ages that fall somewhere within a certain number of years and can be made more precise by comparing many dates from the same or nearby roughly coeval materials. The amount of ^{14}C in the atmosphere has varied globally with time, thus affecting the isotopic ratios used to calculate an age. Graphs that show the variations aid in converting the raw date into the most probable calibrated date (still with error range). *In general*, calibrated dates older than 10,000 years are about 2000 years older than the raw dates. For example, the first dates for the Manis mastodon were around 12,000 yr BP *(e.g.,* Kirk and Daugherty, 2007); the current calibrated date is 13,800 yr BP (Waters *et al*., 2011). This kind of date is often presented as cal yr BP. BP means ‘before present’; by convention, ‘present’ is 1950.

2. Glaciers do not move backward. Recession is a process of melting in place, shrinking, wasting away. A glacier (lobe) snout melts and appears to recede. The land surface is gradually relieved of its stagnant ice cover. "Retreat" is a poor term for this process but is ingrained.
3. What we call peat in the Whidbey Formation here is not the classic bog peat of Canada, Scotland, and Ireland, which is mostly sphagnum moss. Whidbey peat is an accumulation of woody vegetation at a swamp or oxbow lake that has been compressed by passing ice. The peat near the lagoon (see cover photo) is similar to bog peat.
4. Units that geologists deem mappable (for whatever purpose) are assigned names, most of which refer to some geographic feature near where they were first intensively studied. The interglacial deposit at the "corner" is named for Whidbey Island. Unsurprisingly, the Fraser Glaciation was named for the Canadian river, the Vashon deposits for the island near Seattle, the Double Bluff Glaciation and its deposits for that location on Whidbey Island, and the Possession Glaciation for Possession Point on Whidbey's southern tip. There is a protocol for establishing a geologic name. Names that have gone through this process, like the aforementioned, are considered "formal." An example of an informal unit is the Olympia-age deposits of the table on page 6. Literature discussing deposits of this age should refer to them as Olympia beds or an Olympia interglacial unit until the name is made formal. Lower-case letters for a unit label show that it is not a formal name. This nicety is often ignored, confusing readers and mappers.

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The Survey's library's catalog is at: https://www.dnr.wa.gov/programs-and-services/geology/washington-geology-library#search-the-library-catalog.The library has a large collection of theses about Washington's geology, as well as of Washington geo-lit. The librarian (*aka* Public Information Geologist) can be reached at 360-902-1473. The library doesn't loan.