WASHINGTON STATE DEPARTMENT OF
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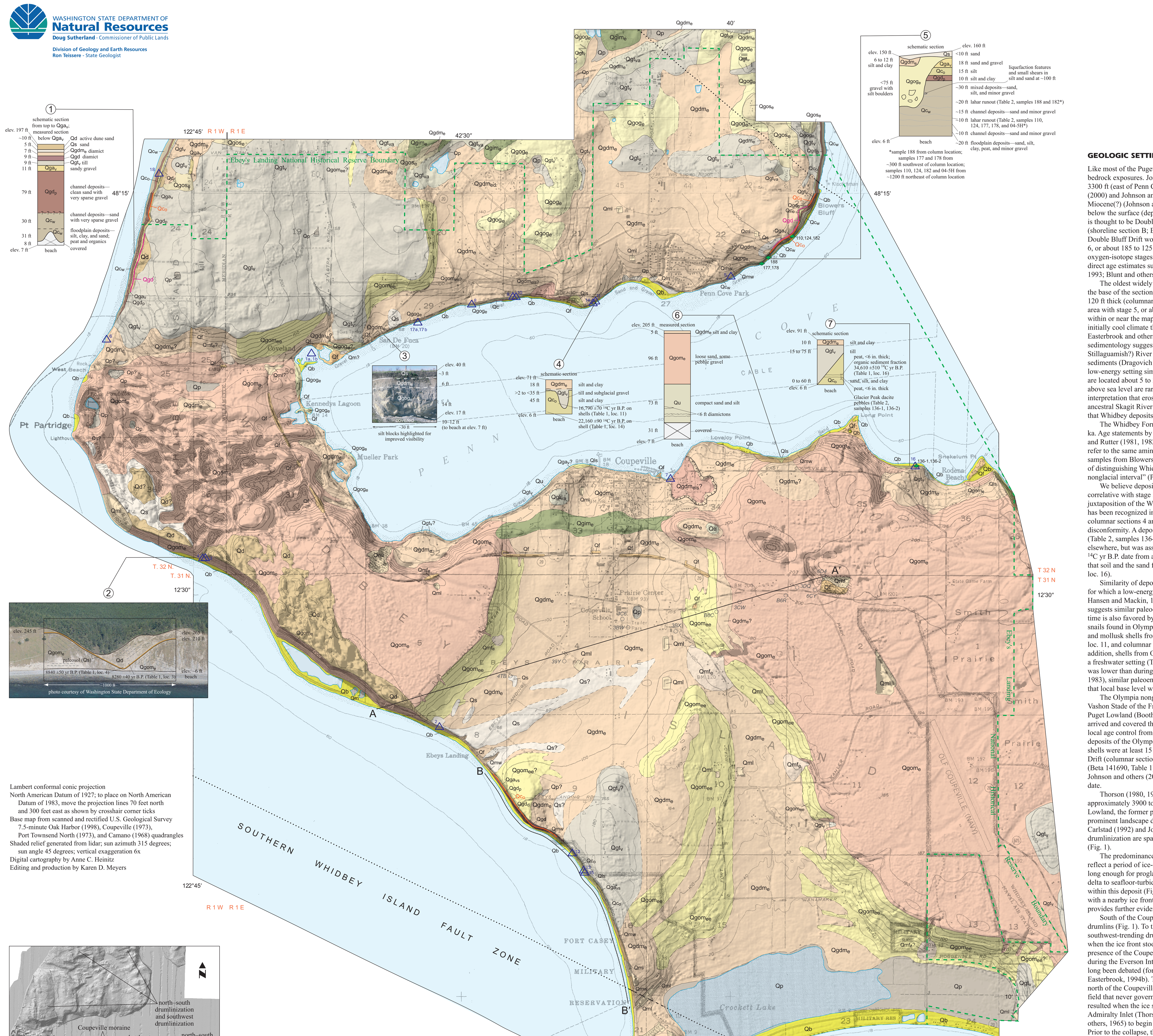
WASHINGTON DIVISION OF GEOLOGY AND EARTH RESOURCES
OPEN FILE REPORT 2005-2

Geologic Map of the Ebey's Landing National Historical Reserve, Island County, Washington

by Michael Polenz, Stephen L. Slaughter, Joe D. Dragovich, and Gerald W. Thorsen

June 2005



Lambert conformal conic projection
North American Datum of 1927; to place on North American Datum of 1983, move the projection lines 70 feet north and 300 feet east as shown by crosshair corner ticks
Base map from scanned and rectified U.S. Geological Survey 7.5-minute Oak Harbor (1998), Coupeville (1973), Port Townsend North (1973), and Camano (1968) quadrangles
Shaded relief generated from lidar; sun azimuth 315 degrees; sun angle 45 degrees; vertical exaggeration 6x
Digital cartography by Anne C. Heinitz
Editing and production by Karen D. Meyers

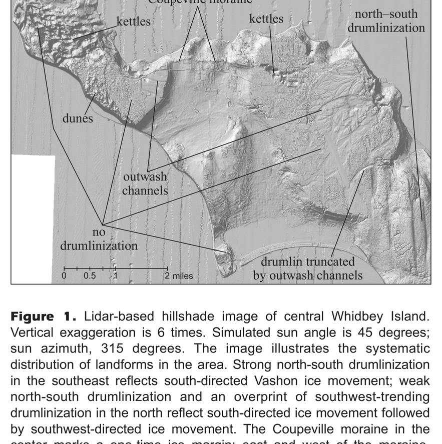
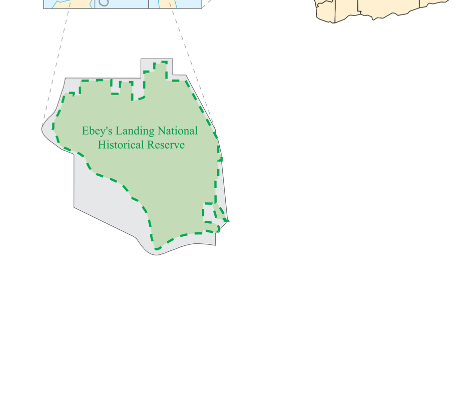
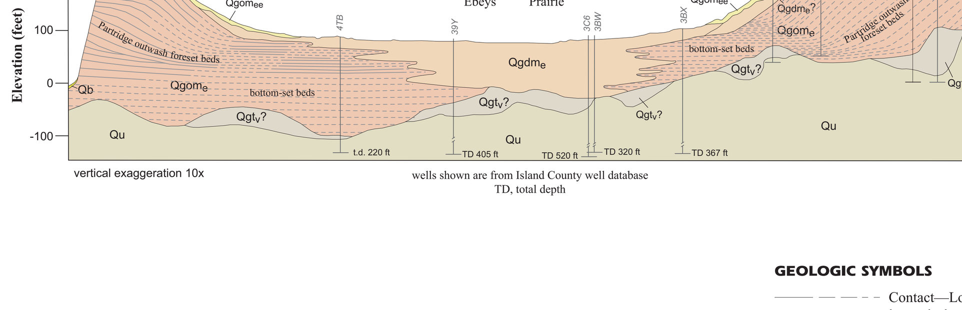
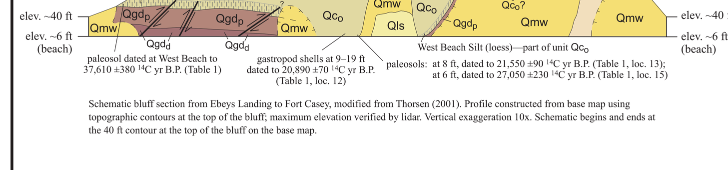


Figure 1. Lidar-based hillshade image of central Whidbey Island. Vertical exaggeration is 6 times. Simulated sun angle is 45 degrees; sun azimuth, 315 degrees. The image illustrates the systematic distribution of landforms in the area. Strong north-south drumlinization in the southeast reflects south-directed Vashon ice movement; weak north-south drumlinization and an overprint of southwest-trending drumlinization in the north reflect south-directed ice movement followed by southwest-directed ice movement. The Coupeville moraine in the center marks a one-time ice margin; east and west of the moraine, elevated outwash terraces with braided relict channels and kettles reflect ice-proximal, marine-deltaic deposition of Partridge Gravel outwash. Smooth lowlands north and south of the moraine represent paleo-sea floor.







Schematic bluff section from Ebeys Landing to Fort Casey, modified from Thorsen (2001). Profile constructed from base map using topographic contours at the top of the bluff; maximum elevation verified by lidar. Vertical exaggeration 10x. Schematic begins and ends at the 40 ft contour at the top of the bluff on the base map.

GEOLOGIC SYMBOLS

- Contact—Long dashed where approximately located, short dashed where inferred
- Fault, unknown offset—Dashed where inferred, dotted where concealed
- Qgd, Qc$_o$ Geologic unit too narrow to show as a polygon at map scale
- Landslide scarp—Hachures on downslope side; dashed where approximately located
- 178 Geochemistry sample location
- 17 Radiocarbon date sample location
- B6R Water well

BLUFF SECTION B–B′ ONLY

- Dip-slip motion on fault—Arrows show apparent relative motion

Table 1. Age control data from the map area and surrounding areas. New analyses for this report were performed by Beta Analytic, Inc. (Miami, Fla.). Uncertainty values preceded by '±' are one standard deviation (68% confidence interval); age ranges reported as two numbers separated by a dash span two standard deviations (95% confidence interval). 'Cal yr B.P.' is calibrated age in calendar years before 1950 as reported by lab or prior publication; 'ka' is thousands of calendar years before 1950. Ages less than 1000 Cal yr B.P. are converted to AD. Ages are 'conventional' (adjusted for measured ^{13}C/^{12}C ratio) if a ^{13}C/^{12}C ratio is shown; other entries may be 'measured' or 'conventional'. Elevations are estimated in feet above mean sea level; elevations in quotation marks are as reported by referenced sources (we converted some from metric). AMS, accelerator mass spectrometry

Loc. no.	^{14}C yr B.P.	Cal yr B.P. (or ka)	Material dated	Geologic unit	Sample no.	Elev. (ft)	Reference	Notes
WITHIN MAP AREA								
1a	140 ±40	AD 1660–1950	Douglas Fir (?[1]) wood	tidal estuary	Beta 199432	±2	This report	AMS analysis of 7th-outermost tree ring; ^{13}C/^{12}C = -22.1‰
1b	170 ±40	AD 1650–1890; or 1910–1950	Douglas Fir (?[1]) wood	tidal estuary	Beta 202078	±2	This report	AMS analysis of 89th- to 99th-outermost tree rings; ^{13}C/^{12}C = -23.7‰
(combination of above dates)		AD 1740–1790; or 1810–1960	Douglas Fir (?[1]) wood	tidal estuary	n.a.	±2	This report; Oxcal v3.9 (Ramsey, 1995, 2001; Ramsey and others, 2001)	Age of tree death implied by combination of Beta 199432 and 202078 (for method see Ramsey and others, 2001)
2	935 ±110		marine shells	Qs	I-1093	near "90"	Trautman and Willis (1966)	Collected by D. J. Easterbrook, 1963
3	8,280 ±40	9,420–9,130	vole bone[2]	Qd	Beta 199434	50–65	This report	AMS analysis; ^{13}C/^{12}C = -20.2‰
4	8,840 ±50		deer vertebra	Qd	GX-25892-AMS	~30–40	Mustoe and others (*in press*)	AMS analysis; ^{13}C/^{12}C = -21.9‰
5	11,850 ±240		marine shells	Qgdm$_e$	I-1448	"ca. 10"	Easterbrook (1966a,b)	Elevation from Trauman and Willis (1966)
6	12,535 ±300		shells	Qgdm$_e$	I-1079	"0–15"	Easterbrook (1966a,b)	Elevation from Trautman and Willis (1966)
7	12,640 ±150		shells in diamict	Qgdm$_e$	USGS 1304	"3"	Dethier and others (1995)	Collected by E.W. Domack
8	13,010 ±170		shells	Qgdm$_e$	UW-32	10?	Easterbrook (1966a,b)	Some references report date as 13,100 ±170
9	13,090 ±90		marine shells	Qgdm$_e$	PC-02	~20	Swanson (1994)	Swanson advocates a 400 yr reservoir correction and suggests that best age estimate is therefore 12,690 ±90 ^{14}C yr B.P.
10	13,230 ±90		marine shells	Qgdm$_e$	PC-01	~10	Swanson (1994)	Swanson advocates a 400 yr reservoir correction and suggests that best age estimate is therefore 12,830 ±90 ^{14}C yr B.P.
11	16,790 ±70	20,480–19,530	freshwater(?) shells[3]	Qc$_o$	Beta 199431	25–30	This report	AMS analysis; ^{13}C/^{12}C = -10.1‰
12	20,890 ±70		freshwater shells[4]	Qc$_o$	Beta 199429	9–19	This report	AMS analysis; ^{13}C/^{12}C = -4.0‰
13	21,550 ±90		paleosol	Qc$_o$	Beta 169087	8	Gerald Thorsen (consulting geologist, written commun., 2004)	Date courtesy of Kurt Koger (Associated Earth Sciences, Inc.); location verified by Koger (oral commun., Feb. 2005)
14	22,160 ±90		bivalve shell	Qc$_o$	Beta 199430	10	This report	AMS analysis; ^{13}C/^{12}C = -15.5‰
15	27,050 ±230		paleosol	Qc$_o$	Beta 169086	6	Gerald Thorsen (consulting geologist, written commun., 2004)	Date courtesy of Kurt Koger (Associated Earth Sciences, Inc.); location verified by Koger (oral commun., Feb. 2005); stratigraphically overlies West Beach silt facies
16	34,610 ±510		organic sed. in peat	Qc$_o$	Beta 199433	35	This report	Conventional 14C analysis; ^{13}C/^{12}C = -27.8‰
18	37,610 ±380		paleosol	Qc$_o$	Beta 154508	148	Gerald Thorsen (consulting geologist, written commun., 2004)	Date courtesy of Gerald Thorsen and Kitty Reed; located on West Beach, at base of (aeolian) West Beach silt facies of unit Qc$_o$
17a	11,060 ±185		peat bed	?	UW 33	"a few ft"	Trautman and Willis (1966)	Date erroneous due to lab contamination; reanalyzed as I-1446
17b	>33,200		peat	Qc$_w$	I-1446	<5?	Easterbrook (1968)	Reanalysis of UW-33
WITHIN OR NEAR MAP AREA (LOCATION INSUFFICIENTLY DOCUMENTED)								
		106 ±17 ka	clay	Qc$_w$	BBLF-4	<15	Berger and Easterbrook (1993)	Thermoluminescence dating analysis from "Blowers Bluff"
OUTSIDE BUT NEAR AND PERTINENT TO MAP AREA								
	13,650 ±350		shell	Qgdm$_e$	Beta-1319	79	Dethier and others (1995)	Located at Whidbey Island Naval Air Station, Oak Harbor (lat. 48°19'25" N, lon. 122°39'9" W)
	15,190 ±220	18,985–17,435	organic laminae	Qc$_o$	Beta 141690	?	Johnson and others (2001)	Utsalady Point, 7 mi east of Blowers Bluff (lat. 48°15'25" N, lon. 122°30'13" W); Johnson and others (2001) caution that date may be too young
		77 ±6 ka	shells	Qc$_w$	79-9	~49	Kvenvolden and others (1980)	Amino acid, 2.8 mi south of map area (lat. 48°07'30" N, lon. 122°36'00" W)

[1] Wood tentatively identified as Douglas fir (*Pseudotsuga menziezii*) by Patrick Pringle (Wash. Div. of Geology and Earth Resources, oral commun., Feb. 2005), who added that it might be pine.

[2] Based on photos, location and date, skull bones and teeth identified by Richard Johnson (Wash. State Univ., written commun., Dec. 2004) and John Fleckenstein (Wash. Dept. of Natural Resources, written and verbal communs., Nov. 2004 to Feb. 2005) as microtine rodent(s) (voles), specifically, *Microtus townsendii*, *Microtus oregoni*, *Microtus longicaudus*, or *Microtus oeconomus*, with a small chance of *Microtus miurus*.

[3] Shell fragments after extraction from sediment too small for positive identification; probably mollusks similar to those from loc. 12, implying a quiet freshwater setting.

[4] Shells identified by Liz Nesbitt (Univ. of Wash., written commun., 2005) as freshwater mollusks, including *Pisidium* pea-clams, implying a lacustrine or pond setting, and viviparid snails (*Viviparus* or *Lioplax*), implying well-oxygenated lake or stream setting.

GEOLOGIC SETTING AND DEVELOPMENT

Like most of the Puget Lowland, the map area is dominated by glacial sediment and lacks bedrock exposures. Jones (1999) inferred between 1800 ft (west of Point Partridge) and 3300 ft (east of Penn Cove) of unconsolidated deposits in the area; Mosher and others (2000) and Johnson and others (2001) used geophysical data to suggest that the top of Miocene(?) (Johnson and others, 1996) bedrock in the map area is about 1150 to 2600 ft below the surface (depending on location). The oldest sediment exposed in the map area is thought to be Double Bluff Drift, which is found at beach level south of Ebeys Landing (shoreline section B; Easterbrook, 1968; Thorsen, 2001). Based on stratigraphic position, Double Bluff Drift would likely date to marine oxygen-isotope stage (hereinafter "stage") 6, or about 185 to 125 ka (thousands of calendar years before 1950) (references to oxygen-isotope stages in this report are as defined in fig. 4 of Morrison, 1991), although direct age estimates suggest that some exposures may be older (Berger and Easterbrook, 1993; Blunt and others, 1987; Easterbrook, 1994a,b).

The oldest widely exposed unit is the interglacial Whidbey Formation, which forms the base of the section along West Beach and Blowers Bluff, where it is as much as about 120 ft thick (columnar section 5). We believe the formation to be correlative in the map area with stage 5, or about 125 to 80 ka, based on stratigraphic position and dates from within or near the map area (Table 1). Pollen within the Whidbey Formation suggests an initially cool climate that warmed later during Whidbey time (Hansen and Mackin, 1949; Easterbrook and others, 1967; Heusser and Heusser, 1981). Petrography and sedimentology suggest that a south- to west-flowing(?) ancestral Skagit (or Stillaguamish?) River extended into the map area and deposited the Whidbey Formation sediments (Dragovich and others, 2005, and petrographic studies from this project) in a low-energy setting similar to the modern lower Skagit River, flood plain, and delta, which are located about 5 to 20 mi northeast of the map area. Exposures of Whidbey deposits above sea level are rare or absent in the map area south of Penn Cove, inviting the interpretation that erosion has largely obliterated Whidbey sediments there, or that the ancestral Skagit River may have reached a lake or the sea in the vicinity of Penn Cove, so that Whidbey deposits never were deposited south of Ebey's Landing.

The Whidbey Formation is overlain by Possession Drift of stage 4 or about 80 to 60 ka. Age statements by Easterbrook (1994 a,b), Blunt and others (1987), and Easterbrook and Rutter (1981, 1982) range between 50 to 80 ka and 80 ±22 ka. However, all appear to refer to the same amino acid-based analyses, some of which were reportedly derived from samples from Blowers Bluff. Possession Drift in many locations provides the only means of distinguishing Whidbey sediment from very similar, younger "deposits of the Olympia nonglacial interval" (Pessl and others, 1989).

We believe deposits of the Olympia nonglacial interval in the map area to be correlative with stage 3 or about 60 to 20 ka (Morrison, 1991; Table 1). No direct juxtaposition of the Whidbey Formation and deposits of the Olympia nonglacial interval has been recognized in the map area, but the lower parts of some bluffs (for example, columnar sections 4 and 7) may include Whidbey Formation beneath an unrecognized disconformity. A deposit east of Long Point contains Glacier Peak volcanic pebbles (Table 2, samples 136-1 and 136-2) and strongly resembles Whidbey Formation deposits elsewhere, but was assigned to the Olympia nonglacial interval based on a 34,610 ±510 ^{14}C yr B.P. date from a soil upsection and the lack of a recognized unconformity between that soil and the sand from which the pebbles were sampled (columnar section 7; Table 1, loc. 16).

Similarity of deposits of the Olympia nonglacial interval to the Whidbey Formation, for which a low-energy freshwater paleoenvironment is well-documented (see above; Hansen and Mackin, 1949; Heusser and Heusser, 1981; Easterbrook and others, 1967), suggests similar paleoenvironments. A similar setting in the map area during Olympia time is also favored by the freshwater, low-energy habitat requirements of clams and snails found in Olympia nonglacial sediments south of Ebey's Landing (Table 1, loc. 12) and mollusk shells from similar sediments along the north shore of Penn Cove (Table 1, loc. 11, and columnar section 4) (Liz Nesbitt, Univ. of Wash., written commun., 2005). In addition, shells from Olympia sediments in the map area have ^{13}C/^{12}C ratios that suggest a freshwater setting (Table 1, locs. 11, 12, 14). Because global sea level during stage 3 was lower than during Whidbey time (for example, Ludwig and others, 1996; Bloom, 1983), similar paleoenvironments suggest either that local tectonic history is complex, or that local base level was elevated during stage 3.

The Olympia nonglacial interval ended when advance outwash sand and gravel of the Vashon Stade of the Fraser Glaciation (Armstrong and others, 1965) (stage 2) buried the Puget Lowland (Booth, 1994). Porter and Swanson (1998, fig. 4) suggested that ice arrived and covered the map area approximately 18 ka. That assessment is consistent with local age control from a 20.48 to 19.53 ka date (Table 1, loc. 11) from shell material in deposits of the Olympia nonglacial interval along the north shore of Penn Cove. The shells were at least 15 to 20 ft beneath an unconformable contact with overlying Vashon Drift (columnar section 4). A separate date of 18.99 to 17.44 ka in Olympia deposits (Beta 141690, Table 1) is similarly consistent with ice arrival about 18 ka, although Johnson and others (2001) noted that sample contamination might have compromised this date.

Thorson (1980, 1981, 1989) indicated that Vashon ice thickness reached approximately 3900 to 4300 ft in the map area. In surrounding areas of the Puget Lowland, the former presence of that ice is reflected in widespread lodgment till and prominent landscape drumlinization. In contrast, our mapping and the prior work of Carlstad (1992) and Jones (1999) show that in and near Coupeville, lodgment till and drumlinization are sparse, whereas glaciomarine drift and recessional outwash dominate (Fig. 1).

The predominance in the map area of glaciomarine drift and outwash appears to reflect a period of ice-margin stabilization at Coupeville (Carlstad, 1992), which lasted long enough for proglacial meltwater to deposit the Partridge Gravel, a marine, kame-delta to seafloor-turbidite deposit (Easterbrook, 1968; Carlstad, 1992). Kettles formed within this deposit (Fig. 1) where stagnant ice was buried by outwash and are consistent with a nearby ice front (Carlstad, 1992). A west-trending moraine in Coupeville (Fig. 1) provides further evidence for a local ice front.

South of the Coupeville moraine, a distinct north-south alignment dominates drumlins (Fig. 1). To the north, this north-south drumlinization is overprinted with southwest-trending drumlinization (Fig. 1). We suggest that this difference reflects a time when the ice front stood at Coupeville, and that deposition of Partridge Gravel, the presence of the Coupeville moraine, and the southwest drumlinization favor the presence during the Everson Interstade of grounded ice north of Penn Cove, a concept that has long been debated (for example, Armstrong and Brown, 1954; Domack, 1983; Easterbrook, 1994b). The secondary drumlinization suggests that for a time, grounded ice north of the Coupeville moraine flowed southwest and was therefore subject to a stress field that never governed ice south of the map area. We speculate that this stress field resulted when the ice sheet collapsed across the eastern Strait of Juan de Fuca and Admiralty Inlet (Thorson, 1980), thus allowing the Everson Interstade (Armstrong and others, 1965) to begin as sea water entered ice-free areas below relative paleo–sea level. Prior to the collapse, the ice across the Strait of Juan de Fuca confined ice flow in the Puget Lowland to a north-south direction. The collapse removed that confining pressure in the central to northern Puget Lowland, thus triggering a reorientation to the southwest of ice flow in and north of the map area, as recorded by the overprint of southwest drumlinization north of the Coupeville moraine (Fig. 1).

The ice collapse across Admiralty Inlet that marked the onset of the Everson Interstade in the map area appears to have occurred before deposition of a shell that yielded a 13,650 ±350 ^{14}C yr B.P. date, which is the oldest date from nearby glaciomarine drift (Table 1; Dethier and others, 1995). The sample location for this date is 5 mi north of the map area. If the hypothesis of a temporary, grounded ice margin at Coupeville and coeval formation of southwest-trending drumlinization north thereof is correct, then the ice sheet north of Coupeville persisted for some time after it had collapsed across Admiralty Inlet (Thorson, 1981; Waitt and Thorson, 1983). It follows that ice collapse across Admiralty Inlet may have occurred significantly before deposition of the shell that yielded the 13,650 ^{14}C yr B.P. date.

The presence around Penn Cove of substantial glaciomarine drift (columnar sections 3–7), marine terraces(?) (Carlstad, 1992), and relict shorelines (Carlstad, 1992) suggests that deposition of the Partridge Gravel was completed and Penn Cove became ice-free early in the Everson Interstade, likely before deposition of the above-mentioned shell that provided the oldest known date of 13,650 ±350 ^{14}C yr B.P. (Table 1) for the Everson Interstade. This reinforces the suggestion that the Everson Interstade locally may have begun significantly before deposition of the shell.

Southwest-directed outwash channels (Fig. 1) are apparent in Partridge Gravel on the upland surface surrounding Smith Prairie. Similar features on the upland surface northwest of Ebeys Prairie indicate south- to east-trending paleoflow (cross section A). Both cases require a vigorous sediment source to the north, where Penn Cove had to be ice-filled to permit transport of this sediment into the depositional area (Carlstad, 1992). We suggest that this sediment source is partly documented by a high-energy outwash gravel unit (unit Qgog$_e$), which locally grades up into Partridge Gravel, and which we interpret as mostly subglacial flow deposit.

The Partridge Gravel outwash channels east and west of Ebeys Prairie terminate at a slope break, which represents the upper slope break of marine kame-delta fronts prograding into Ebeys Prairie (Carlstad, 1992) and therefore approximates paleo–sea level (Thorson, 1981). Consequently, we agree with Carlstad (1992) that Ebeys Prairie was sea floor on which glaciomarine drift was deposited while Partridge Gravel was deposited to the east and west. The two units interfinger and grade into each other beneath Ebeys Prairie (Carlstad, 1992; cross section A). Together, the two units fill irregularities in an underlying surface that may represent the subglacial topography that preceded the Everson Interstade incursion of marine water (cross section A).

Partridge outwash channels truncate some drumlins (Fig. 1), implying that a former till plain was locally obliterated by the meltwater that deposited the Partridge Gravel. However, some till plain likely remains preserved beneath Ebeys Prairie and the Partridge Gravel (cross section A). A partial underlayment of till plain is supported by well records southwest of Penn Cove, weak drumlinization(?) at relatively low elevation southeast of Ebeys Landing and around the Coupeville moraine (Fig. 1), and till exposures along the bluff south of Ebeys Landing (shoreline section B).

The maximum Everson Interstade sea level had previously been estimated at up to 196 ft (Thorson, 1980; Carlstad 1992). Regional contouring suggested that it did not exceed 230 ft (Thorson, 1981). We suggest that it rose to at least between 216 and 229 ft, based on deposits of glaciomarine drift about 220 ft above sea level (3300 ft south of Lovejoy Point).

Aside from the above-mentioned shell that suggests that the Everson Interstade began before 13,650 ^{14}C yr B.P., the age of the Everson Interstade in the map area is further defined by six radiocarbon dates from locally collected samples (Table 1, locs. 5–10). The interstade ended locally when post-glacial crustal rebound exceeded global sea level rise, causing the land in the map area to emerge. We agree with Swanson (1994) that an age estimate of 12,690 ^{14}C yr B.P. (Table 1, loc. 9) from the upper end of glaciomarine drift at 10 ft above sea level along the north shore of Penn Cove likely provides the best estimate for the end of the Everson Interstade in the map area, but others have favored other dates (Dethier and others, 1995; Easterbrook, 1966a,b; Blunt and others, 1987).

Since the end of the Everson Interstade, the landforms and deposits in the map area have changed little, except for dune development (Fig. 1), which must have begun by about 10 ka (shoreline section 2; Table 1; Mustoe and Carlstad, 1995; Mustoe and others, *in press*) and continues along the western shore, and shoreline erosion that began when sea level approximated modern sea level in the mid-Holocene (Kelsey and others, 2004; Mosher and Hewitt, 2004; Hutchinson, 1992).

STRUCTURE

No demonstrably tectonic fault scarps have been mapped onshore, but the map area is tectonically active. Gower (1980) used gravity, aeromagnetic, and well data to infer a northwest-trending "Southern Whidbey Island Fault" with possible Quaternary movement; his structure crosses southern Whidbey Island near Lagoon Point (six miles southeast of Admiralty Head) and enters the Coupeville quadrangle about two miles south of Admiralty Head. Wagner and Wiley (1980) used geophysical data to extend it to west of Point Partridge as a Holocene fault and added multiple subsidiary(?) faults and folds, some of which are truncated by the Southern Whidbey Island fault. They also showed a queried Holocene(?) fault extending from the Southern Whidbey Island fault east to the shore south of Ebeys Landing, where multiple north-dipping thrusts are exposed in pre-Vashon sediment but do not appear to penetrate the Vashon deposits (shoreline section B). More recently, Johnson and others (1996) characterized the Southern Whidbey Island fault as a heterogeneous and broad (4-7 mi wide), long-lived, transpressional zone that trends northwest (310°), dips near-vertically to steeply north-northeast, and can be traced for over 43 miles. They noted that it separates two major crustal blocks, has been the source of several historic, shallow crustal earthquakes, and appears capable of generating large (surface-wave magnitude 7 or greater) earthquakes. Kelsey and others (2004) attributed 3 to 7 ft of uplift of Crocket Lake 2800 to 3200 years ago to an inferred moment-magnitude 6.5 to 7 earthquake on the Southern Whidbey Island fault zone. According to Brian Sherrod (U.S. Geological Survey, oral commun., 2005) recent trenching investigations suggest a "reasonable likelihood" of four—and a "possibility" of up to eight—postglacial earthquakes with ground deformation along the fault zone, such that it is now recognized as "one of the most active, documented shallow crustal faults in the Puget Lowland". The fault strands shown on this map are from Mosher and others (2000). The short strand that heads southeast from Admiralty Head coincides with shears in glacial deposits at Admiralty Head; however, these shears may be glaciotectonic.

Dragovich and others (2005) inferred a concealed, northwest-trending, poorly defined pre-Vashon-age(?) fault, the southeastern end of which we show in the northeast corner of the map area. North of and parallel to that unnamed structure, they showed another fault which they named the Oak Harbor fault.

Johnson and others (2001) and Dragovich and others (2005) showed the Utsalady Point, Strawberry Point, and Devils Mountain fault (zones) a few miles north of the map area. These three fault (zones) compose a west-trending "active complex, distributed, transpressional deformation zone" (Johnson and others, 2001) that has uplifted Pleistocene strata in the Oak Harbor area relative to those in the map area (Dragovich and others, 2005). The implied north-up deformation may extend into the map area—Whidbey Formation strata at West Beach seem to dip about 0.7 degrees (apparent) to the south, which is anomalously high for the inferred low-energy paleoenvironment (see Geologic Setting and Development) and suggests post-depositional, south-down tilting. However, such down-to-south tilting appears unlikely to extend south of Penn Cove, because no consistent southerly dip is apparent in Olympia nonglacial deposits south of Penn Cove. In addition, (pre-Whidbey) Double Bluff deposits are exposed south of Ebeys Landing but have not been noted further north in the map area, and a south-down, apparent tilt slope of 0.06 degrees in the upper slope break of the kame delta front east of Ebeys Prairie matches the regional, postglacial rebound tilt in the Puget Lowland (Thorson, 1989) and therefore need not imply a Holocene, southern extension of the Pleistocene deformation seen to the north.

Trenching of the Utsalady Point fault (Johnson and others, 2003) suggested possible postglacial fault offset between AD 1550 and 1850. A submerged log sampled during this study at the northwest end of Penn Cove may have been tectonically lowered into the intertidal zone sometime between AD 1740 and 1790, or between 1810 and 1960 (Table 1, loc. 1); local history suggests it occurred prior to 1850. If so, the event would appear to require a minimum surface lowering of 4.5 ft at the site. Such deformation would be consistent with the above-mentioned down-to-south tilting of Pleistocene strata north of Penn Cove and may be consistent with Johnson and others' postulated AD 1550 to 1850 event. Further documentation and examination of the Penn Cove log would provide more information on the timing and magnitude of the surface lowering but exceeds the scope of this project.

Table 2. Geochemical analyses from the map area, and average geochemical values for samples from central and northern Whidbey Island and for Glacier Peak–sourced samples from elsewhere. Analyses were performed by Washington State University GeoAnalytical Laboratory (Pullman, Wash.). Major elements are normalized on a volatile-free basis, with total Fe expressed as FeO. Each analysis from this study represents a single clast of vesicular dacite or dacitic pumice. Inductively coupled plasma mass spectrometry (ICP-MS) values for sample 124 are averages of two analytical runs. Elevations are estimated in feet above mean sea level. Differences between our chemical values for unit Qc$_w$ and those previously published by Easterbrook (1994a) likely reflect Easterbrook's use of electron microprobe as opposed to the x-ray fluorescence (XRF) and ICP-MS we employed. "Average of 20 Whidbey Island volcanic clasts" represents the average of single-clast analyses of vesicular dacite to dacitic pumice pebbles from the Oak Harbor and Coupeville areas. Average includes 12 dacite clasts from the Whidbey Formation in the Oak Harbor area (Dragovich and others, 2005) and all samples from this table, except sample 188 (excluded as outlier that may reflect an altered clast or different source). "Average of 107 Glacier Peak dacite clasts from elsewhere" is from Dragovich and others (2005)

Sample no.	136-1	136-2	110	124	177	178	04-5H	182	188	Average of 20 Whidbey Island volcanic clasts	Average of 107 Glacier Peak dacite clasts from elsewhere
Location	East of Long Point, sand with sparse volcanic pebbles		Blowers Bluff, lower lahar run-out					Blowers Bluff, upper lahar run-out			
Elev. (ft)	16-26	16-26	40-45	45-50	50-55	43-57	~50	55-70	70		
Geol. unit	Qc$_o$	Qc$_o$	Qc$_w$	Qc$_w$	Qc$_w$	Qc$_w$	Qc$_w$	Qc$_w$	Qc$_w$		
MAJOR ELEMENTS NORMALIZED (XRF; in weight percent)											
SiO_2	65.82	65.05	66.87	67.15	66.47	66.00	66.20	66.13	64.80	65.57	65.09
Al_2O_3	16.64	16.34	15.94	16.11	16.39	16.26	16.23	16.30	16.55	16.52	16.62
TiO_2	0.590	0.637	0.577	0.540	0.564	0.594	0.590	0.595	0.695	0.60	0.59
FeO*	3.79	4.33	3.89	3.48	3.64	3.88	3.89	3.91	3.99	3.96	4.03
MnO	0.074	0.087	0.083	0.074	0.071	0.077	0.17	0.075	0.084	0.08	0.083
CaO	4.60	4.85	4.13	4.18	4.41	4.56	4.30	4.50	5.11	4.66	4.79
MgO	1.92	2.40	1.89	1.74	1.84	2.09	1.980	1.98	2.43	2.12	2.31
Na_2O	4.16	3.92	4.05	4.16	4.11	4.06	4.13	4.03	3.96	4.07	4.12
K_2O	2.25	2.21	2.41	2.43	2.35	2.32	2.35	2.33	2.20	2.27	2.04
P_2O_5	0.159	0.169	0.157	0.145	0.149	0.155	0.16	0.159	0.179	0.16	0.155
Total	100.00	100.00	100.00	100.00	100.00	100.00	99.993	100.00	100.00		
Unnorm. Total	99.14	98.67	98.69	98.70	98.72	97.80	98.77	98.69	98.65		
TRACE ELEMENTS (XRF; in parts per million)											
Ni	16	17	18	15	14	17	22	15	20	19.44	18
Cr	16	20	17	14	16	18	16	19	29	19.36	18
V	75	90	77	69	73	78	81	83	81	83.57	81
Ba	552	529	586	586	575	567	606	569	551		
Ga	17	18	17	18	18	18	16	17	17	17.42	17
Cu	6	10	8	4	8	5	11	4	8	7.94	10
Zn	55	62	57	53	53	56	59	54	64	57.42	57
TRACE ELEMENTS (ICP-MS; in parts per million)											
La	18.45	17.34	18.72	18.91	19.11	18.05	18.75	18.39	19.53	18.15	16.02
Ce	35.76	33.89	35.86	36.23	36.61	34.66	37.00	35.50	38.48	35.33	31.23
Pr	4.12	3.92	4.06	4.12	4.19	3.97	4.15	4.07	4.59	4.04	3.47
Nd	16.28	15.80	15.99	16.25	16.63	15.68	16.54	16.39	18.46	16.11	13.83
Sm	3.66	3.51	3.47	3.50	3.61	3.41	3.60	3.58	4.16	3.56	3.08
Eu	1.03	0.98	0.93	0.98	1.01	1.00	1.00	1.00	1.13	1.00	0.92
Gd	3.26	3.25	3.09	3.20	3.21	3.04	3.31	3.27	3.72	3.22	2.75
Tb	0.52	0.53	0.50	0.51	0.52	0.49	0.53	0.52	0.60	0.51	0.44
Dy	3.18	3.13	3.00	3.11	3.18	2.96	3.19	3.16	3.65	3.09	2.64
Ho	0.64	0.65	0.61	0.62	0.64	0.60	0.65	0.64	0.73	0.63	0.54
Er	1.81	1.77	1.69	1.77	1.79	1.68	1.84	1.77	2.01	1.76	1.48
Tm	0.27	0.27	0.26	0.27	0.27	0.25	0.28	0.27	0.30	0.26	0.22
Yb	1.73	1.75	1.65	1.73	1.68	1.64	1.77	1.74	1.89	1.69	1.43
Lu	0.28	0.27	0.27	0.28	0.28	0.27	0.29	0.28	0.31	0.28	0.23
Ba	548	511	562	576	571	534	606	548	537	544.68	495
Th	6.25	5.98	6.81	6.88	6.85	6.44	6.43	6.70	6.69	6.39	5.39

DESCRIPTION OF MAP UNITS

Postglacial Deposits (Late Pleistocene to Holocene)

Qf **Fill**—Clay, silt, sand, gravel, organic matter, rip-rap, and debris emplaced to elevate and reshape the land surface; includes engineered and nonengineered fills; shown where fill placement is relatively extensive, readily verifiable, and appears sufficiently thick to be of geotechnical significance.

Qml **Modified land**—Local sediment, ranging from clay to gravel, mixed and reworked by excavation and (or) redistribution to modify topography; includes mappable sand and gravel pits excavated mostly into unit Qgom$_e$.

Qb **Beach deposits**—Sand and cobbles; may include boulders, silt, pebbles, and clay; pebble-sized and larger clasts typically well rounded and oblate; locally well sorted; loose; typically a mix of sediment locally derived from shoreline bluffs and underlying deposits and (or) carried in by longshore drift.

Qd **Dune deposits**—Hills and ridges of wind-blown sand; moderately to well sorted; deposited on upland surfaces and in kettle sidewalls along or near west-facing shoreline bluffs north of Ebeys Landing. Age estimates of 8840 ±50 and 8280 ±40 ^{14}C yr B.P. (shoreline section 2; Table 1, loc. 3 and 4) indicate that deposition of at least some dunes began during the early Holocene. Dune morphology suggests a depositional environment free of the forests that cover most of these dunes today, but minimal soil development and location of the dunes within 0.5 mi of the present-day shoreline bluffs suggest that deposition may also be recent and ongoing.

Qp **Peat**—Organic and organic-matter-rich mineral sediments deposited in closed depressions; includes peat, muck, silt, and clay in and adjacent to wetlands; the freshwater equivalent of unit Qm and may locally grade down to that unit.

Qm **Marsh deposits**—Organic and organic-matter-rich mineral sediments deposited in a saltwater or brackish marsh (estuarine or lagoonal) environment.

Qmw **Mass wasting deposits**—Boulders, gravel, sand, silt, and clay; generally unsorted but may be locally stratified; typically loose; shown along mostly colluvium-covered or densely vegetated slopes that are demonstrably unstable or appear potentially unstable; contains exposures of underlying units and landslides that we either could not map with confidence or are too small to show as separate features.

Qls **Landslide deposits**—Gravel, sand, silt, clay, and boulders in slide body and toe, and underlying units in scarp areas; clasts are angular to rounded; unsorted; generally loose, unstratified, broken, and chaotic, but may locally retain primary bedding; may include liquefaction features; deposited by mass-wasting processes other than soil creep and frost heave; typically unconformable with surrounding units; includes active as well as inactive slides; shown where scale permits. Absence of a mapped slide does not imply absence of sliding or hazard. All shoreline bluffs in the map area are subject to episodic landsliding and resultant bluff retreat, but most slide deposits are quickly removed by beach wave action.

Qs **Late Pleistocene sand**—Fine sand to silt; light gray where fresh, light tan to reddish medium brown where weathered; moderately well sorted; blankets much of the map area as a 0.5 to 4 ft thick sheet that typically forms topsoil and is mapped only where thickness appears to exceed 5 ft; well to very well drained; grain size, sorting, and morphology suggest wind-blown origin for some exposures, but elsewhere, mineralogy, poor sorting, and high angularity suggest till or glaciomarine drift (units Qgdm$_e$, Qgt$_v$, and Qgt$_{va}$) or mixed sources; appears to represent a postglacial, late Pleistocene pulse of sedimentation because it is stratigraphically beneath, and typically separated by a paleosol from, Holocene dunes (unit Qd) that lack a similar degree of soil development (shoreline section 2). The paleosol may reflect a late Pleistocene to early Holocene climate conducive to more rapid soil development than modern climate.

Deposits of the Fraser Glaciation (Pleistocene)

EVERSON INTERSTADE

Qgom$_{ee}$ **Glaciomarine drift, emergence (beach) facies**—Sand and gravel, locally silty; loose; typically only a few feet thick; underlain by glaciomarine drift (unit Qgdm$_e$) or Partridge Gravel (unit Qgom$_e$), but may rest on older sediments north and west of Penn Cove and along parts of the slope east of Ebeys Prairie; represents emergence deposits (Domack, 1983) that record a falling relative sea level at the end of the Everson Interstade. Subtle benches at varying elevations are characteristic of the unit and represent paleo–beach berms (Carlstad, 1992). This unit is partly the youngest facies of glaciomarine drift but may also include terrestrial deposits (Domack, 1983). It is mapped as outwash to maintain continuity with maps to the north (Dragovich and others, 2005).

Qmf$_e$ **Fan deposits**—Sand, fine gravel, silt, and clay; variably sorted; loose; bedded; consists of either terrigenous nearshore marine deltaic or terrestrial alluvial fans that record a late Everson Interstade (?), onshore hydrologic regime conducive to surface runoff in loose, well-drained units like Partridge Gravel (unit Qgom$_e$); located at the foot of small, relict valleys that lack modern streams and were incised into Partridge Gravel or other easily eroded deposits. The unit may mark a climatic shift or an elevated (but dropping) relative sea level late in the Everson Interstade. If unit deposition is tied to sea level change, valley incision and fan deposition ceased when relative sea level dropped sufficiently below the head of the fan to cause the groundwater table to lower, resulting in termination of surface runoff capable of incision. Valley incision into and fan deposition on the delta front landform in Partridge Gravel indicate that Partridge deposition had locally ceased; it follows that the ice front that had supplied the water that deposited the Partridge Gravel was locally no longer supplying much meltwater, and the runoff that deposited unit Qmf$_e$ near Coupeville was likely fed by other sources. The unit is thus best viewed as neither glaciomarine drift nor outwash, even though deposition was likely coeval (and may interfinger) with nearby deposition of glaciomarine drift. This unit is assigned to the Everson Interstade on the above speculation that it is associated with Everson sea level.

Qgdm$_e$ **Glaciomarine drift, undivided**—Most commonly clayey to silty diamicton with variable content of gravel-sized clasts, but also includes silt, clay, sand, and combinations of the above; contains marine shells; weathered color most commonly buff but ranges to olive gray, ash gray, or white; dark gray where unweathered; dry face characteristically includes vertical desiccation cracks with dark brown staining; commonly forms vertical faces prone to sudden failure along desiccation cracks; massive to rhythmically bedded, commonly with sharp upper and lower, unit-bounding unconformities (Domack, 1984); mostly loose and soft but locally hard and compact. Some exposures are very like till (Domack and Lawson, 1985), but till generally lacks fossils, and glaciomarine drift generally has a finer-grained, smoother-feeling matrix, and is more likely to be stratified, more likely to be buff-colored, and typically less compact (and less water-restrictive) than till. Till-like deposits are most prominent along elevated portions of Blowers Bluff, the north shore of Penn Cove, and the cliff between Ebeys Landing and Fort Casey. The unit consists of sea-floor sediment, and its variegated character appears to reflect initial proximity of the ice front (Domack, 1983). For detailed characterization, see Domack (1983, 1984, 1982), Domack and Lawson (1985), and Dethier and others (1995). The age of the unit spans the entire Everson Interstade (see Geologic Setting and Development). Locally divided into:

Qgdm$_{els}$ **Landslides**—Apparent landslides that lack evidence for recent activity. Slide surfaces are dominated by glaciomarine drift material that may be slightly looser than glaciomarine drift outside the slump area. We infer the subunit to be Everson Interstade(?) submarine(?) slumps that do not necessarily pose a slide hazard.

Qgos$_e$ **Glaciomarine sand deposits**—Sand, pebbly sand, and silty fine sand with local thin interbeds of silt and rare cobbly sand; mostly structureless to locally plane bedded, laminated, or rarely cross-bedded; locally complexly interlayered with glaciomarine drift; includes minor glaciofluvial deposits. Facies relations, including fining trends, and sedimentary structures suggest deposition in a shallow glaciomarine setting as foreshore deposits or submarine fan turbidites.

Qgim$_e$ **Ice-marginal moraine**—Cobbly to bouldery, angular to rounded gravel with loose, powdery matrix, plenty of void spaces, and abundant erratics on the surface; forms a gentle, 500 to 800 ft wide ridge across Coupeville (Fig. 1); marks the ice margin during the early part of the Everson Interstade, likely before deposition of a shell in glaciomarine drift (unit Qgdm$_e$) dated at 13,650 ^{14}C yr B.P. (Table 1, sample no. Beta 1319; see Geologic Setting and Development for field relations).

Qgom$_e$ **Partridge Gravel** —Sand, gravel, and sand-gravel mixtures with minor interlayered silt and silty sand; at least 210 ft thick above sea level southeast of its type section at Partridge Point, with well records locally suggesting an additional 135 ft below sea level (Carlstad, 1992); forms angle-of-repose slopes, such as at Partridge Point. The unit includes three outwash facies that compose a coarsening-upward, marine, kame-delta–turbidite complex (Carlstad, 1992; cross section A): a mostly horizontally bedded, sand-dominated, bottom-set sea floor facies with common low-energy gravity flow cross-bedding, flame structures, and other soft sediment deformation features, but apparently lacking (?) dropstones; an overlying foreset-bedded sand and gravel facies; and a capping, top-set, channelized gravel and sand facies that locally coarsens to a bouldery gravel and reflects a shallow-water deltaic to subaerial, braided stream environment (outwash channels in Fig. 1) with abundant cut-and-fill cross-bedding. Many exposures of the bottom-set sand facies include sparse, randomly distributed inclusions and apparently gravity-sorted trains of sand- to fine gravel-sized, detrital fragments of peat, charred wood, charcoal, coal, pumice, and dacite. Carlstad (1992) suggested that tephra found in this unit is the Lake Tapps tephra. However, we agree with Franklin Foit (Washington State University, written commun., Feb. 2005) and Dragovich and others (2005) that the tephra chemistry and field relations instead favor a Glacier Peak origin and suspect that the deposits are re-worked from nearby units, mostly units Qc$_o$ and Qc$_w$. The age of the unit is confined to the early Everson Interstade, sometime after initial incursion of marine water into the Puget Lowland but before deposition of a marine shell dated at 13,650 ±350 ^{14}C yr B.P. (Table 1; see Geologic Setting and Development for field relations). Assuming an average thickness of 100 to 250 ft, we estimate that the unit holds approximately 0.2 to 0.6 mi^3 of sand and gravel.

Qgog$_e$ **High-energy outwash gravel**—Variegated deposit of gravel with lenses of sand, silt, and clay and with inclusions of boulder-sized, subangular to well-rounded silt and clay rip-up clasts and channel lag gravel derived from massive to well-bedded, compact, pre-Fraser deposits of fines (columnar sections 3 and 5; Easterbrook, 1994b); crudely to well bedded, locally unbedded, and commonly including steep bedding, gravelly incisions (intrusions?) into underlying units, and other indicators of a high-energy flow regime; typically supports vertical bluff faces but locally forms angle-of-repose slopes; widely exposed beneath glaciomarine drift (unit Qgdm$_e$) along the Penn Cove shoreline between Coupeville and Blowers Bluff, where it steeply truncates at least 40 ft of pre-Fraser section (columnar section 5). The unit is interpreted herein as dominantly a subglacial flow deposit, except in upland areas between State Route 20 and Penn Cove near the northern map boundary, where the depositional and time-stratigraphic setting is unclear. Like the Partridge Gravel (unit Qgom$_e$), this unit is clearly overlain by glaciomarine drift (unit Qgdm$_e$). Based on exposures in a gravel pit southwest of Penn Cove, we believe that the unit locally grades up into and thus is a lateral facies equivalent of the Partridge Gravel. For that reason and because the unit is apparently nowhere overlain by convincing exposures of Vashon till (unit Qgt$_v$), we assign it to the Everson Interstade. We separate the unit from Partridge Gravel because Partridge Gravel is marine-deltaic and lacks the characteristics of high-energy flow that mark this unit.

VASHON STADE

Qgt$_v$ **Till**—Mix of clay, silt, sand, and gravel deposited as diamicton directly by Vashon Stade glacier ice; gray where fresh, light yellowish brown where oxidized; unsorted and highly compacted; permeability very low where lodgment till is well developed; most commonly matrix supported, but locally clast supported; matrix more angular than water-worked sediments, resulting in a grittier feel than the matrix of unit Qgdm$_e$; cobbles and boulders commonly faceted and (or) striated; forms a patchy cover varying from less than 0.5 to more(?) than 50 ft thick, with thicknesses of 10 to 30 ft most common; may include outwash and ablation till that are too thin to substantially mask the underlying, rolling till plain; locally capped with 0.5 to 4 ft of sand that is equivalent to but too thin to be separately mapped as unit Qs; up to house-sized erratic boulders commonly signal that till is underfoot, but such boulders may also occur as dropstones, or as lag deposits where the underlying deposits have been modified by meltwater; modern soil typically caps loose surface sediment, but the underlying till is unweathered; may include flow banding; typically forms vertical faces in coastal bluffs. The unit locally resembles unit Qgdm$_e$ (Domack, 1982, 1984; Domack and Lawson, 1985). Unit Qgt$_v$ lies stratigraphically between overlying recessional glaciomarine drift (unit Qgdm$_e$) and underlying advance outwash (units Qga$_v$ and Qga$_{vs}$). Its stratigraphic position relative to unit Qgog$_e$ remains unresolved. Local and nearby age control constrains the age of the unit to between about 18 ka (~15,000 ^{14}C yr B.P.; Swanson, 1994; Porter and Swanson, 1998; Booth, 1991) and sometime before deposition of a shell that yielded an age estimate of 13,650 ±350 ^{14}C yr B.P. (see Geologic Setting and Development and Table 1). This unit may include local exposures of older till that are similar in stratigraphic position, lithology, and appearance. Locally divided into:

Qgt$_{va}$ **Ablation till**—Unsorted, unstratified melt-out deposit of loose gravel, sand, silt, and clay.

Qga$_v$ **Advance outwash**—Sand and pebble to cobble gravel with some bouldery facies; local silt and clay; may contain till fragments; gray to grayish brown and grayish orange; clasts well rounded; typically well sorted and clean except in some ice-proximal deposits near the top of the unit; compact, but in many exposures only minimally cohesive; parallel-bedded, locally cross-bedded; less than 20 ft thick in most exposures; commonly overlain by unit Qgt$_v$ along a sharp contact and stratigraphically above unit Qc$_o$; commonly forms angle-of-repose benches within coastal bluffs. The age of this unit is bracketed to between about 18 and 20 ka by local and nearby age control from within the underlying unit Qc$_o$ (Table 1; columnar section 4) and an estimate of Vashon ice arrival by Porter and Swanson (1998) (see Geologic Setting and Development). Locally divided into:

Qga$_{vs}$ **Sand-dominated advance outwash**

Qgd **Vashon and Everson drift, undivided**—Glaciomarine drift (unit Qgdm$_e$), till (unit Qgt$_v$), and advance outwash (units Qga$_v$ and Qga$_{vs}$) combined into single unit where map scale or exposure do not permit separate presentation.

Deposits of the Olympia Nonglacial Interval (Pleistocene)

Armstrong and others (1965) defined as "Olympia Interglaciation" the "climatic episode immediately preceding the last major glaciation" and associated with it "nonglacial strata lying beneath Vashon Drift". We avoid the label "Olympia Interglaciation" because stage 3 (60-20 ka) is not a true interglacial period (as defined in fig. 4 of Morrison, 1991).

Qc$_o$ **Nonglacial deposits**—Silt, clay, sand, and local lenses and interbeds of fine gravel; includes the widespread "West Beach silt" facies interpreted as loess by Thorsen (1983a,b, 2001); compact; typically horizontally bedded to massive; commonly forms vertical bluffs; silt facies locally contain sparse gastropod fossils (columnar section 4 and shoreline section B; Table 1). Petrographic study (Dragovich and others, 2005, and this study) indicates that alluvial facies reflect ancestral Skagit River provenance. Sparse, local Glacier Peak dacite and pumice pebbles, such as those found to the east of Long Point (columnar section 7; Table 2, samples 136-1 and 136-2), are chemically indistinguishable from lahar runout deposits within the Whidbey Formation (unit Qc$_w$), but no lahar runout deposits were recognized in this unit. The age of the West Beach silt is constrained in the map area to between about 37,000 and 27,000 ^{14}C yr B.P. by dates from overlying and underlying units (Table 1, sample nos. Beta 154508 and Beta 169086). The age of the entire unit may be limited to between about 37,000 and 16,800 ^{14}C yr B.P. by six radiocarbon dates from the field area and the above-mentioned 37,000 ^{14}C yr B.P. date from West Beach just north of the field area (Table 1). Alternatively, undated strata within the unit may include significantly older deposits of the Olympia nonglacial interval. This unit may include fine-grained early Vashon advance deposits ("Transitional beds" of Pessl and others (1989)), such as at North Penn Cove (columnar section 4), where the upper radiocarbon date and sedimentary characteristics of overlying silty sediment may be compatible with early Vashon association.

Deposits of the Possession Glaciation (Pleistocene)

Qgd$_p$ **Possession Drift**—Glaciomarine drift and underlying till and advance outwash sand; distinguished from equivalent Fraser Glaciation units by stratigraphic position. Glaciomarine drift facies highly variegated; typically clayey silt, silty clay, clay, and clay-rich diamicton; buff, ranging to ash gray or white; compact and commonly with vertical desiccation cracks; commonly contains shells; more compact than Everson Interstade equivalent; locally indistinguishable from till. Till facies typically sandy diamicton; ash gray to white; compact. Outwash sand gray; medium to fine grained; classified as advance based on field relations along West Beach north of map area (Dragovich and others, 2005). The unit is mostly glaciomarine drift along Blowers Bluff; it is dominantly sand at West Beach and within 1.5 mi southeast of Ebeys Landing, but glaciomarine drift overlying till further south along the same bluff. Sand at West Beach is very similar to and was distinguished from underlying channel sand of unit Qc$_w$ based on mineralogic content determined from petrography. We believe the unit age to be about 80 to 60 ky (see Geologic Setting and Development).

Interglacial Deposits of the Whidbey Formation (Pleistocene)

Qc$_w$ **Whidbey Formation**—Sand, silt, clay, peat layers, occasional fine gravel, and rare medium gravel; where exposed, most commonly weathered to a subtly multicolored to light-yellowish appearance; forms base of section along shoreline bluffs of West Beach and Blowers Bluff and most commonly consists of a basal flood-plain facies overlain by a channel sand facies. The flood-plain facies is typically 10 to 20 ft thick, well stratified (subhorizontally), and commonly slightly oxidized, forms prominent vertical bluffs, and contains discontinuous peat beds. Along West Beach, the flood-plain facies is at least 30 ft thick at columnar section 1, but descends below sea level 3000 ft to the south (see Structure). The flood-plain facies is overlain by a roughly 30 ft thick, clean, gray, cross-bedded to massive channel sand facies (columnar section 1) that typically forms an angle-of-repose cliff and so resembles the overlying Possession glacial sand (unit Qgd$_p$) that petrographic analysis may be needed for separation of these two units. At Blowers Bluff, the flood-plain facies reaches a maximum thickness of 25 ft and is overlain by a gravelly, cross-bedded channel sand facies that is lavender to light yellowish gray, 15 to 80 ft thick, and somewhat prone to forming angle-of-repose benches; this facies is continuous with similar deposits in the Blowers Bluff portion of the Oak Harbor 7.5-minute quadrangle north of the field area, where Dragovich and others (2005) informally named it the lahar runout of Oak Harbor and used mineralogic composition to demonstrate an ancestral Skagit River basin provenance. We agree with Dragovich and others (2005) that local concentrations of dacite and pumice pebble trains (see columnar section 5 and Easterbrook, 1994b) come from Glacier Peak lahar runout deposits (Table 2; Dragovich and others, 2005). We believe the unit age to be about 125 to 80 ka (see Geologic Setting and Development).

Deposits of the Double Bluff Glaciation (Pleistocene)

Qgd$_d$ **Double Bluff Drift**—Glaciomarine drift (silt, clay, and diamicton) and locally underlying till; resembles equivalent Vashon Drift units but is assigned to the Double Bluff Glaciation based on stratigraphic position; recognized in the map area only along about 1500 ft of shoreline southeast of Ebeys Landing (shoreline section B); lithology reflects British Columbian provenance (Easterbrook and others, 1967). The age of the unit appears to be 185 to 125 ky or older (see Geologic Setting and Development).

Undivided Pre-Fraser Nonglacial Deposits (Pleistocene)

Qc **Pre-Fraser nonglacial deposits, undivided**—Sand, silt, clay, peat, some fine gravel, and rare medium gravel; well stratified to massive; resembles units Qc$_o$ and Qc$_w$ and is thought to be nonglacial but may locally include glacial material; mapped in a single exposure about 3000 ft west of columnar section 4; stratigraphically situated below Fraser glacial deposits but otherwise of unknown age and association; likely of Olympia or Whidbey age, but an older origin has not been ruled out.

Undivided Pleistocene Deposits

Qu **Pleistocene deposits, undivided**—Sediment of unknown age and association; may include both glacial and interglacial deposits. In an exposure west of Long Point (columnar section 6), the unit consists of a 73 ft thick section of gray, medium- to fine-grained, subangular to subrounded, poorly sorted, compact to mildly compact, plane- to gently cross-bedded, lithologically diverse sand with sparsely disseminated, thin (< 1 in. thick) elongate pockets of granule-sized pumice and coal; soft-sediment deformation structures and (or) liquefaction features are exposed in the basal 20 ft of section; sand is interlayered with at least three compact, discontinuous diamictons up to 6 ft thick, with sparse to rare, subrounded to angular granule to pebble clasts; diamictons greenish to olive and dark gray; grains angular to subangular; lithologic composition mixed and not indicative of specific source area or glacial or interglacial conditions; angularity of particles in diamicton suggests till. In a separate exposure 0.3 mi southwest of the Coupeville dock, the unit consists of compact, quartz-rich sand. The unit also includes an exposure of somewhat compact cobble gravel near the top of a hill 4000 ft southeast of Lovejoy Point. This exposure is in the sideslope of a hill that rises about 10 ft above the surrounding glaciomarine drift and recessional outwash gravel, suggesting that the hill is cored with older sediment.

ACKNOWLEDGMENTS

This report was compiled from Polenz and others (2005), Dragovich and others (2005), and field work in the Camano 7.5-minute quadrangle. It was produced in cooperation with the U.S. Geological Survey National Cooperative Geologic Mapping Program, Agreement No. 04HQAG0069, and the National Park Service, agreement for geologic mapping of the Ebey's Landing National Historical Reserve, which partially supported our mapping. We thank Pat Pringle for considerable assistance with tree ring and radiocarbon data analysis; the officials and volunteers at Ebey's Landing National Historical Reserve, the Ebey's Prairie Land Trust, and Forts Ebey and Casey of the Washington State Parks for assistance and permission to map on their land; Doug Kelly (Island Co. Health Dept.) and other Island County staff for geologic, hydrogeologic, geotechnical, and other assistance and records; Toby Rodgers and Crystal Briggs (Natural Resources Conservation Service) for soil scientific expertise and consultation; Steve Koblyk (Washington State Parks and Recreation Commission), Roger Sherman, John Harris, Chuck Arnold, and the staff and volunteers of the Coupeville Museum for historical expertise and records; Mac McKay, Yvonne Dettlaff, and Regine Polenz for assistance with field work; Pat Pringle, Eric Schuster, and Ingrid Polenz for assistance with the processing of a sub-fossil tree ring sample; Liz Nesbitt (Univ. of Wash. Burke Museum), Dick Johnson (Wash. State Univ.), and John Fleckenstein, Helen Berry, and Tom Mumford (all three Wash. Dept. of Natural Resources) for identification of fossils; George Mustoe (Western Wash. Univ.) for records, age control, and assistance pertaining to the geology of Cedar Hollow; Curt Koger (Associated Earth Sciences, Inc.) for permission to publish his radiocarbon dates; David Mosher (Geological Survey of Canada), David Dethier (Williams College), Ralph Haugerud and Brian Sherrod (both U.S. Geological Survey), and Michael Sternberg (Northwest Paleontological Association) for assistance with geologic questions; Nick Foit (Wash. State Univ.) for assistance with geochemical questions; Charles Lutrell (Eastern Wash. Univ.) for assistance with archeological and anthropological questions; and Julie Stein and Jacob Fisher (Univ. of Wash.) for sharing geoarcheological data. Thanks also to the Washington State Department of Ecology for permission to use proprietary shoreline aerial photos for our fieldwork and shoreline section 2, and to fellow Department of Natural Resources staff members Josh Logan, Tim Walsh, Hank Schasse, Joe Dragovich, Gary Petro, and Mac McKay for technical assistance and reviews. Last, but not least, thanks to the uncounted people who permitted us to study geologic exposures on their land and provided site-specific records and local knowledge.

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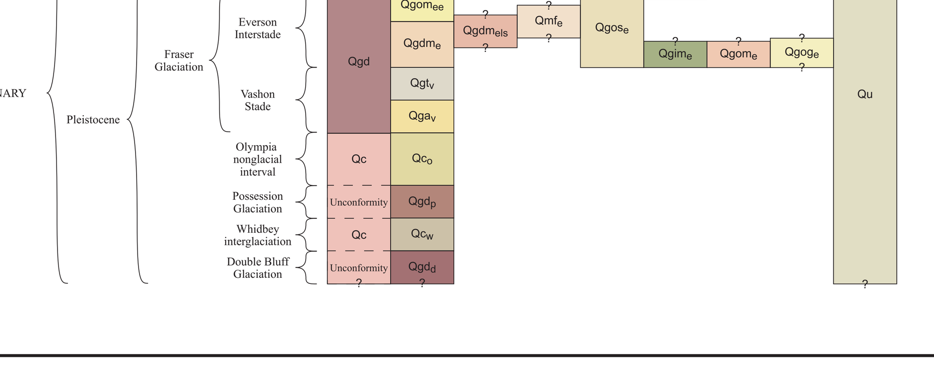
CORRELATION OF MAP UNITS



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