NATURAL RESOURCES

ANALYTICAL DATA FROM THE HOLLY 7.5-MINUTE QUADRANGLE, JEFFERSON, KITSAP, AND MASON COUNTIES, WASHINGTON—SUPPLEMENT TO OPEN FILE REPORT 2011-5

by Trevor A. Contreras,
Sarah A. Weeks, and
Benjamin B. Perry

WASHINGTON
DIVISION OF GEOLOGY
AND EARTH RESOURCES
Open File Report 2011-6
August 2012

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Publications List:
http://www.dnr.wa.gov/ResearchScience/Topics/GeologyPublicationsLibrary/Pages/pubs.aspx

Washington Geology Library Catalog:
http://www.dnr.wa.gov/ResearchScience/Topics/GeologyPublicationsLibrary/Pages/washbib.aspx

Washington State Geologic Information Portal:
http://www.dnr.wa.gov/ResearchScience/Topics/GeosciencesData/Pages/geology_portal.aspx

Suggested Citation: Contreras, T. A.; Weeks, S. A.; Perry, B. B., 2012, Analytical data from the Holly 7.5-minute quadrangle, Jefferson, Kitsap, and Mason Counties, Washington—Supplement to Open File Report 2011-5: Washington Division of Geology and Earth Resources Open File Report 2011-6, 16 p.

Published in the United States of America
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Analytical Data from the Holly 7.5-minute Quadrangle, Jefferson, Kitsap, and Mason Counties, Washington—Supplement to Open File Report 2011-5

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INTRODUCTION

This supplemental report contains additional data, descriptions, and discussions pertaining to and acquired for the geologic map of the Holly 7.5-minute quadrangle (Contreras and others, 2012). It includes geochemical data, a single optically stimulated luminescence (OSL) age estimate, and grain-size analyses of Vashon-age till and ice-contact deposits.

GLACIER PEAK DACITE AND WHIDBEY- TO POSSESSION-AGE DEPOSITS

The nonglacial, rhythmically bedded Whidbey-age unit Qc_w grades into laminated sands and silts that contain dropstones of dacite and a dacite-rich volcaniclastic diamicton, unit Qvc (Figs. 1 and 2). These gradational contacts are found at multiple locations between Anderson Creek and Nellita. Unit Qvc appears to represent the transition from nonglacial to glacial conditions during marine oxygen isotope stages (MIS) 5 to 4; it records the onset of the Possession glaciation. The geochemistry of the dacite clasts indicates a Glacier Peak source (Franklin F. Foit, Wash. State Univ., written commun., 2011; Thomas W. Sisson, USGS, written commun., 2011) and appears to match that of clasts found on central Whidbey Island by Polenz and others (2005), Dragovich and others (2005), and Dethier and others (2008); most of our analyses fall within the standard deviation for clasts analyzed by Polenz and Dragovich. Thought to represent glacial marine drift of early Possession age, this deposit could also represent a submarine debris flow on a delta draining the Glacier Peak area.

While we found no marine fossils in this transitional diamicton deposit, we did find one small (~0.2 in.) piece of charcoal. The bulk sample reacted violently to a 7.5% solution of hydrogen peroxide during pretreatments for the grain-size analysis. This reaction may indicate the presence of additional organic particles in the diamicton, which contains as much as 20 percent clay-size particles. (See Fig. 3 for grain-size results.)

Good exposures (Figs. 1 and 2) at the end of Thunder Ridge Way (on Hood Canal Seafood property) show lenses of dacite pebbly sand surrounded by a diamict rich in dacite clasts and laminated sands and silts with dacite dropstones.

Age Estimates and Correlations

Age control for unit Qc_w consists of a single OSL sample and a tephra in the nonglacial prodelta deposits of this unit. The dacite clasts found above the Whidbey-age unit in the dacite-rich diamict, unit Qvc, likely correlate to those found on Whidbey Island.

Dethier and others (2008) dated the dacite in the Whidbey Formation at Blowers Bluff at 128 ±9 ka. Below these dated dacite clasts, Berger and Easterbrook (1993) obtained a thermoluminescence age estimate of 120±20 ka.

Our sample yielded an age of 82.5 ± 3.89 ka for unit Qc_w deposits below the dacite-rich diamict, and the tephra found at beach level, correlated to a Mount St. Helens tephra, provided a date of approximately 100 ka, placing this nonglacial deposit below the diamict at between approximately 78 to 100 ka and firmly in MIS 5. This is consistent with the age control at Blowers Bluff and with Dragovich and Polenz's findings that the dacite was scattered throughout Whidbey-, Possession-, and Olympia-age deposits.

Figure 1. Thunder Ridge Way exposure of diamict (unit Qvc) with lenses of pebbly sand, primarily of subangular dacite. Clast sizes range from sand to small boulder in a clay-rich matrix. The diamict is hackly with a dominant subvertical joint pattern.

QUARTZ OPTICALLY STIMULATED LUMINESCENCE (OSL) AGE ESTIMATE

The OSL sample collected at Anderson Creek from the Whidbey-age unit Qc_W was analyzed by Shannon Mahan of the U.S. Geological Survey. It was taken from a 14-in.-thick layer of medium sand at latitude 47.56841°, longitude -122.964201°; elevation 47 ft. The analysis provided an age of 82.5 ±3.89 ka (Table 1; sample site shown on map as a blue starburst symbol).

Table 1. Quartz optically stimulated luminescence age estimate calibration data for a sample of fine (180–90 microns) quartz sand. [1], Field moisture; figures in parentheses indicate the complete sample saturation as a percentage; ages calculated using 90% of saturation. [2], Analyses obtained using laboratory gamma spectrometry (high resolution Ge detector). [3], Cosmic doses and attenuation with depth were calculated using the methods of Prescott and Hutton (1994). [4], n is the number of replicated equivalent dose (De) estimates used to calculate the mean; figures in parentheses indicate the total number of measurements made, including failed runs with unusable data. [5], Dose rate and age for quartz sand. Linear + exponential fit used on equivalent dose, with single aliquot regeneration. Gy, gray, a unit of measure for absorbed dose. Errors to one sigma.

Sample number	% Water content[1]	K (%)[2]	U (ppm)[2]	Th (ppm)[2]	Cosmic dose[3] additions (Gy/ka)	Total dose rate (Gy/ka)	Equivalent dose (Gy)	n[4]	Age (ka)[5]
WA-196	20 (52)	1.02 ± 0.02	0.90 ± 0.06	2.68 ± 0.09	0.13 ± 0.01	1.06 ± 0.02	96.5 ± 4.05	21 (24)	82.5 ± 3.89

Figure 2. Dropstones of dacite in laminated sand, silt, and clay (unit Qvc). The brown clast in the center of the photo is altered pumice, approximately 2.5 in. long. Gray clasts are dominantly subangular dacite. Location is 400 ft south of Figure 1 on a skidder road at 200 ft elevation.

TEPHRA

A 0.3-in.-thick, light gray tephra was found in unit Qc_w at beach level on Hood Canal between Nellita and Frenchman's Cove (shown on the map as a gray-filled circle labeled "Mount St. Helens tephra in Qc_w"). Franklin Foit at the Washington State University (WSU) GeoAnalytical Lab, who analyzed the glass (Table 2; see also Whitlock and others, 2000), wrote:

> "The composition of the glass is a good match (similarity coefficients = 0.96-0.97) to several older Mount St. Helens tephras, in particular to a MSH C-like tephra from Carp Lake in southwestern Columbia Basin which is thought to be ~100 ka in age" (Foit, written commun., 2011).

Table 2. Microprobe results and correlation for tephra sample 64-t-871-e (glass; latitude 47.598237°, longitude -122.922°; elevation 5 ft). Probable source: Mount St. Helens C-like tephra. *, analyses normalized to 100 weight percent. **, Borchardt and others (1972).

no. of shards	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	Na_2O	K_2O	Cl	Total*	Age	Similarity coefficient**
19	76.88	0.09	13.82	0.89	0.24	1.6	3.91	2.49	0.08	100	~100 ka	0.97+
standard deviation	0.2	0.03	0.12	0.05	0.03	0.05	0.13	0.13	0.01			

DACITE CHEMISTRY

Individual dacite clasts in unit Qvc were chosen for various geochemical analyses at the WSU GeoAnalytical Lab. The clasts consisted of both pumiceous dacite and lithic dacite from the diamicton and dropstones in the laminated sand and silt.

Results of Microprobe on Pumice

Franklin Foit (WSU) analyzed and correlated the three pumice samples from Table 3. He wrote (2011):

> "Based on the composition of its glass, the pumice sample 2-K-9 appears to be from Glacier Peak. The composition of the glass is quite variable as indicated by the high standard deviations of the analyses and also have low total analytical totals (~90 wt %) suggesting, perhaps some alteration. A search of my database for the bulk glass composition yields a weak match (similarity coefficient = 0.94) to the Glacier Peak D tephra (6060 cal yrs BP). If you divide the data set into compositional groups (glasses 1 & 2) you also get a weak match (SC = 0.93) to the 11,600 BP (Kuehn and others, 2009) Glacier Peak tephra. Although the best fit is to the Glacier Peak D, it could also be a mixture of these two Glacier Peak tephras."

Because the stratigraphy of the section suggests pre-Fraser deposition and the geochemistry appears to match that for the samples found on Whidbey Island, we suggest that the weak correlation with younger Glacier Peak deposits (11,600–6,060 ka) is not appropriate. Instead, we assert that these clasts are better correlated with those from the Whidbey-age eruption discussed by Dethier and others (2008)(Table 4).

Table 3. Microprobe results for glass from dacite pumice in unit Qvc taken at an elevation of 115 ft (latitude 47.585397°, longitude -122.950524°). *, analyses normalized to 100 weight percent. **, Borchardt and others (1972).

Sample	Comment	No. of shards	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	Na_2O	K_2O	Cl	Total*	Probable source	Age	Similarity coefficient**
Pumice 2-k-9 bulk glass	dacite pumice bulk	24	78.11	0.39	11.66	1.12	0.15	0.6	3.44	4.26	0.27	100	Glacier Peak D	6,060 cal yr BP	0.94
	standard deviation		1.45	0.07	0.9	0.16	0.07	0.48	0.44	0.37	0.14				
Pumice 2-k-9 glass 1	dacite glass	18	78.73	0.39	11.36	1.09	0.12	0.43	3.39	4.27	0.22	100	Glacier Peak D	6,060 cal yr BP	0.89
	standard deviation		0.64	0.05	0.42	0.08	0.03	0.13	0.19	0.27	0.03				
Pumice 2-k-9 glass 2	dacite glass	6	75.84	0.38	12.88	1.23	0.21	1.26	3.75	4.09	0.35	100	Glacier Peak	11,600 yr BP	0.93
	standard deviation		1.46	0.11	1.25	0.3	0.11	0.74	0.84	0.58	0.23				

Grain-size Analysis

Two samples of the dacite-rich diamict were analyzed for grain-size distribution (Fig. 3). The samples were dried, washed, and sieved, and the fines were subjected to pipette analysis for which the final two withdrawals were extrapolated. The results indicate that the diamict contains approximately 20 percent clay and 40 to 65 percent silt.

While this testing was carried out with ASTM standards in mind, we were limited by our lab capabilities. Thus the results should be considered estimates only. The two samples were sieved in our lab by an intern using a nonstandard set of sieves. The results are shown in millimeters, not sieve mesh sizes. Both samples were subjected to pipette analysis, and the grain-size distribution was estimated for the fines fraction of the samples.

Table 4. X-ray fluorescence (XRF) and inductively coupled plasma mass spectrometry (ICP-MS) results for four dacite clasts in unit Qvc. Included for comparison are results from Dragovich and others (2005) and Polenz and others (2005). *, normalized on a volatile=free basis, with total Fe expressed as FeO.

Sample ID	53S179A	1-T-13	2-K-9-Bb	K-9-B	Ave. of 4 clasts, this study	Std. dev. of 4 clasts, this study	Ave. of 20 Whidbey Is. volcanic clasts (Polenz and others, 2005)	Stan. dev. of 20 clasts (Polenz and others, 2005)	Ave. of 107 Glacier Peak dacite clasts from east and north of Whidbey Is. (Dragovich and others, 2005)	Stan. dev. of 107 clasts (Dragovich and others, 2005)
Latitude	47.57945°	47.579349°	47.585397°	47.585397°						
Longitude	-122.959047°	-122.959829°	-122.950524°	-122.950524°						
Elev. (ft)	197	197	115	115						
Location	Tekiu Point Rd NW	Tekiu Point Rd NW	Thunder Ridge Way	Thunder Ridge Way						
MAJOR ELEMENTS NORMALIZED (XRF*; in weight percent)										
SiO_2	64.72	64.65	64.97	65.07	64.85	0.20	65.57	0.88	65.09	1.24
TiO_2	0.459	0.444	0.450	0.495	0.46	0.02	0.60	0.03	0.59	0.07
Al_2O_3	16.53	16.65	16.11	16.88	16.54	0.32	16.52	0.30	16.62	0.47
FeO*	3.71	3.62	3.65	4.02	3.75	0.18	3.96	0.23	4.03	0.46
MnO	0.080	0.079	0.079	0.083	0.08	0.00	0.08	0.02	0.083	0.007
MgO	2.39	2.31	2.34	2.36	2.35	0.03	2.12	0.23	2.31	0.28
CaO	4.62	4.71	4.55	4.68	4.64	0.07	4.66	0.35	4.79	0.40
Na_2O	4.30	4.33	4.25	4.16	4.26	0.07	4.07	0.09	4.12	0.12
K_2O	1.69	1.69	1.87	2.06	1.83	0.18	2.27	0.10	2.04	0.16
P_2O_5	0.169	0.164	0.165	0.188	0.17	0.01	0.16	0.01	0.155	0.022
Total	98.66	98.64	98.43	100.00						
TRACE ELEMENTS (XRF; in parts per million)										
Ni	44	45	36	43	42	4.04	19.44	3.35	18	5
Cr	34	33	32	31	32	1.23	19.36	4.97	18	5
V	75	74	72	81	76	3.89	83.57	7.96	81	12
Ga	18	18	19	19	18	0.78	17.42	0.76	17	1
Cu	13	13	17	22	16	4.10	7.94	3.00	10	4
Zn	55	54	55	59	56	2.17	57.42	3.01	57	6
TRACE ELEMENTS (ICP-MS; in parts per million)										
La				14.54			18.15	0.79	16.02	1.23
Ce				29.84			35.33	1.41	31.23	2.65
Pr				3.8			4.04	0.15	3.47	0.53
Nd				15.05			16.11	0.59	13.83	2.15
Sm				3.15			3.56	0.12	3.08	0.50
Eu				0.91			1.00	0.03	0.92	0.15
Gd				2.75			3.22	0.11	2.75	0.45
Tb				0.41			0.51	0.02	0.44	0.07
Dy				2.4			3.09	0.11	2.64	0.44
Ho				0.48			0.63	0.03	0.54	0.09
Er				1.29			1.76	0.07	1.48	0.24
Tm				0.18			0.26	0.01	0.22	0.04
Yb				1.21			1.69	0.06	1.43	0.23
Lu				0.2			0.28	0.01	0.23	0.04
Ba				628			544.68	26.78	495	38
Th				3.26			6.39	0.38	5.39	0.58
Nb				3.45			5.22	0.29	4.94	0.40
Y				13.08			17.44	0.64	14.96	1.32

Table 4. *(Continued)*

Sample ID	53S179A	1-T-13	2-K-9-Bb	K-9-B	Ave. of 4 clasts, this study	Std. dev. of 4 clasts, this study	Ave. of 20 Whidbey Is. volcanic clasts (Polenz and others, 2005)	Stan. dev. of 20 clasts (Polenz and others, 2005)	Ave. of 107 Glacier Peak dacite clasts from east and north of Whidbey Is. (Dragovich and others, 2005)	Stan. dev. of 107 clasts (Dragovich and others, 2005)
Latitude	47.57945°	47.579349°	47.585397°	47.585397°						
Longitude	-122.959047°	-122.959829°	-122.950524°	-122.950524°						
Elev. (ft)	197	197	115	115						
Location	Tekiu Point Rd NW	Tekiu Point Rd NW	Thunder Ridge Way	Thunder Ridge Way						
TRACE ELEMENTS (ICP-MS; in parts per million) *(Continued)*										
Hf				2.81			4.11	0.18	3.44	0.51
Ta				0.27			0.45	0.03	0.44	0.25
U				1.09			2.14	0.15	1.79	0.32
Pb				7.62			10.17	0.77	9.38	1.14
Rb				24.3			41.76	3.57	36.9	4.3
Cs				0.56			1.82	0.13	1.59	0.40
Sr				730			468.40	31.33	480	50
Sc				8.8			12.12	1.39	11.7	1.4
Zr				100			150.11	7.46	130	8

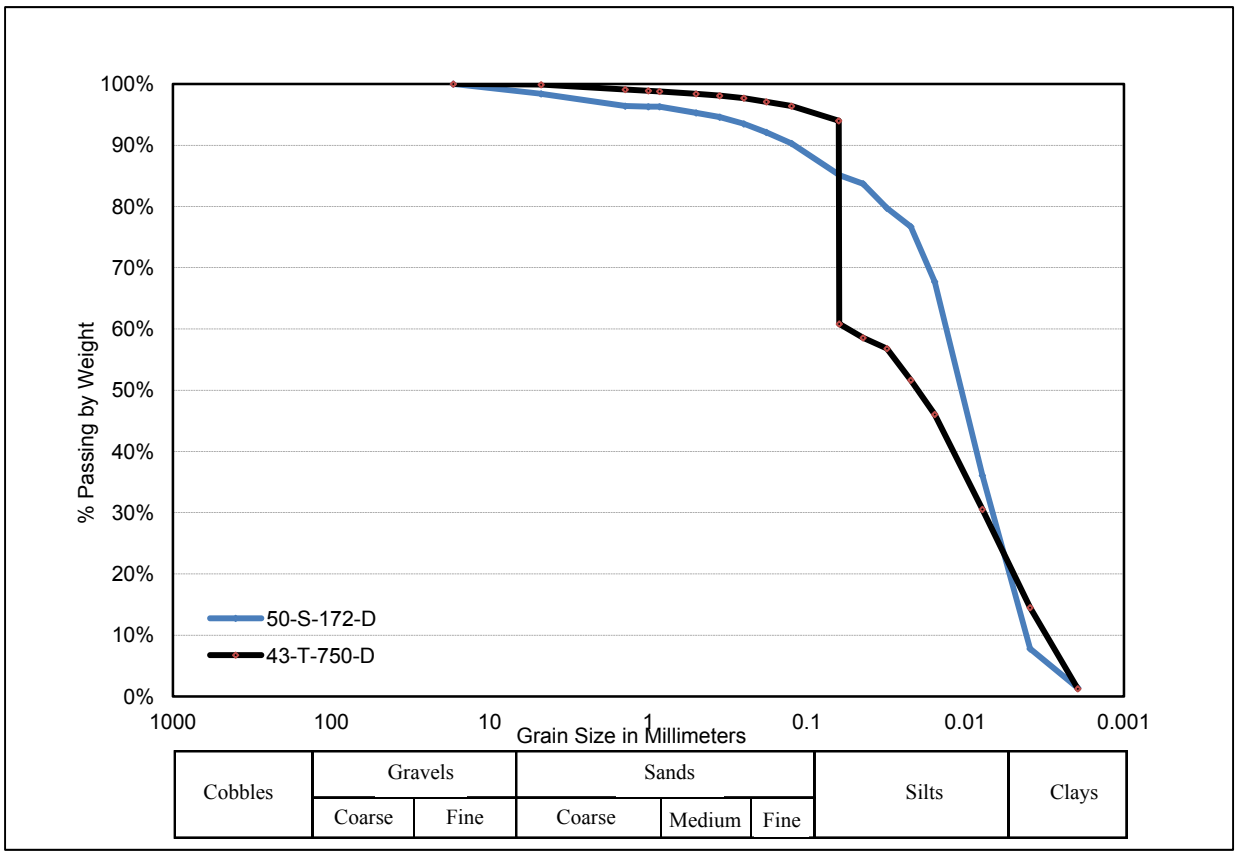

Figure 3. Grain-size distribution estimates of two Glacier Peak diamict samples of Whidbey–Possession age (unit Qvc); includes sieve and pipette analysis. Blue line represents sample 50-S-172-D, and black line represents sample 43-T-750-D.

VASHON-AGE TILL AND SUBGLACIAL MELT-OUT TILL

The Vashon-age fluted upland on the Kitsap Peninsula is commonly mantled with a veneer of ablation till (unit Qgic) consisting of loose, slightly oxidized sandy gravel, typically less than 5 ft thick (Fig. 4). Under this ablation till there is in many places a dense, fresh subglacial diamict (unit Qgic). The diamict, while compact, is permeable, friable, and lacks the foliation typical of lodgment till. We rarely found a lodgment till in the map area that displayed foliation and was not easily friable to a powder. We speculate that the diamict lacked clay-size particles because it was so easily friable. Our grain-size analysis (Fig. 5) did not completely verify this because we subjected only two samples to pipette analysis. The results do suggest that the diamict has a broad range of grain sizes and is generally coarser than well-developed lodgment till.

This diamict occurs in transverse-ribbed terrain and may have a stagnant-ice affinity, as suggested by the other ice-contact landforms nearby. Conversely, the lodgment tills appear to be restricted to broader, well-formed drumlins that look smooth in lidar images and lack the transverse-ribbed terrain found elsewhere in the map area and within the adjacent Lilliwaup quadrangle (Contreras and others, 2010).

We mapped the diamict within unit Qgic (ice-contact deposits) on the basis of its association with the ribbed topography, its permeability and friability, and the absence of foliation. It would be misleading to map these deposits as glacial till, which implies a lodgment till, when it has drastically different geotechnical and hydrological properties.

Haugerud (2005) found that the Vashon-age till on Bainbridge Island rarely exhibited subhorizontal foliation, and Laprade (2003) found "subglacially reworked till" in the lee of drumlins in Seattle. This material has the appearance of till, but it is permeable and has widely varying engineering properties.

Figure 4. Vashon-age diamict under a slightly oxidized ablation till, typical in the map area. The lower fresh gray diamict with subrounded cobble to pebble gravel (unit Qvc) has a matrix of sand, silt, and clay and is friable. The notebook shown is approximately 7.5 by 4.75 in.

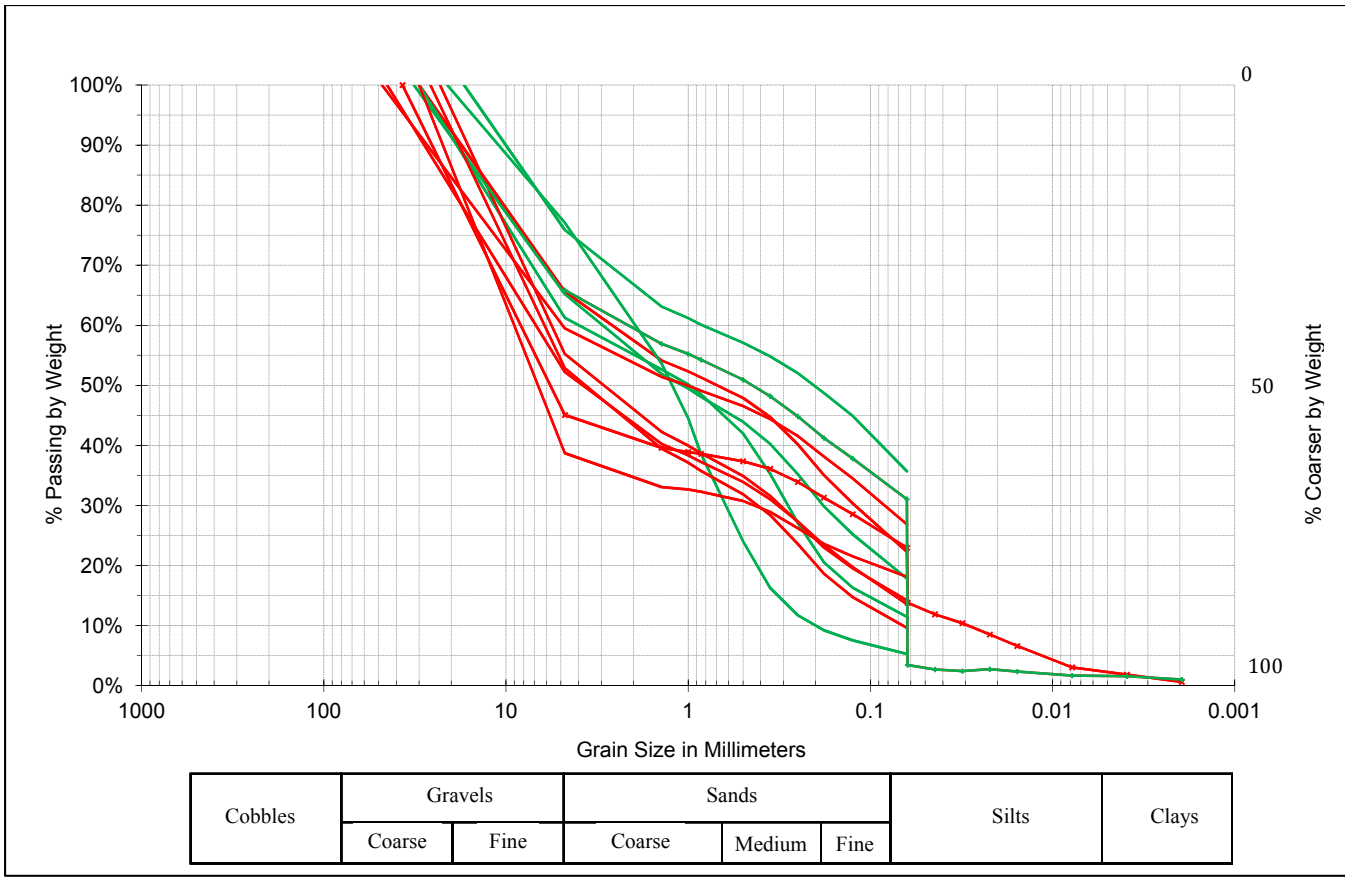

Figure 5. Grain-size distribution in 12 samples of Vashon-age subglacial melt-out and lodgment till from where?. Each was sieved and had two pipette analyses. Green lines indicate lodgment tills, and red lines indicate subglacial melt-out tills.

Previous Mapping

Previous mapping suggests that the upland was covered by Vashon-age till. Deeter (1979) suggested that between Holly and Lake Tahuya, an ablation till covers a lodgment till, perching the water table. We have made similar observations for the Holly quadrangle but suggest the lower lodgment till in this area is considerably older than Vashon, likely MIS 6, and is a product of he Double Bluff glaciation as suggested by the oxidation, stratigraphy, and the few age estimates available in the area.

Subglacial Melt-Out Till?

Benn and Evans (2010) define subglacial melt-out till as "sediment released by the melting of stagnant or slowly moving debris-rich glacier ice, and directly deposited without subsequent transport or deformation". We suggest this definition is applicable to the diamict found over much of the map area, included that in unit Qgic. This diamict makes up the narrow drumlins and transverse-ribbed terrain within the map area and appears to be associated with stagnant-ice landforms, such as kettles and eskers.

ALLUVIAL TERRACES

Description

The drainages of Anderson and Stavis Creeks (Figs. 6 and 7) contain terraces that we found to be unexpectedly old, suggesting less geomorphic activity during the Holocene than expected. Radiocarbon age estimates from these terraces are between 1,400 ±40 and 5,680 ±40 yr B.P., with apparent age increasing with elevation in the drainages. In numerous places along modern stream channels these terraces contained organic materials within a few feet of the modern stream level. A coarse sand can be found with some of these organics, suggesting possible tsunami origin; thus further study is warranted.

While the terraces may record a tectonic story (due to their proximity to the Seattle fault zone), the scope of this geologic mapping did not include a topical study of the terraces. Thus, not all terraces with carbon were sampled, and not all samples collected were submitted for analysis. The terraces are widespread in drainages of the area, including Seabeck, Big Beef, and Anderson Creeks (near Warrenville).

The oldest age estimate came from disseminated charcoal at modern stream level in the upper reaches of the west fork of Stavis Creek, approximately 850 ft northeast of the waterfall. The site is depicted in Figure 6 as a diamond with an elevation of 371 ft. The conventional radiocarbon estimate of 5,680 ±40 yr B.P. (2σ calibrated estimate of 6,550–6,400 cal yr B.P.) appears similar in age to two samples of detrital charcoal from near Price Lake (~14.5 mi to the southwest) (Jonathan Hughes, Univ. of the Fraser Valley, 2011) and subsequently published by Polenz and other (2012). Hughes' samples were found in relict fluvial terraces in the outflow channel of Price Lake and are suggested to represent a post-fire pulse of geomorphic activity that has been followed by minimal geomorphic activity in the past 6,000 years.

Terrace Formation

The terraces do not appear to be the result of landslides because they appear in multiple drainages at similar elevations and most lack obvious landslide dams—with the possible exception of the lower terraces in Anderson Creek. They also do not appear to be relicts of historical logging or recessional glacial lake levels; the ^{14}C age estimates rule both of these out. The fact that the carbon layers are just slightly elevated above modern stream channels may suggest periodic changes to the system with a return to a similar baseline. The individual terraces may record multiple events as shown by multiple layers of carbon (Figs. 8 and 9). Some of the terraces contain coarse sand above the organics, which could be evidence of tsunamis in Hood Canal; however, this study did not determine their origin.

The age estimates for the carbon support the theory that some of the terraces could be the result of forest fires, as suggested by Polenz and other (2012). Some deposits in the Oregon Coast Range show an increase in fire-episode frequency between 4,200 and 3,000 cal yr B.P. and from 2,000 to 1,200 cal yr B.P. (Long and others, 2007)—within the age estimates of our samples.

SIGNIFICANT SITES

Five significant sites are shown on the geologic map, depicted by orange diamonds. The sites (discussed below) were chosen because they provide additional insight into the geology of the area.

Diatoms and Pumice

Diatoms were found north of Seabeck–Holly Road on the upland surface where a small drainage cut exposes older deposits (Fig. 10). The diatoms were deposited on what appears to be a Possession-age diamict, on the basis of its oxidation, compaction, and stratigraphic position. It is unlikely, but possible, that it could be Vashon or Double Bluff in age. We speculate that the diatoms are from a recessional lake. We also noticed rare pumice fragments in this sample, but did not analyze them because the sample did not contain enough pumice and appeared altered. In thin section, we found only two shards of pumice.

Fossil Echinoid

A macrofossil of what appears to be an echinoid was found in a fossil-bearing siltstone interbed of the Crescent Formation. The fossil was delivered to the Burke Museum of Natural History for identification, but results were not available when this report was released.

Glacier Peak Dacite

The diamict (unit Qvc) containing dacite from Glacier Peak is well exposed at the end of Thunder Ridge Way on Hood Canal Seafood property. It is depicted on the map between Tekiu Point and Nellita.

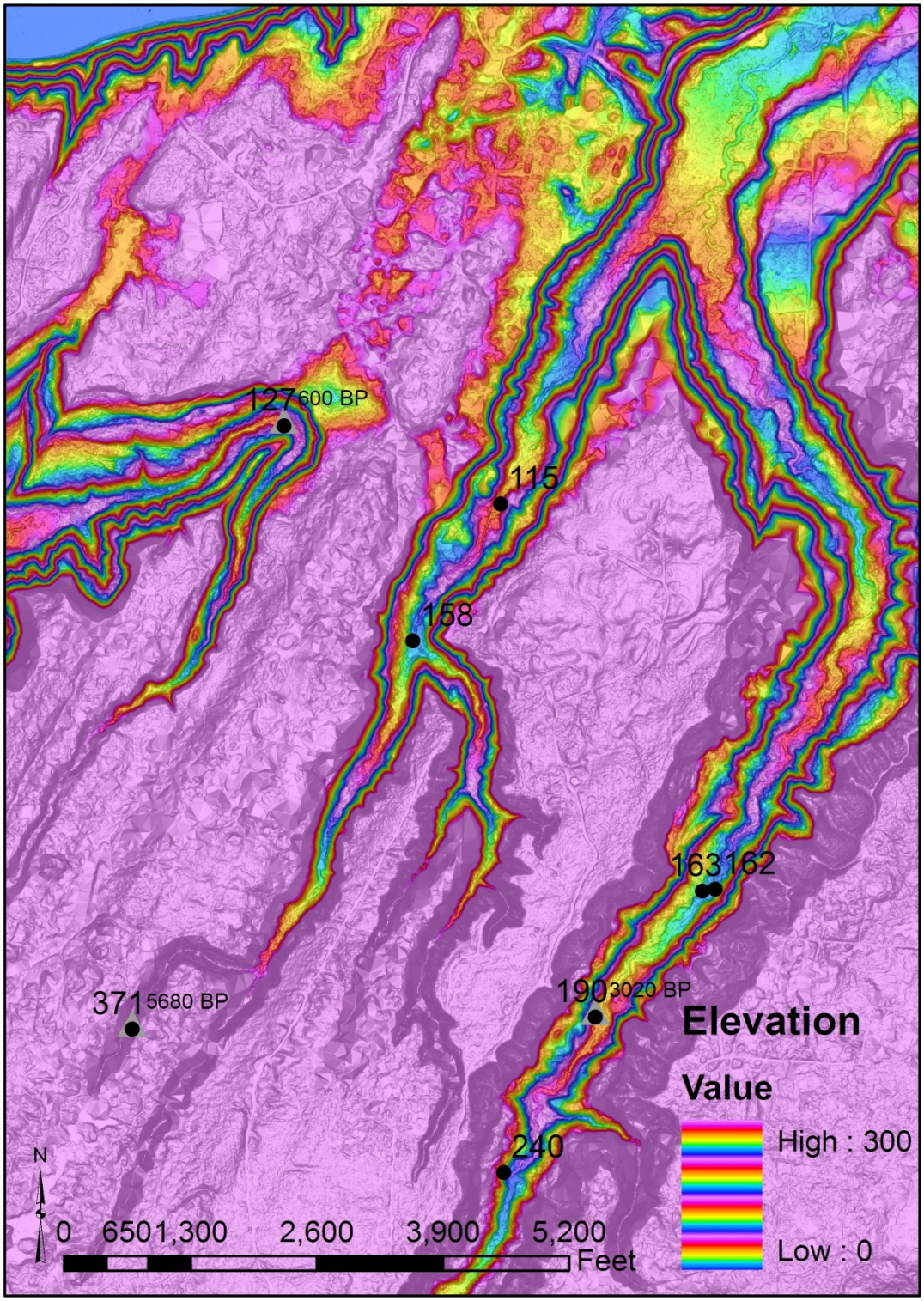

Figure 6. Terraces in the Stavis Creek drainage. Dots indicate sites visited during the field season where terrace deposits were noted. (Notice additional terraces throughout drainages.) Light gray triangles are locations with abbreviated age estimates. Numbers next to the dots are elevation in feet at modern stream level taken from a lidar digital elevation model. Shading is a processed lidar-derived hillshade from the Puget Sound Lidar Consortium. The hillshade has a vertical sun angle and six times vertical exaggeration to accentuate subtle elevation changes. The colors are a result of symbolizing elevations between 0 and 300 ft with four sets of rainbow color ramps.

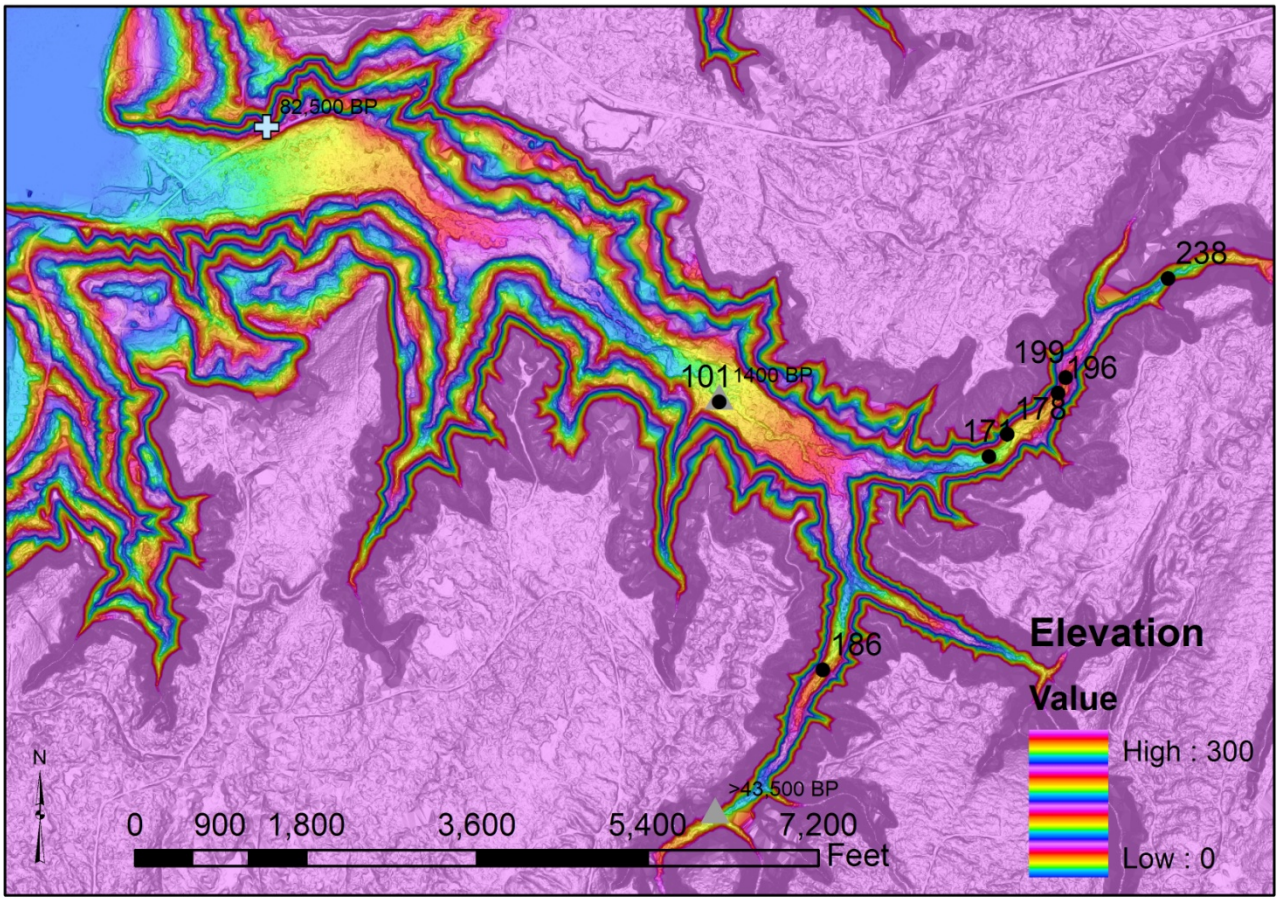

Figure 7. Terraces in the Anderson Creek drainage. Dots indicate sites visited during the field season where exposures of terrace deposits were noted. (Additional terraces occur throughout the drainages.) Numbers next to dots are elevation in feet at modern stream level taken from a lidar digital elevation model. Gray triangle or cross indicates an age site with abbreviated age estimate. Shading is a hillshade derived from lidar obtained from the Puget Sound Lidar Consortium; it has a vertical sun angle and six times vertical exaggeration to accentuate subtle elevation changes. The colors are a result of symbolizing elevations between 0 and 300 ft with four sets of rainbow color ramps.

Fault?

A juxtaposition of units of apparently different ages occurs at this significant site in Anderson Creek. A more-weathered unit $Qguc_1$ is found on the south side of the creek, and a less-weathered unit appears at the same elevation on the north side of the creek. There are multiple ways these units could be juxtaposed at this location without faulting (landslide or depositional), but in view of their proximity to strands of the Seattle fault at Green and Gold Mountains, the outcrop is worth mentioning.

Organics in Unit Qc_w

The only exposure of unit Qc_w that clearly contains organic material is in the Boyce Creek drainage. It consisted of a half-inch layer of disseminated wood and plant fragments within laminated silt and sand. The wood did not appear to be charcoal, but instead, well-preserved fragments that may be a storm deposit. The organics support our interpretation of a nonglacial environment during deposition, consistent with the age estimates for the unit and lack of obvious glacial features within the unit. A sample was collected and dried but not submitted for age dating because the expected age is beyond the limits of the technique.

Figure 8. Terrace along Anderson Creek. Terrace surface is approximately 5 ft above the modern stream bed at an elevation of 171 ft. The terrace deposit has approximately 1.5 ft of brown medium sand that includes organic materials at the base; it is covered by a 0.5- to 1- ft layer of buff fine sand, then by an oxidized layer containing dark organics. Above this is a layer of bioturbated silty sand with matrix-supported pebble gravel. For scale, the blue Paleo Pick (hidden behind vegetation below the dead limb in center) is approximately 26 in. long.

Scarp

A scarp south of Holly, shown on the geologic map as striking northwest, has a maximum relief of approximately 12 ft (Fig. 11). The scarp exposes Vashon-age friable, sandy subglacial melt-out till that we mapped as unit Qgic. This scarp may have some connection to minor magnetic anomalies in the area, shown in Blakely and others (2009),but currently this is speculative. The scarp does not appear continuous in the lidar image, but the extent may be difficult to trace due to its orientation parallel to transverse ripples in the area.

The scarp could be the result of mechanisms other than Holocene faulting, including landslides, lateral spreading, and uneven topography due to ice-contact deposits (transverse ripples) or outwash streams. We found no indications of faulting in the drainage to the southeast. However, the coarse material, which appeared to be advance outwash sands and pebble gravels, likely would not preserve evidence of movement.

Figure 9. Disseminated charcoal in older, oxidized alluvium in Anderson Creek at an elevation of 199 ft. Notice that the grusified granitic boulder is also within the older alluvium behind the blue paleo-pick, which is approximately 26 in. long..

LANDSLIDES?

Several large landforms in the map area were noted by previous workers as landslides (Deeter, 1979; Wash. Dept. of Ecology, 1979; Gold, 2004; Serdar and Powell, 2007). The largest of these apparent slides where? is more than 2,500 ft long. They are mapped within most drainages in the map area at and north of Anderson Creek. Previous workers have concluded that many of these are relict deep-seated slides. However, some of these landforms may have failed due to lateral spreading during earthquakes or may not be landslides at all. Without site-specific studies and long-term monitoring, we cannot confidently distinguish landslides from stable alluvial terraces or ice-contact deposits.

The idea that these features could be lateral spreads is based on their location, stratigraphy, and morphology. Most of these features appear restricted to the area north of Anderson Creek where they are underlain by Whidbey-age deposits. These deposits include layers of saturated, cohesionless, well-sorted sands and silts, which are liquefiable when subjected to earthquakes. The morphology of these landforms suggests that the large blocks may have slid laterally.

Figure 10. Light gray diatomite layer above a diamict that is likely of Possession age. The blue Paleo Pick is 25 in. long.

While some of these large features are likely landslides and show continued instability in the headscarps or rotational failures—as in 1999 at the Willcox mansion (Baker, 1999)—others may not be. Some of these large features, particularly those at the south side of Anderson Creek and north side of Boyce Creek could be "benched" by some other mechanism than landslides. These benches may correspond to alluvial terraces found elsewhere in the area. That stated, the apparent sag ponds and constriction of Boyce Creek make the Boyce Creek landform more likely a landslide feature.

In the drainage of Anderson Creek, we mapped some landforms previously mapped as landslides as unit Qgo (glacial outwash deposits). We did so because (1) the benches appearing extensively throughout the drainage resemble those in Boyce and Stavis Creeks at similar elevations and (2) the sands and gravels on these terraces are well sorted. For other possible landslides, we had little convincing evidence either way and, in the end, relied heavily on lidar images to interpret landforms. Where less confident in our determinations, we tried to convey this with the geologic contact line symbols—areas mapped with less confidence are symbolized to show this lower level of certainty.

ACKNOWLEDGMENTS

The associated geologic map was funded in part by the U.S. Geological Survey National Cooperative Geologic Mapping Program under award no. G10AC00363. Special thanks to Jeff and Julie Forville for such luxurious accommodations at Siloam Retreat—you two are amazing hosts; thanks to Lee Walkling for continued support in the Washington Geology Library, Jari Roloff for editing, Tim Walsh for his time and continued support (all Washington Division of Geology and Earth Resources); Robert Carson (Whitman College) and Pat Pringle (Centralia College) for their time and insight into the dacite deposit on Thunder Ridge Way; Bill Laprade (Shannon & Wilson) for help understanding the subglacial melt-out till. And thanks to all the landowners who provided access to their land, especially Jamie Courtney at Hood Canal Seafood for making available the best exposures of the deposit from Glacier Peak, and Manke Lumber, Pope Resources, Rick Whitcomb, Frank Marcinko, Don Seavy, and Gregory Schorr.

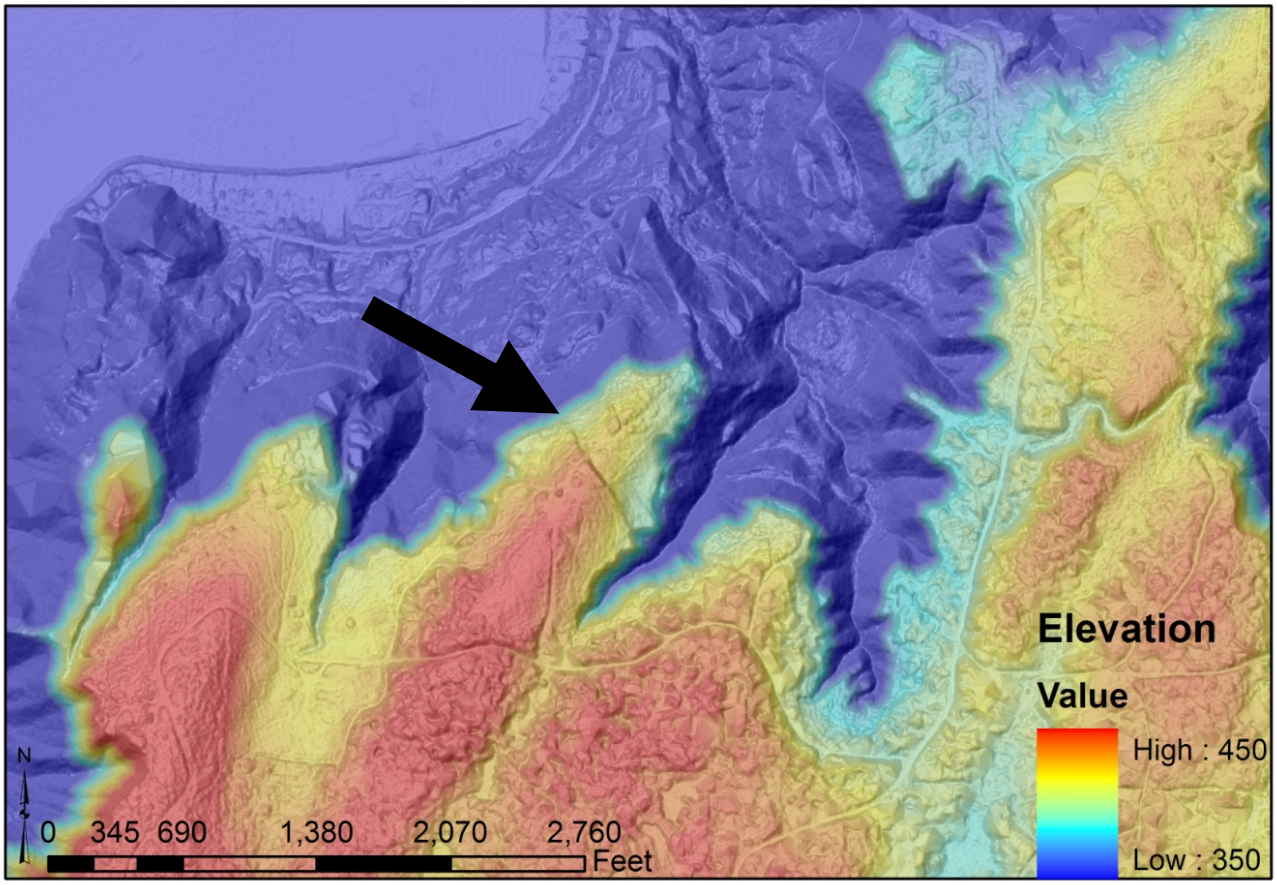

Figure 11. Scarp (significant site) south of Holly appears in middle of this figure at end of a drumlin. Arrow points to the scarp. The colors represent elevations between 400 and 440 ft. The hillshade image has been processed to accentuate changes in elevation; it has six times vertical exaggeration. Lidar obtained from the Puget Sound Lidar Consortium.

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