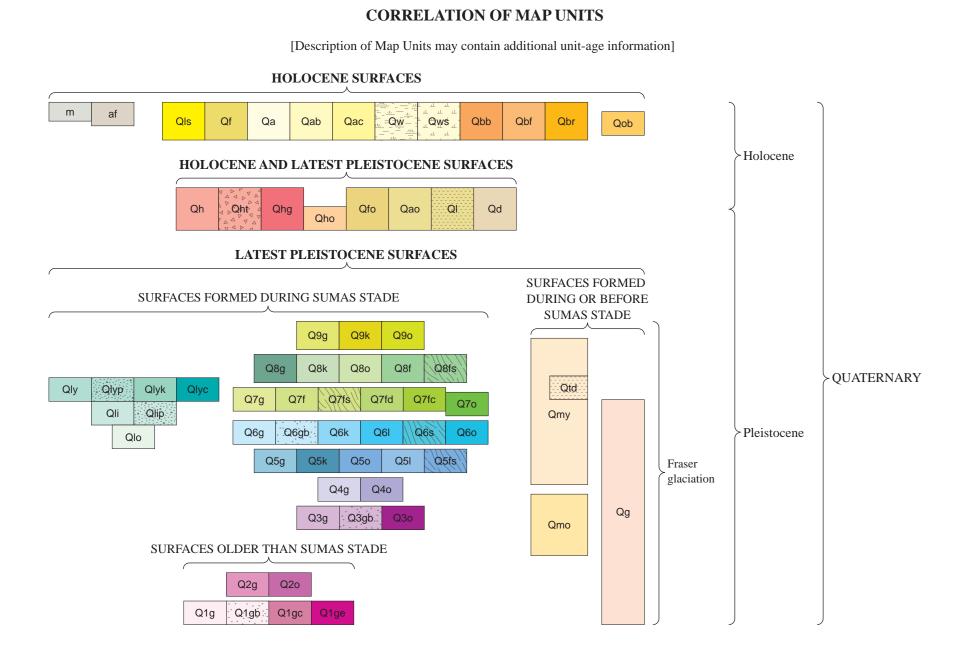
U.S. Department of the Interior Prepared in cooperation with U.S. Geological Survey Whatcom County and the Washington State Department of Natural Resources

BOUNDARY BAY



DESCRIPTION OF MAP UNITS [Some unit exposures on printed or plotted maps are too small to distinguish color for unit identification. These units are labeled where possible, and unlabeled units are attributed in the digital files]

HOLOCENE SURFACES m Modified land (Holocene)—Filled and (or) graded area; surface smooth to irregular. Locally includes areas of landfills, quarries, excavations, road and railroad embankments, settling ponds, and extensive urban and (or) industrial development. Generally not mapped except along major roads and where filling and grading is sufficient to preclude inference of the precursor surface. An exception Artificial fill—Surface of fill bodies beneath highways and railways, also surface of extensive fill at Port of Bellingham. Mapped because of propensity to fail during

toes, position in hillslope hollows, locally irregular surface, and position below associated headscarps. Includes intact slump blocks. Mostly in bedrock. Mostly located along escarpments or on steep valley sides. Does not include headscarps. Queried where identity is less certain **Fan (Holocene)**—Mostly moderately sloping (2–5°), cone-shaped surfaces; formed where a stream issues from a narrow valley into a broad valley, or where a tributary stream is near or at its junction with the main stream, or where a constriction in a valley abruptly ceases, or where the gradient of a stream abruptly decreases. Steepest hillslopes occur near the mouth of the valley where fan apex points upstream and slopes gently and convexly outward with gradually decreasing gradient; often exhibits well defined axial streams; may be coalesced. Formed in part or entirely by debris flows. Includes fan deltas in the Lake Whatcom basin. Includes similar sloping surfaces that are entirely confined within valleys Qa Alluvial flat (Holocene)—Low-slope surface formed by stream flow. May exhibit

Landslide (Holocene)—Surfaces of deep-seated landslides. Recognized by bulbous

meander scars or bar-and-swale morphology. Position on valley floor demonstrates Holocene age. Locally mapped as channel belt (Qab) and crevasse splay-natural levee complex (Qac) **Channel belt**—Meander belt or braid plain characterized by low, natural-levee ridges that flank abandoned stream courses, oxbow lakes, scroll-bar-and-swale topography. Former courses of Nooksack River Crevasse splay–natural levee complex—Complex map unit of flood-plain flats

and channels characterized by bar-and-swale topography. Crevasse splays

generally associated with breach in natural levee that carries flow away from channel during large floods. Associated with Nooksack and Sumas Rivers; Fishtrap, Bertrand, and Johnson Creeks. As mapped includes some artificial levees. Backswamp areas mapped as wetland or starved wetland (Qw or Qws) Wetland (Holocene)—Planar surface that has a low slope. Mapped on basis of geometry—position in topographic lows, local basins, or in former stream channels—and distinctive surface texture that probably reflects wetland vegetation. Includes swamp, marsh, peat bog, and fluvial backswamp. In places, has lumpy texture associated with compaction of a variable (sand-rich to sand-poor) substrate. Locally mapped as starved wetland (Qws) "Չատել" Starved wetland—Wetland that has been starved of water and (or) water-borne sediment. Identified by drainage ditches; position behind dikes and levees; and

(locally) lumpy texture developed by differential compaction that we infer reflects compaction of a variable substrate Back beach (Holocene)—Relatively flat surface constructed by modern beach accretion. Situated immediately landward of beach face and inundated only by storm-driven extreme high tides. Commonly bounded by a distinct berm crest at or near mean higher high water line. Locally includes lagoons. Some spits have flat axial areas that are mapped as back beach **Beach face (Holocene)**—Steeper upper beach found at intertidal elevations. At upper edge, bounded by berm crest and back beach or by toe of bluff. For the most part, smoothness suggests substrate is unconsolidated gravel and (or) sand. Mapped

down to waterline at time of lidar data acquisition or contact with lower slope tideflat, whichever is lower Rocky beach face (Holocene)—Irregular, lumpy upper beach found at intertidal elevations. Irregular morphology indicates substrate is bedrock or boulders. Mapped down to waterline at time of lidar data acquisition or contact with lower slope tideflat, whichever is lower

Old beach (Holocene)—Fossil beach at supra-tidal elevations. May include equivalents of modern back beach, beach face, and tide flat HOLOCENE AND LATEST PLEISTOCENE SURFACES Hillslope (Quaternary)—Steep (commonly 20–35°) surfaces that appear to be formed by creep, debris flow, shallow landsliding, and other mass-movement processes.

minor gullies. Locally mapped as talus (Qht), gullied hillslope (Qhg), and older **Talus**—Smooth, vertically extensive, in part free of vegetation. On west face of Gullied hillslope—Hillslope dissected by shallow, closely-spaced, sub-parallel

Commonly has distinct breaks in slope at upslope and downslope margins. Cut

into adjacent topography. As mapped, includes narrow alluvial flats on floors of

streamflow. Occurs either as terrace above modern drainage but below obviously

[yr B.P., years before present (where "present" is 1950); N.A., not applicable; Ref., reference (see footnote for key); max., maximum; min., minimum; cm, centimeters

13,760–13,020 220

12,390–11,500 124

14,100–13,760 180

Location Conventional age Reservoir-corrected age Calibrated age Sample altitude

Pleistocene outwash flats, or in a valley-bottom position but apparently without

Older hillslope—Lower-gradient slope located uphill of hillslope that typically has igher gradient. Position and lower gradient argue that these older slopes developed in a regime of less slope stability, perhaps without a vegetation cover Older fan (Quaternary)—Setting and morphology similar to younger fans (unit Qf). Distinguished from younger fans by greater stream-channel incision. Inactive Older alluvial flat (Quaternary)—Low-slope surface formed by deposition from

Table 1. Selected radiocarbon ages from western Whatcom County.

adequate modern contributing drainage area. Setting does not allow determination of whether these alluvial flats are Holocene or Pleistocene in age Lacustrine surface (Quaternary)—Smooth, nearly horizontal surfaces formed during former submergence. Mapped upslope to elevation of probable lake spillway. Includes some lake shoreface surfaces

Dune (**Quaternary**)—Curvilinear spur or parabolic dunes that drape discontinuously over older topography. Surface mounded, irregular, with local relief of 1–5 m LATEST PLEISTOCENE SURFACES SURFACES FORMED DURING SUMAS STADE Post-Clearbrook age surfaces, phase 9 (Pleistocene)—End moraines, outwash flats, and kettled surfaces associated with the youngest phase of glacial retreat in

Glaciated surface—End moraine formed by irregular deposition from melting ice, locally present at margin of Sumas prairie Kettled surface—Gently sloping surface with mostly closed depressions indicative of melting of subjacent ice, located inboard of Clearbrook moraine or at lower elevations than Clearbrook-age outwash flats Outwash flat—Gently sloping alluvial flat, locally with bar-and-swale topography. Landscape position, including association with adjacent end moraine and kettled surface, indicates formation by glacial meltwater Clearbrook-age surfaces, phase 8 (Pleistocene)—End moraine, outwash flat, scoured outburst flood surface, and kettled surfaces. Includes type Sumas moraine

Glaciated surface—Clearbrook moraine, formed by irregular deposition from melting ice, near margin of Sumas prairie **Kettled surface**—Lumpy, kettled surface formed by melting of subjacent ice. Mostly located inboard of Clearbrook moraine crest, but at same elevation as adjacent unit Q80 and significantly higher than unit Q9g, thus likely formed late Outwash flat—Gently sloping surface with bar-and-swale topography, local kettles (closed depressions, mapped as unit Q8k), and association with adjacent end moraine demonstrate formation by glacial meltwater

Scoured outburst flood surface—Surface with subparallel furrows and swales as much as 4 km long and 8 m deep. Mapped north of Everson, and south of Lynden-Abbotsford plain (Pleistocene)—Smooth, planar, low-relief surfaces of probable glaciofluvial (outwash), intertidal, and shallow marine origin. Surface textures in lidar DEM are almost entirely anthropogenic: roads, drainage ditches, and plow furrows (all unmapped) and manure lagoons mapped as open water surrounded by dikes (unit af). Incised by Holocene stream valleys. Set into, and thus younger than, Dakota Creek moraine of probable phase 5, Van Wyck, age. Distal parts are older than some or all of phase 7. Youngest, most proximal parts apparently in part coeval with phase 8, Clearbrook, moraines. Divided into youngest (Qly), intermediate-age (Qli), and oldest (Qlo)

Outburst flood surface—Low terrace above Nooksack River floodplain in vicinity

of Ferndale. Relative age, sea-level history, and setting appear to rule out an

Youngest surface—Smooth, low-relief surface. Includes small terraces along upper Bertrand Creek. Locally mapped as proximal fan (Qlyp), kettled surface (Qlyk), and channel (Qlyc) **Proximal fan**—Steeper part of surface with relict bar-and-swale topography, near coeval ice margin as demonstrated by adjacent kettled surface (Qlyk) **Kettled surface**—Proximal fan with closed depressions indicative of melting of **Channel**—Dendritic network of shallow troughs incised into youngest part of Lynden-Abbotsford plain. In headwaters of Fishtrap Creek

Intermediate-age surface—Smooth, low-relief surface. Separated from unit Qly by subtle ~1 m (3 ft) scarp. Locally mapped as proximal fan (unit Qlip) **Proximal fan**—Steeper part of surface with relict bar-and-swale topography and kettles that are now wetlands Oldest surface—Fragments of smooth, low-relief surface adjacent to Boundary upland. Separated from unit Qli by subtle ~1.5 m (4–5 ft) scarp Wiser Lake-age surfaces, phase 7 (Pleistocene)—Surfaces formed after commencement of flow via modern Nooksack River valley and abandonment of Tenmile Creek channel. Locally associated with discontinuous dunes (unit Qd). No end moraines preserved, but coeval ice margin was probably in vicinity of Pole Road (north edge sec. 12, T. 39 N., R. 3 E.; early phase 7) and Everson (late phase 7) **Glaciated surface**—Lumpy ground indicative of deposition by melting of nearby

ice, locally with moraine-crest ridges. Only recognized on west slope of Sumas Mountain, where identification as Wiser Lake age is tentative Outburst flood surface—Generally planar surface with large bar forms that suggest high-discharge flow. As mapped includes a kettle west of Ferndale. Locally mapped as mostly scoured (unit Q7fs), mostly depositional (Q7fd), and Mostly scoured—Nearly horizontal surface in Custer trough, accordant with Wiser Lake plain, with extensive subtle longitudinal lineations that we attribute

Mostly depositional—Plain, mostly with large bar forms that indicate deposition

Channel—Trough-like depression set into outburst flood surface; smooth except

E In situ wood in Deming sand; max. age of sand

E In situ wood in Deming sand; max. age of sand

KE In situ wood in Deming sand; max. age of sand

Tenmile Creek meltwater channel K Peat (basal; core TM2) within channel; min. age for tenmile moraine; min. age for surface of Wiser Lake outwash plain

Tenmile Creek meltwater channel K Peat (basal; core TM3) within channel; min. age for Tenmile moraine; min. age for surface of Wiser Lake outwash plain

K Peat (basal; core DH2) within channel; min. age for unit Qlip, Lynden-Abbotsford plain, proximal surface

Shell in Kulshan glaciomarine drift near present beach level; age of Kulshan glaciomarine drift

K Detrital wood in massive stony mud; min. age of Bellingham glaciomarine drift; max. age for unit Q5g K Detrital wood in massive stony mud; min. age of Bellingham glaciomarine drift; max. age for unit Q5g K Detrital wood in massive stony mud; dates Bellingham glaciomarine drift; max. age for unit Q5g K Shell in massive stony mud; dates Bellingham glaciomarine drift; max. age for unit Q5g K Shell in massive stony mud; dates Bellingham glaciomarine drift; max. age for unit Q5g

K Shell in Kulshan glaciomarine drift near present beach level; age of Kulshan glaciomarine drift

K Shell in massive stony mud; dates Bellingham glaciomarine drift; max. age for unit Q5g

Near intersection of Meridian and TS Shell in stony mud; dates Bellingham glaciomarine drift; max. age for unit Q5g

TS Shell in stony mud; dates Bellingham glaciomarine drift

Intersection of McLeod Road and E Peat below stony mud; max. age for Bellingham glaciomarine drift; max. age for unit Q4g, Airport moraine

KE Detrital wood in sand, below Kulshan glaciomarine drift; max. age for Kulshan

KE Detrital wood in sand below Kulshan glaciomarine drift; max. age for Kulshan

K Plant fragments (in basal peat; core FL1) around fringe of lake; min. age for surface of Wiser Lake outwash plain

Tenmile Creek meltwater channel K Plant fibers (1 cm below peat; core TM1) within channel; min age of channel; min age for Tenmile moraine; min age for surface of Wiser Lake outwash plain

K Organic-rich clay (50 cm below peat; core FAZ1) around fringe of lake; min. age for unit Q6g; min. age for Goshen moraine

K Plant fibers (below basal peat; core NW1) within channel; min. age for unit Qly, Lynden-Abbotsford plain, youngest surface

TS Shell in stony mud; dates Bellingham glaciomarine drift; max. age for unit Q5g?; max. age for Lynden-Abbotsford plain

for low local scarps and terraces; crudely anastomosing; now largely filled with

lakes and wetlands

Everson type locality

from outburst floods. As mapped includes small northeast-trending deflation

Tenmile Creek, but ice was still thick enough to block discharge via the modern Nooksack River valley Glaciated surface—End moraine and ground moraine. Includes Tenmile, Cedarfrom melting ice. Locally mapped as glaciated bedrock (unit Q6gb)

Kettled surface—Alluvial flat with closed depression formed by melting of subjacent ice. Remnant of delta surface built into Q6l lake Lake bed—Smooth, mostly horizontal surface formed during former submergence. Lake was impounded by phase 6 glacier to north and east, as evinced by Cedarville moraine, Stewart Mountain to south, and divide between Nooksack River and Tenmile Creek to west. Mapped upslope to elevation of probable lake **Scabland**—Mostly irregular, locally streamlined, scoured surface formed as lake

ters of Tenmile Creek. Streamlining shows convergent flow from east. Traces of bedding in underlying Eocene sandstone are locally evident Outwash flat—Smooth, nearly planar surface with faint bar-and-swale topography or local streamlining that demonstrates water flow. Found inset into lake bed (unit Q6l), on floor of Tenmile Creek channel, and—most extensively—downstream of Tenmile Creek channel where unit partly submerges islands of older glaciated surface Van Wyck-age surfaces, phase 5 (Pleistocene)—Surfaces formed when Sumas glacier locally readvanced across Squalicum meltwater channel, obliterating head of channel. On Boundary and Mountain View uplands, apparently coeval surfaces are associated with minor retreat of the Sumas glacier from Grandview (phase 4)

locally with kettled surface (unit Q5k) Squalicum Lake. Lake was impounded by Squalicum Lake moraine Mostly scoured outburst flood surface—Low-relief surface with sub-parallel (also mapped as Q5fs) where cataract spilled over crest of Birch Point moraine outwash flats formed by Sumas glacier as it advanced, or readvanced, over

coeval with lower relative sea level and thus is younger Glaciated surface—End moraine and ground moraine. Includes Haynie Creek, Grandview, Lummi, and Airport moraines. Includes minor ice-molded surface Q40 Outwash flat—Includes floor of Squalicum channel, top of relict Squalicum delta in northwest Bellingham and extensive alluvial flat east of Lake Terrell Holman Hill-age surfaces, phase 3 (Pleistocene)—Extensive end moraine and associated surfaces, formed when relative sea level was at ~73–65 m elevation west of Ferndale and ice margin was near Ferndale **Glaciated surface**—End moraine, ground moraine, and glacially shaped ground.

mapped as glaciated bedrock (unit Q3gb) Glaciated bedrock—Glaciated ground at King Mountain with bedding traces that indicate subjacent bedrock. Exterior to (thus older than) phase 5 Squalicum Lake moraine; interior to, thus coeval with or younger than phase 3 Alderwood and Sunset moraines; could be of phase 4 age Outwash flat—Alluvial flat nestled outside of phase 3 moraine crest on lower

Younger marine-modified surface (Pleistocene)—Surface smoothed by marine deposition, tidal current scour, and wave erosion and deposition. Commonly decorated by fossil shorelines. Coeval with, and younger than, maximum extent of phase 4 (Grandview-age) ice, as shown by change in form of Grandview and Haynie Creek moraine crests: sharp (subaerial deposition) above upper limit of unit Qmy and subdued (submarine deposition) at lower elevations; also presence of Qmy surface inboard of phase 4 moraines. Locally mapped as tidal delta (unit **Tidal delta**—Ebb tide delta in Custer trough, recognized by near-flat surface, lobate western (distal) margin, and location where channel expanded. Formed in phase 7 (Wiser Lake) or younger time

Description and significance

Plant fragment (4 cm below peat; core TM2) within channel; min. age of channel; min. age for Tenmile moraine; min. age for surface of Wiser Lake outwash plain

K Seed pod (~10 cm below basal peat; core PB2) around fringe of lake, within kettle; min. age of kettle; min. age for unit Qlyp, Lynden-Abbotsford plain, proximal fan

K Plant fibers (1 cm below basal peat; core PB1) around fringe of lake, within kettle; min. age of kettle; min. age for unit Qlyp, Lynden-Abbotsford plain, proximal fan K Seed pod (~10 cm below basal peat; core PB2) around fringe of lake, within kettle; min. age of kettle; min. age for unit Qlyp, Lynden-Abbotsford plain, proximal fan

K Bellingham glaciomarine drift; massive stony mud; age of Bellingham glaciomarine drift; max. age of unit Q4g; max. age of Airport moraine; max. age for fossil shorelines

Peat (basal; core TM1) within channel; min. age of channel; min. age for Tenmile moraine; min. age for surface of Wiser Lake outwash plain

K Organics (organic-rich clay below basal peat; core DH2) within channel; min. age for unit Qlip, Lynden-Abbotsford plain, proximal surface

K Shell in Bellingham glaciomarine drift; age of Bellingham glaciomarine drift; max. age for Airport moraine; max. age for fossil shorelines

TS Peat around fringe of lake, within kettle; min. age of kettle; min. age for unit Q3g?, Sunset moraine; min. age for unit Q5g, Squalicum moraine

TS Peat (basal) from depression; min. age for Wiser Lake outwash plain; min. age for establishment of Holocene sedimentation on Nooksack floodplain

Outwash flat—Local bar-and-swale morphology. Formed by water flow from southeast (Nugents Corner) to northwest (Everson), thence to southwest (Ferndale) along modern Nooksack River drainage. Slightly older than, and perhaps overlapping in age with, outburst flood surfaces Q7f, Q7fs, and Q7fd Tenmile Creek-age surfaces, phase 6 (Pleistocene)—Surfaces formed after Sumas glacier retreated sufficiently to allow discharge of ice-marginal drainage via

ville, and Goshen moraines. Locally with nearly-parallel lineations ("flutes") formed by ice flow. Locally with regular (washboard) and irregular deposition Glaciated bedrock—Glaciated ground with bedding traces, or distinctive microtopography suggestive of control by substrate competency contrasts, that indicate

that occupied the Nooksack River valley near Cedarville spilled into the headwa-

Glaciated surface—End moraine and ground moraine. Includes Wahl, Squalicum Lake, Northwest Drive, Lampman Road, Lummi Shore Road, Birch Point, Dakota Creek moraines. Locally fluted by ice flow. Common irregular local relief, up to 5 m (16 ft), suggests deposition from melting debris-rich ice. Local "washboard," oblique to ice flow direction, formed by meltout of crevasse fillings. Absence of smoothing indicates no subsequent marine or lacustrine **Kettle, kame**—Includes kettles near Ferndale, on Boundary upland, and on King Mountain upland; kame surfaces along Squalicum Creek near Van Wyck

Outwash flat—Nearly planar, low-slope surface adjacent to phase 5 end moraine,

Lake bed—Smooth, nearly horizontal surface that partly rims depression around ridges. At east end of surface, ridges terminate in plunge pools and local scabland **Grandview-age surfaces, phase 4 (Pleistocene)**—Extensive end moraines and local formerly wave-washed areas. Coeval relative sea level was ~30 m near Ferndale and ~50 m east of Blaine. The Alderwood moraine south of Bellingham airport is

Includes Monument 11, Holman Hill, Alderwood, and Sunset moraines. Locally

SURFACES FORMED DURING OR BEFORE SUMAS STADE

Glaciated surface of undifferentiated age (Pleistocene)—Largely glaciated bedrock surface, mapped on west slope of Sumas Mountain where subdivision into phases 1–6 is not possible, in part because of low quality of lidar topography Older marine-modified surface (Pleistocene)—Similar in morphology and setting to unit Qmy, having a surface smoothed and modified by marine deposition, tidal scour, and wave erosion and deposition, punctuated by fossil shorelines, but mapped at higher elevations. Older than maximum extent of phase 4 (Grandview age) ice but younger than phase 2 (Monument 10 age) surfaces

SURFACES OLDER THAN SUMAS STADE Monument 10-age surfaces, phase 2 (Pleistocene)—Surfaces formed after significant thinning of Vashon-age ice sheet and before or at the time of highest observed post-Vashon-age relative sea level **Glaciated surface**—Includes Monument 10 moraine at United States-Canada border: low-relief moraine crest and lumpy ground moraine, without smoothing

by marine and beach processes, located above highest fossil shoreline; and

formed under stagnant late-Vashon ice, minor ablation moraine, and minor local

end moraine. Identified by higher elevation and north-south ice-flow lineations

Glaciated surface—Mostly smooth, undulating surface, typically with generally

sharply crested, mostly smooth Anderson Creek end moraine on north side Outwash flat—Includes kame surface built against Anderson Creek moraine or northwest side Stewart Mountain, somewhat lower alluvial flats north of Lake Whatcom, and isolated alluvial flats near Lake Samish at near maximum post-Vashon local relative sea level elevation Vashon-age surfaces, phase 1 (Pleistocene)—Ice-molded ground that formed beneath thick, south-flowing Vashon-age ice sheet, eskers and channels that

south-trending ice-flow lineations. Limited to southern and higher-elevation areas outside the extent of Sumas-stade ice. Includes minor lumpy ablation moraine and small, sinuous ridges of end moraine. Locally mapped as glaciated bedrock Glaciated bedrock—Glaciated ground with bedding traces, or distinctive microtopography suggestive of control by substrate competency contrasts, that indicate subjacent bedrock **Sub-ice channel**—Short segments (as long as 1.5 km) of smooth-walled channel, as wide as 300 m (1,000 ft) and as deep as 60 m (200 ft), apparently water-carved,

but without apparent source or sink for flowing water. Mostly on ridge crests. Smooth transitions between floor and steeper walls suggest that channels were entirely filled with flowing water. Inferred to have been eroded by meltwater at base of ice sheet. Lack of subsequent glacial smoothing suggests formation under Esker—Sinuous, narrow (20–40 m, 65–130 ft) ridge formed by stream deposition beneath enclosing ice. Preservation suggests ice was stagnant

Contact—Continuous where estimated location uncertainty less than 50 meters, dashed where estimated location uncertainty greater than 50 meters Fossil shoreline—Where fossil shoreline follows contact, fossil shoreline is shown

EXPLANATION OF MAP SYMBOLS

..... Moraine crest Glacial lineation

[See pamphlet for more detailed discussion of map area]

sea-level change, fluvial erosion and deposition, landsliding, nearby volcanic activity, and human

modification. This map documents the landscape of western Whatcom County and interprets its

history. The map was produced by analysis of a digital elevation model derived from lidar (light

Earth materials, this geomorphic map focuses on the form and position of the Earth's surface. The

Western Whatcom County sits at the junction of the Fraser Lowland and the foothills of the

northern Cascade Range (fig. 1), commonly called the North Cascades. Subsurface preservation of

accompanying pamphlet presents detailed descriptions of our methods, interpretations, and the

supporting landform evidence. The following paragraphs summarize our interpretations.

detection and ranging) data. Unlike a traditional geologic map, which describes and interprets

The landscape of western Whatcom County preserves evidence of a rich history of glaciation,

— Fault gully Possible fault and (or) fault-line scarp—Identity is uncertain ¹⁴C sample locality with laboratory sample number

Neogene strata (Hopkins, 1968) suggests that the Fraser Lowland has been subsiding since the Miocene. The Fraser Lowland is part of the Georgia Basin (or Georgia Depression), which preserves strata of Late Cretaceous and Eocene age. Although many authors have suggested localized subsidence of the Georgia Basin since the Late Cretaceous, there is scant evidence that the modern Georgia Basin coincides with Late Cretaceous and Eocene basins. The physiographic record of the area largely begins with the Vashon stade of the Fraser glaciation of Armstrong and others (1965) (phase 1). At the peak of the Vashon stade, shortly after 16,000 years ago (Haugerud, 2020), the Cordilleran ice sheet was ≥1.6 km thick in the Bellingham area (Easterbrook, 1963; Booth, 1987; Haugerud and Tabor, 2009). Glacial lineations on high ground in the southeastern part of the map area demonstrate that ice flow was from north to south. Storage of water in ice sheets at this time resulted in global sea level ~120 m lower than at present. In the Fraser Lowland, the weight of the ice sheet depressed the land (glacio-isostatic adjustment) more than 320 m at Vancouver, British Columbia, Canada (35 km north of the map area) (Mathews and others, 1970; see also Hutchinson and others, 2004), resulting in local relative sea level at least 200 m higher than at present.

As the Vashon-age Cordilleran ice sheet melted and thinned, it locally floated, broke up, and was replaced by marine water, which flooded much of western Whatcom County at ~14,000 years ago (Mathews and others, 1970; Kovanen, 2002). The depositional record shows that the margin of the Cordilleran ice sheet—or at least its grounding line—retreated to the northeast of our map area (Armstrong, 1981). The highest observed post-Vashon marine shoreline surrounds the Monument 10 moraine (phase 2, fig. 2) on the Boundary Upland at a modern elevation of ~150 m. Marine deposition, currents, and waves smoothed earlier-formed surfaces in the western part of the map area. During and after thinning of the ice sheet, global sea level rose (because of melting of continental ice sheets), but the Fraser Lowland rose even faster (due to glacio-isostatic rebound following the loss of ice-sheet load), and thus local relative sea level fell. A rich suite of fossil shorelines formed on most uplands near the present coast, probably during occasional storms. Rebound was greater to the northeast, towards the center of the Cordilleran ice sheet: our analysis of fossil shorelines shows a mean post-glacial tilt of about 1.3 m/km up toward N 30° E, which is reasonably consistent with the 1 m/km up-to-the-north tilt observed by Thorson (1989). As glacio-isostatic rebound continued and relative sea level fell, the Cordilleran ice sheet readvanced across most of western Whatcom County during the Sumas stade of Armstrong and others (1965) (phases 3 through 9, fig. 2). Earlier authors (such as Easterbrook, 1963; Clague and others, 1997; Kovanen, 2002; Kovanen and Easterbrook, 2002a), working largely from depositional evidence, saw a limited extent to Sumas glaciation and discerned one to four phases. Our mapping shows that Sumas ice was more extensive and details a richer history. The oldest Sumas moraines formed during phase 3, when relative sea level at Bellingham was ~55 m. A second set of moraines formed during phase 4, when relative sea level at Bellingham was ~25 m, sometime after ~13,500 years ago. The amount of Sumas ice retreat and readvance between phases 3 and 4 is unknown, but it could have been significant. The maximum extent of Sumas ice occurred during phase 4, during which the ice sheet reached at least as far as the modern coastline. A well-developed fossil shoreline, found on the south side of the Boundary upland on the north and east sides of the Mountain View upland, and at the northeast end of the Lummi peninsula (all identified on fig. 1), is associated with phase 4. We use this shoreline and its lateral extrapolation to separate marine-modified surfaces into older (unit Qmo) and younger (unit Qmy) units. Phases 5 through 9 are marked by local moraines, progressive isostatic rebound and lowering of relative sea level, and changes in the flow of ice-marginal water. During phase 5, the southeastern margin of the Sumas ice sheet advanced, perhaps because capture of ice-marginal drainage by the Samish River (east and south of the map area) meant the glacier here was no longer trimmed by high-discharge flow along the Squalicum channel. Farther west and north, the Sumas ice

margin retreated between phases 4 and 5. Phases 6 through 9 may mark stillstands during ice retreat. There were glacial outburst floods (jökulhlaups) during phases 7 and 8, and perhaps during Easterbrook, 2002a), the Nooksack River appears to have discharged northeast through Sumas Valley to the Fraser River. Details of the switch to its modern course are speculative, but geomorphic evidence demonstrates that between Everson and Lynden the Nooksack River filled a pre-existing trough. Archaeological (Hutchings, 2004) and sediment-supply (Maudlin and Stark, 2007) arguments suggest that the modern Nooksack River delta south of Ferndale formed in late Holocene time, within the past 5,000 years. The foothills of the North Cascades are decorated with abundant deep-seated landslides of Holocene (post-glacial) age. These landslides are largely a consequence of glacial steepening of slopes underlain by weak bedrock, perhaps abetted by occasional large earthquakes and abundant rainfall. There are no clear signs of earthquake-related surface rupture within the map area, although there are anomalously high late Holocene beaches at Birch Bay, Neptune Beach, perhaps at Maple Beach on the east side of Point Roberts, and perhaps at the northwest corner of the Lummi Peninsula. These beaches may have been uplifted by earthquakes that did not rupture the The low-relief landscape shaped by the Cordilleran ice sheet, along with fluvial infilling of

When Sumas ice left the area, perhaps about 11,500 years ago (Kovanen, 2002; Kovanen and low areas, resulted in abundant wetland. In the past century and a half, much wetland has been

diked and (or) drained to control flooding and facilitate farming. Our mapping, which may

percent of pre-1860 wetland.

Figure 1. Location and topography of western Whatcom County. Solid red line is the boundary of the geomorphic map. Arrows show the inferred flowpath of glacial meltwater during phase 5 from Cultus Lake through Columbia Valley to the Samish River valley.

48.73° N.; Central meridian -120.83° W.; North American Datum of 1983

underestimate the extent of drained wetland, shows loss of at least 40 km² (15 square miles), 70 Post-Clearbrook Moraine crests, by phase (moraine name in brown)

Post-Clearbrook—phase 9 Tenmile Creek—phase 6 Grandview—phase 4 Monument 10—phase 2 Clearbrook—phase 8 Van Wyck—phase 5 Holman Hill—phase 3 Vashon—phase 1 Figure 2. Shaded-relief map showing the distribution of end moraines in western Whatcom County. Also shown are Lynden-Abbotsford plain and Wiser Lake outwash plain, formed by glacial meltwater approximately 13,000 years ago, the modern flood plain of the Nooksack River (in pale yellow) and communities mentioned in the pamphlet text. We assign end moraines and the Wiser Lake outwash plain to 9 phases in the glacial history of the region, from approximately 15,000 to 11,500 years ago. These phases are identified by their associated moraines, ice flow directions, meltwater pathways, and relative sea levels. Cross-cutting relations establish a relative

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e modified from U.S. Geological Survey and other Federal and State digital dat 73° N.; Central meridian -120.83° W.; North American Datum of 1983

history; see Description of Map Units and the Correlation of Map Units diagram.

BELLINGHAM Terrestrial contours and base image calculated from U.S. Geological Survey 2006 North Puget Sound lidar survey, Puget Sound Lidar Consortium 2005 Lummi-Nooksack River survey, and PS Mapped from lidar topography by R.A. Haugeru and D.J. Kovanen, 2008–2011 09 Nooksack River and San Juan County and Lummi Island surveys. Lidar data available at GIS database and digital cartography by Haugerud and Kovanen $\label{eq:market} \mbox{Marine contours and base image calculated from NOS hydrographic survey data available at }$ Edited by C.M. Landowski; digital cartographic nttp://www.ngdc.noaa.gov/mgg/bathymetry/hydro.ht production by J.F. Mangano Lake Whatcom bathymetry from City of Bellingham Manuscript approved for publication April 30, 2018 CONTOUR INTERVAL 20 METERS Place names from USGS Geographic Names Information System VERTICAL DATUM NAVD 1988 DEPTH CONTOUR INTERVAL 10 METE Roads from Washington Department of Transportation

B-230133 48.77° N, 122.53° W 11,660±80 TS Detrital wood in Bellingham glaciomarine drift; min. age of Bellingham glaciomarine drift; max. age of Airport moraine; max. age for fossil shorelines The reservoir corrected age for marine shells is the conventional ¹⁴C age minus a reservoir value of -1,100 years; Kovanen and Easterbrook, 2002b). The ± is the reported laboratory precision and does not include any error associated with determination of the reservoir value.

14,270–13,810 206 Detrital wood Everson type locality

Marine shell Everson type locality

Detrital wood Everson type locality

Bertrand Creek

³2-sigma age range determined from CALIB5.2 program (Stuiver and Reimer, 1993). Rounded to nearest decade. ⁴E—Easterbrook, 1963; K—Kovanen, 2001; KE—Kovanen and Easterbrook, 2002a; TS—this study.

This map is offered as an online-only, digital publication. Users should be aware that some sligh

not imply endorsement by the U.S. Government.

PLSS lines, Whatcom County boundary, and road names from Whatcom County GIS data

¹University of British Columbia;

²U.S. Geological Survey; ³Western Washington University

Lat-long tics, North American Datum of 1927