

# Geologic Map of the Elwha and Angeles Point 7.5-minute Quadrangles, Clallam County, Washington

#### METHODS This project was mapped concurrently with the Port Angeles and Ediz Hook

quadrangles (Schasse and others, 2004), which assisted us in our interpretation of geologic structure and Quaternary units. We used a digital elevation model (DEM) based on lidar data from the Puget Sound Lidar Consortium (http://rocky2.ess.washington.edu/data/raster/lidar/index.htm) to identify landforms and map geologic contacts with a level of confidence not previously attainable in densely vegetated or inaccessible areas. We believe that contacts are within about 200 ft of their shown location. To make our mapping consistent with conditions implied by the underlying basemap, we adjusted some contacts where the basemap is inaccurate, such as along the Elwha River. Consequently, some contacts are shifted up to 550 ft from their true location. These contacts are identified by purple contact lines. We used selected water well logs supplied by the Washington Department of Ecology to interpret structure and subsurface geology. We used the geologic time scale of the Correlation of Stratigraphic Units of North America Project of the American Association of Petroleum Geologists (Salvador, 1985), with boundary-age modifications of Montanari and others (1985). We use 'ka' to mean thousands of calendar years before

A.D. 1950. We identify radiocarbon years by the term '<sup>14</sup>C'. We conform data provided by other workers to the same terminology, unless we are unsure of their meaning, in which case we report their terminology in quotation marks. Some volcanic rocks are identified using whole-rock geochemistry and total-alkali silica diagrams (Zanettin, 1984). Sandstones are named using the classification scheme of Dickinson (1970). Most of our bedrock linework and interpretations differ little from those of Brown and others (1960) and the

regional summaries of Tabor (1975) and Tabor and Cady (1978a,b). We agree with Schasse (2003) in inferring faulting not shown by Tabor and Cady. Our other revisions pertain mostly to the Quaternary sediments. We sought to map Quaternary units where they mask the underlying units and appear to be thick enough to be of geotechnical significance, generally 5 ft or thicker. **GEOLOGIC SETTING AND DEVELOPMENT** 

Tertiary sedimentary rocks of the upper Eocene to lower Miocene Twin River Group and the middle Eocene Aldwell and Lyre Formations overlie the early to middle Eocene Crescent Formation and Blue Mountain unit in the map area. We agree with Snavely and others (1978) in referring to the upper, middle and lower members of the Twin River Group (Twin River Formation of Brown and Gower, 1958, and Brown and others, 1960) as the Pysht, Makah, and Hoko River Formations. The Tertiary units are folded and thrustfaulted together by post-early Miocene tectonism. For a north-south bedrock cross section, see Schasse and others (2004). Late Quaternary sediments thinly and discontinuously drape the foothills below 1500 ft elevation and locally thicken to several hundred feet in the coastal plain (Wash. Dept. of Ecology, 1978; K. L. Othberg and R. L. Logan, Wash. Divn. of Geology and Earth Resources, unpub. field notes, 1977). Sediments from Vancouver Island and the Canadian Coast Ranges (herein termed 'northern') were deposited in the map area by the late Wisconsinan and earlier continental glaciations. Northern sediments are distinguished from sediments from the Olympic Range (Olympic) based on their lithologic

The remaining 10 percent includes basalt, argillite, and low-grade metamorphosed rocks (mostly metasedimentary). Northern sediments are more polymict and include the rock types found in the Olympics as well as high-grade metamorphic rocks, granitics, and other crystalline rocks. Northern sand is generally lighter in color, rich in polycrystalline quartz, better sorted, and more mature than Olympic sand. **CONCEPTUAL MODEL OF LATE QUATERNARY** 

constituents. Olympic sediments consist of about 90 percent lithic sandstone.

### LANDSCAPE DEVELOPMENT

The modern landscape was formed by the interaction of the Juan de Fuca lobe (JFL) of the late Wisconsinan glaciation and the Elwha River. JFL till (unit Qgt) discontinuously conceals JFL advance outwash (unit Qga), older sediments, and bedrock. The Pleistocene Elwha River delta fan consists almost entirely of a thick sheet of compact Olympic gravel (unit Qoa<sub>p</sub>) with less than 1 percent northern sediment. Unit Qoap is discontinuously covered by till that is rarely underlain by advance outwash and is locally dominated by Olympic clasts. This suggests that Olympic sediment overwhelmed the glacial input, and drift was, to some extent, diverted away from the Elwha River delta region by Elwha River sediment. The scarcity of northern sediment above unit Qoa<sub>p</sub>, coupled with a relative abundance of northern sediment beneath unit Qoa<sub>p</sub>, further suggests that some time prior to the late Wisconsinan glaciation, the lower Elwha followed a different course.

Continental ice advanced to roughly the 3800-ft contour along the mountain front (Long, 1975) and 2.3 mi south of the Little River in the Elwha valley, where it deposited a 100-ft-high terminal moraine. South of this moraine, Long (1975) interpreted as till what we believe to be glaciolacustrine sediments, and Long thus mapped the Elwha valley ice limit south of the Elwha quadrangle. Most workers appear to favor a JFL ice advance at about 17<sup>14</sup>C ky B.P. and recession at about 14.5 to 14<sup>14</sup>C ky B.P. (Fig. 1; Anderson, 1968; Heusser, 1973; Petersen and others, 1983; Waitt and Thorson, 1983). Blunt and others (1987) favor an advance some time "after 17,000 years ago". We did not find Olympic alpine drift in the map area. Sediment of Olympic provenance arguably must include alpine glacial

outwash, but because we can not distinguish it from other Olympic alluvium, we have reserved the terms 'glacial', 'outwash', 'drift', etc., to deposits associated with JFL ice (except in the unit description for Qoa<sub>p</sub>). Because JFL ice failed to override most of the Elwha watershed, outwash in the lower Elwha valley was quickly covered by alluvium (unit Qoa). Terrace grading along the Little River valley suggests that some outwash deposition away from the Elwha valley was coeval with deposition of unit Qoa in the Elwha valley. Such coeval deposition and mixing of units Qoa

and Qgo are further supported by data of Heusser (1973), who suggests that some JFL ice may not have melted until after 8 <sup>14</sup>C ky B.P. (~8.8–9 ka). Deposition of unit Qgo began with locally ice-free conditions some time between 14,460  $\pm$ 200 and 12,000  $\pm$ 310 <sup>14</sup>C yr B.P. (Heusser, 1973; Petersen and others, 1983). Outwash is now only sparsely exposed because latest Pleistocene and Holocene alluvium (units Qoa and Qa) largely obscures the outwash. Drainages were eliminated during glaciation, and new drainage networks were later established. Glacial ice significantly depressed the crust in the region. When the ice

melted, the global rise in sea level (see fig. 8 of Booth, 1987) initially outstripped crustal rebound in the field area (Mathews and others, 1970), raising relative sea level in the field area to >130 ft above modern mean sea level (MSL) (Dethier and others, 1995). That late Wisconsinan relative sea level maximum (**RSLM**) is recorded by deposition of glaciomarine drift (included with unit Qgo<sub>s</sub>) to at least 125 ft above MSL. Possible deposits of glaciomarine drift at higher elevations may be concealed by younger sediments. The timing of glaciomarine drift deposition is constrained by data of Dethier and others (1995), who report a radiocarbon age of  $12,600 \pm 200$ <sup>14</sup>C yr B.P. from a shell in glaciomarine drift 19 mi east of the study area (their locality 11, fig. 2), and by beach uplift data from the Victoria area on Vancouver Island, which suggest maximum post-glacial relative sea level there at about "13,000 y B.P." (Mathews and others, 1970). Low energy sediments on the coastal plain (units Qgo and Qoa) and

extensive river terraces (unit Qoa), which are perched up to about 200 ft above the modern valley floor along the Elwha River, appear graded to the RSLM. The slope and elevation of these river terraces relative to the slope and elevation of glaciomarine drift above the sea cliffs suggest terrace grading to a base level significantly above MSL. Although ice- or landslidedamming of the lower Elwha valley could alternatively have temporarily elevated base level west of the "Dry Hills" along the lower Elwha River, field relations provide little support for such a local, lake-forming base level control. Thus, an elevated relative sea level in the area likely controlled position of the highest terraces of unit Qoa along the Elwha River and coeval terraces of unit Qgo in smaller basins, which suggests deposition of these terraces during the time of recessional late Wisconsinan glaciomarine drift deposition about 13.3 ka (Fig. 1; Mathews and others, 1970; Dethier and others, 1995). After RSLM, crustal rebound in response to glacial unloading caused

relative sea level to rapidly drop to about 200 ft below MSL (Fig. 1; Mosher and Hewitt, 2004), which triggered cutting of the steep-walled, modern valleys that are mostly limited to the unconsolidated deposits of the field area. The rate of rebound had to greatly outstrip global sea level rise and may have reached between 68 and 74 mm/yr to permit the rate of relative sea level drop estimated by Mosher and Hewitt (2004) at ≤58 mm/yr. Multiple river terraces (unit Qoa) dot the sidewalls of the modern valleys and record this period of incision, with higher terraces being older. Where streams are now bedrock controlled, they have since continued to incise. Close to shore, the larger valleys have an alluvial floor that broadens toward the shore, reflecting alluvial infilling (unit Qa) of deeper post-glacial valleys (Galster, 1989; Steve Evans, Pangeo, Inc., oral commun., 2004). Where streams did not incise into the coastal plain, unit Qa may locally grade down into unit Qoa. Both units Qa and Qoa stratigraphically succeed but may locally interfinger with unit Qgo.

Crustal rebound in the area was apparently mostly completed by 10.7 ka (Fig. 1) (Mosher and Hewitt, 2004, and references therein). Therefore, deposition of unit Qa as infill of the modern valley floors began at roughly 10.7 ka and continued until sea level approximated MSL at about 6 ka (Fig. 1; Mathews and others, 1970; Clague and others, 1982; Booth, 1987; Dragovich and others, 1994; Mosher and Hewitt, 2004). Since then, alluvial valleys near the shore have likely undergone little change. At the shore, the Holocene has been marked by sea level rise, shoreline erosion, and 3000 to 5000 ft of coastal retreat (Galster, 1989).

LARGE-SCALE LANDSLIDING AND STRUCTURAL GEOLOGY Landslides are common in the map area. The Pysht Formation (unit  $\mathbb{H}Om_P$ ) appears most slide-prone, followed by the Quaternary units (especially where glaciolacustrine sediments [unit Qgl] are present), then the Aldwell Formation (unit Em<sub>2a</sub>). Landslides in Quaternary sediments below 1000 ft elevation are common all along the Elwha valley, but most extensive south of the ice limit, perhaps due to lack of compaction by JFL ice. The post-glacial Lower Indian Creek slide complex (LICS) on the north side of Indian Creek

valley incorporates areas mapped as units Qls, Qols, Qlsf, Qas, Qaf, Qp, Em<sub>2a</sub>, Em<sub>2ls</sub>, and Em<sub>2lc</sub>. It spans 1500 ft of relief, has covered at least 1 mi<sup>2</sup> of valley floor with slide debris that has pushed Indian Creek to the southern valley margin, and is even more extensive in the subsurface. Slide body morphology suggests that the LICS may incorporate multiple major events. Evidence for recent activity is limited to rockfalls and debris flows in the headwall. Most debris flows are on the western flank, which lacks Lyre Formation conglomerate (unit Em<sub>2lc</sub>) at the top. Our interpretation of the bedrock structure is based in part on the

structure mapped by Brown and others (1960) and Tabor and Cady (1978a), structural interpretations by MacLeod and others (1977) and Tabor (1983), and geologic structure in the adjoining Port Angeles quadrangle to the east (Schasse and others, 2004). Four previously mapped faults and the Clallam syncline traverse the field

area. The Clallam syncline is an east-southeast-trending, regional open fold across the northern third of the map area. It plunges gently east and northwest away from the Elwha River and has deformed all bedrock units in the area (Brown and others, 1960). Angular unconformities and pinching-out of several units in the north limb suggest that some folding pre-dates deposition of the upper Eocene Hoko River Formation (Brown and others, 1960).

Three faults roughly parallel the C north-side-up reverse slip. The northern the syncline and was noted by Brown a Tabor and Cady (1978a), Tabor (1983) Schasse (2003), but has not been forma within the field area as the Lower Elwl used by Atkins and others (2003). Bro structure as the Freshwater fault. We b fault to be a post-early Miocene structu Brown (1970) showed the south limb of agree with Tabor (1983), Dragovich an and show the north limb as upthrown. The second previously mapped fau Little River and Indian Creek valleys. 1978a; Tabor, 1983; Dragovich and oth the Lake Creek fault (Brown and other Creek fault (Brown and others, 1960) t on the connection but did not show it Lake Creek–Boundary Creek fault (LC field area reveals surface lineaments a trend of the LCBCF in Little Creek va lineament 0.2 mi east of the Elwha Riv maps a possible alternate alignment or several other, subparallel lineaments ( The LCBCF offsets late Eocene and the timing of its activity. Until a lidar-b was no documented evidence for Quate landsliding that dammed Lake Crescen (Logan and Schuster, 1991). But scarps postglacial movement. Whereas some scarps along Little has been confidently identified in the y Elwha River. Some possible scarps are these are either subtle or not subparalle imply that the fault is inaccurately map across a broader zone or that deposition Elwha River post-dates the latest LCB correct, the age of these units relative t

Elwha River stratigraphically brackets If the fault is located near the south (see map), it passes through unit Qoag. undated but appear to be roughly corre rebound at the end of RSLM, which a 1; Mathews and others, 1970; Dethier a 2004). RSLM also marks the inferred 1 terraces that appear to contain scarps a fault alignment as shown is correct, the sometime close to 13.3 ka. If the LCBCF enters Indian Creek LICS. This slide complex rivals in scal workers (Reagan, 1909; Weaver, 1937; ) have ascribed the damming or field area. Tabor (1975) and Logan and sliding at Lake Crescent may have been triggering would be equally reasonable A unit Qoa terrace that appears to c gravel is incised into and therefore pos of the LICS. The gravel clast size on t LICS were active before Lake Crescen events in both locations were seismica

multiple events between RSLM around level that controlled deposition of the a east side of the LICS. Because crustal lowered sea level would have followed most (Fig. 1; Mathews and others, 197 However, a later(?) disturbance in t clastic dike that intruded (landslide-dis end of the LICS (14C loc. 2) and indica major LICS activity coeval with clastic formation of the ancestral Indian Creek sediment from the dike was analyzed a conventional radiocarbon age of 10,19 12,340–11,570; Beta No. 187684); pea conventional radiocarbon age of 10,24 12,360–11,680; Beta No. 188531). Thu clastic dike appears to date to about 12 later than the time of at least partial LI apparent stratigraphic relationships. An supported by an east-west-trending lin

Creek terrace that cross-cuts the LICS commun., March 2004). Though not al LCBCF, this lineament could be a fault Aside from the above, the only evid LCBCF fault activity after RSLM is se and clay (unit Qoa<sub>s</sub>) near the southern These reinforce the record of disturban the north, but they add no stratigraphic The third known fault in the field a Cady, 1978a; Tabor, 1983; Snavely and limit, which elevates the rocks on the n first suggested by Tabor (1975), who i west of our map area. We agree with S extended the fault east of the Elwha to and postulated that it reflects regional,

compression. Dragovich and others (2 the fault on both sides of the Elwha. The fourth known fault is a 2-mi-l inferred to resolve the apparent juxtapo Formation siltstone (unit Em<sub>2a</sub>) and C (Brown and others, 1960; Brown, 1970 exposed in a road rock quarry, we extend to the north of where Brown (1970) ha **DESCRIPTIONS OF MAP UNITS** 



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Callam syncline and appear to include rnmost is located on the north limb of and others (1960) Brown (1970)	Qols	<b>Landslide (late Pleistocene)</b> —Boulders, gravel, sand, silt, and clay in slide body and toe; underlying units in head scarp area; angular to rounded: generally loose: unsorted: generally	<b>Tertiary</b> TWIN R	y Sedimentary and Volcanic Rocks IVER GROUP—Divided into:
), Dragovich and others (2002), and hally named. We refer to the segment	Qols <sub>f</sub>	unstratified, broken, and chaotic, but may locally retain primary bedding structure and include liquefaction features. Includes	<mark>₩</mark> Փՠ <sub>p</sub>	<b>Pysht Formation (Miocene–Oligocene)</b> —Mudstone, claystone, and sandy siltstone; also contains 1- to 20-ft-thick beds of
wha fault, in keeping with the naming own (1970) referred to the same		inactive slides that delivered sediment onto terraces of units Qgo or Qoa during or shortly after their formation; the terraces are now		calcareous sandstone; unweathered mudstone, claystone, and siltstone are medium gray to dark greenish gray; unit weathers
believe that field relations require the ture. Brown and others (1960) and		perched up to 200 ft above modern valley floors, and both units are dissected by modern streams. Some slides lack stratigraphic		pale yellowish brown to medium brown; massive, poorly indurated; marine mudstone may contain thin beds of calcareous
of the structure as upthrown, but we nd others (2002), and Schasse (2003)		evidence to exclude significant more recent activity and were therefore included with unit Qls. Subscript 'f' indicates debris fan,		calcareous concretions; mollusk shell fragments, foraminifera, an
ult runs roughly east to west along the It was inferred (Tabor and Cady.		interfinger with, but are steeper, coarser, and more angular than, alluvial fans (unit Qoat) and reflect a greater hazard from rapid.		with the underlying Makah Formation (unit $\Phi Em_m$ ) (Snavely and others, 1978); approximately 300 ft thick 2 mi west of the Elwha
thers, 2002; Schasse, 2003) to connect ers, 1960) to the east and the Boundary	T A THE XX	high-energy deposition.		River (Brown and others, 1960). Only the lowest strata in the formation are exposed in the map area. The unit contains lower
to the west. Brown (1961) speculated on a map. We refer to this fault as the		<b>Recessional outwash and glaciomarine drift</b> —Gravel, sand, silt,		Saucesian and upper Zemorrian foraminifera (Rau, 1964, 1981, 2000, 2002). Mollusks are indicative of the Juanian Stage
<b>CBCF</b> ). The lidar-based DEM of the and possible scarps along the mapped	Qqoe	clay, and locally peat; glaciomarine drift facies includes pebbly silt and clay and discontinuous layers of silty sand; characterized by	0Em	(Addicott, 1976, 1981). Makah Formation (Oligocene–Eocene)—Siltstone, mudstone,
ver and 0.2 mi north of the Little River	Qgo <sub>i</sub>	locally contain more than 95 percent Olympic sediment; typically well-rounded; loose; generally well-sorted; mostly stratified;	ΦEm	and minor thin-bedded sandstone (unit $\Phi Em_m$ ); basal conglomerate facies (unit $\Phi Em_{mc}$ ) of pebbles and cobbles of
(not shown) in the area. nd older units, but little is known about		glaciomarine drift facies weakly stratified to nonstratified; deposited by meltwater as opposed to modern streams; locally	WEIIImc	varied lithology in a matrix of mostly coarse-grained sandstone; sporadically exposed sedimentary breccia of angular volcanic dabria at the base of the conclomente appears to be creded from
based DEM became available, there ternary movement, except perhaps the		grades up into or interfingers with post-glacial alluvium (units Qoa and Qa). Several subtle topographic steps that roughly		unit $Ev_c$ (Brown and others, 1960); greenish gray to olive-brown, weathers to grayish orange and yellowish brown; dark gray to
ont a few miles west of the field area ps on unit Qgo fluvial terraces suggest		parallel the shoreline on the coastal plain east of the Elwha River may include older, higher, post-glacial shoreline berms. Subscript		black where carbonaceous; massive to thin- and rhythmically bedded; spherical calcareous concretions (often containing fossil
River valley are conspicuous, no scarp		outwash interpreted as ice-contact deposits.		shells and plants) and nodules occur throughout; sandstone is angular, very fine to medium grained, subquartzose, and
e apparent in and near the LICS, but lel to the inferred fault trend. This could	Qgl	<b>Glaciolacustrine sediment</b> —Sand, silt, or clay, locally with northern dropstones; brown to gray; may be massive, laminated,		feldspatholithic; conglomerate facies is massive; unit $\Psi Em_m$ is approximately 1500 ft thick (Brown and others, 1960), unit
upped or that weak splays are scattered on of the post-JFL units west of the		exposures are stiff; includes JFL advance, full-glacial, and recessional lake deposits: may include deposits from earlier		(Brown and others, 1960); crops out about 2 mi west of the Elwh River in a crescent-shaped belt open to the west and spanning bot
CF ground rupture. If the latter is to the age of unit Qgo east of the		glaciations. Along the Elwha valley sidewalls between about 800 and 1100 ft above MSL south of the JFL ice limit, unit Qgl is		limbs of the Clallam syncline; gradational with the more arenaceous rocks of the underlying Hoko River Formation (unit
thern sidewall of Indian Creek valley The sediments in this unit remain		interpreted as a veneer over older Olympic sediment, such as units Qoa <sub>p</sub> and Qols <sub>fp</sub> . The older sediments are inferred based on		Em <sub>2h</sub> ) (Snavely and others, 1978); contains upper Narizian and Refugian foraminifera (Rau, 1964, 2000, 2002).
elative with the onset of crustal pparently occurred about 13.3 ka (Fig.		dissected benches and fans perched on the Elwha valley sidewalls. South of the ice limit, below 800 ft, unit Qgl is widely exposed in	Em <sub>2h</sub>	Hoko River Formation (upper Eocene)—Lithofeldspathic sandstone and siltstone in equal amounts, with pebble-cobble
and others 1995; Mosher and Hewitt, likely time of deposition of unit Qgo		the ice limit, exposures are below 550 ft and less extensive, and landslides less prevalent. The unit is mostly seen in landslides or		conglomerate lenses and laterally and vertically gradational contacts; thick beds of sandstone and pebble-cobble conglomerat
along Little River, suggesting that if the ne fault last caused ground rupture		in subsurface exposures along stream cutbanks, such that few surfaces are mapped as unit Qgl.		occur locally near base of unit along Elwha River; sandstone is gray to olive-gray, fine to very coarse grained to granular, well badded, and this to very thick badded; ellstone contains this bad
valley farther north, it traverses the	Qgt	<b>Juan de Fuca Lobe till</b> —Unsorted and highly compacted mixture		and laminae of very fine-grained sandstone and is well bedded, well indurated, locally cemented with calcium carbonate, and ma
7; Tabor, 1975; Logan and Schuster, Lake Crescent a few miles west of the		by glacier ice of the Juan de Fuca lobe; gray where fresh, light yellowish brown where oxidized; permeability very low where		contain calcareous concretions; 2 mi west of the Elwha River, un thickness reaches 4800 ft on the south limb of the Clallam
d Schuster (1991) speculated that the en triggered by seismicity. Seismic		lodgment till is well-developed; generally characterized by northern source clasts, but locally dominated by Olympic rock		syncline; on the north limb the unit thins to 500 ft, probably due t structural highs in older rocks (Brown and others, 1960);
e for the LICS. consist of ancestral Indian Creek		types, especially where Olympic sediments are abundant in the substrate, such as in the Elwha River delta fan area; most		conformable with the underlying Lyre Formation (units Em <sub>2lc</sub> and Em <sub>2ls</sub> ); contains upper Narizian foraminifera (Snavely and others
st-dates deposition of the eastern flank this terrace implies that the terrace and		commonly matrix supported, but locally clast supported; matrix more angular than water-worked sediments; cobbles and boulders	тертіл	1980; Rau, 2000).
nt was dammed; if all major slide ally triggered by the LCBCF, it implies and 13.3 ka and a slightly lowered sea		across short distances from less than 0.5 to 20 ft thick; thicknesses	OLDER	THAN THE TWIN RIVER GROUP
ancestral Indian Creek terrace on the rebound was very rapid, such a slightly		silt, and gravel, or loose ablation till that is too thin to substantially mask the underlying, rolling till plain; erratic	Em <sub>2lc</sub>	<b>Lyre Formation (middle Eocene)</b> —Conglomerate and sandst one (unit $Em_{2lc}$ ) overlies and is interbedded with sandstone and minor thin hedded interbedded conductors and siltators (unit
the RSLM by a few hundred years at 70; Booth, 1987; Mosher and Hewitt,		boulders commonly signal that this unit is underfoot, but such boulders may also occur as lag deposits where the underlying	Em <sub>2ls</sub>	Em <sub>2ls</sub> ). Conglomerate is subdivided into lenticular or channel deposits of well-indurated well-rounded thin- to very thick
the area is recorded by an organic		deposits have been modified by meltwater; typically, weakly developed modern soil has formed on the cap of loose gravel, but		bedded pebble to boulder conglomerate and pebbly sandstone. Conglomerate also contains lenses of fine-grained to granule
isturbed?) till (from below?) at the east ates either more recent seismicity or		the underlying till is unweathered; local textural features in the till include flow banding. Unit Qgt lies stratigraphically between		sandstone. Conglomerate clasts are dark gray to black argillite, quartzite, chert, metavolcanic rocks, gneiss, quartz, and minor
ek terrace east of the LICS). Organic		outwash (unit Qga). Unit Qgt may include local exposures of older till that are indistinguishable in stratigraphic position lithology		basalt. Sandstone is lithic, phyllitic, and quartzose, light olive- gray, thick bedded, and well indurated. The Lyre Formation is at
$90 \pm 60$ <sup>14</sup> C yr B.P. (2 $\sigma$ cal yr B.P. at from the same sample yielded a		and appearance.		least 1000 ft thick 1.5 mi west of Lake Aldwell, but quickly thins to the west (Brown and others, 1960) and pinches out to the east i the "Dry Hills". It rasts conformably upon and interfingers with
$40 \pm 60^{14}$ C yr B.P. (2 $\sigma$ cal yr B.P. nus the disturbance recorded by the	Qga	Advance outwash—Sand and sandy people to cooble gravel; local silts and clays; may contain till fragments; dominated in most exposures by northern sediment; compact; gray to gravish		the upper part of the Aldwell Formation (unit $Em_{2a}$ ) and contains foraminifera assigned to the upper Narizian Stage (Snavely, 1983)
2,360 to 11,570 ka (Fig. 1), somewhat ICS emplacement suggested by	Qga <sub>s</sub>	brown and grayish orange; clasts well rounded; well sorted; parallel-bedded, locally cross-bedded; most exposures less than 20	Em <sub>2a</sub>	Aldwell Formation (middle Eocene)—marine siltstone and
a more recent event may also be neament across the ancestral Indian		ft thick, but in sea cliffs 2 to 4 mi west of the Elwha thickness may exceed 50 ft; elsewhere, the unit is missing from the section. Unit		feldspatholithic sandstone; siltstone contains thin sandy laminations and local thin to medium beds of fine-grained
aligned with the mapped trend of the lt scarp.		Qga is commonly overlain by unit Qgt along a sharp contact and is stratigraphically above units Qoa <sub>p</sub> and Qu <sub>p</sub> . The age of unit Qga		limestone or calcareous very fine-grained sandstone and sporadically distributed lenses of unsorted pebbles, cobbles, and
idence noted herein for possible evere liquefaction features in sand, silt,		in the project area is suggested by <sup>14</sup> C ages of "18,265 $\pm$ 345" and "17,350 $\pm$ 1260" from bluff exposures at Port Williams, 20 mi to the cast (Blunt and others, 1987). Subscript 's' indicates that		boulders of basalt; pillow basalt, lenses of basalt breccia, and water-laid lapilli tuff (unit Evb <sub>a</sub> ) occur near the base; lenses and
n valley sidewall of Indian Creek valley. nce by seismicity or by the landslide to		deposits are mostly sand-size or finer and are likely glacio- lacustrine. Unit Qgae may contain dropstones and is characterized		pods of rhyolite (unit $Evr_a$ ) occur in the lower and midsection of the unit in the Dry Hills. Siltstone is olive-gray to black, thin- to
area is the Crescent fault (Tabor and ad others, 1003) near the southern map		by planar laminations but may locally include cross-bedding and soft-sediment deformation features. Although rarely exposed at		and weathers to brown and olive-gray. Calcareous beds weather tan. At the type locality on Lake Aldwell, the unit is about 2950 f
north over those on the south. It was		the surface, such glaciolacustrine sediments are more common in the subsurface and locally reach thicknesses of >70 ft in the		thick (Brown and others, 1960). Unit is characterized by lower Narizian foraminifera, indicating a middle Eocene age
Snavely (1983) and Tabor (1983), who the southeastern corner of our map	PL FIST	sidewalls of the Elwha and Little River valleys.		(Armentrout and others, 1983; Rau, 1964). Divided into:
, post-early Eocene north–south 2002) and Schasse (2003) likewise show	Qup	<b>Undifferentiated sediment</b> —Gravel, sand, silt, clay, peat, and till, wrighly pertod, mostly hedded, compact, maximum this	Evba	consists of pods and tongues up to 350 ft thick and occurring up to 1000 ft above the base of unit $\text{Em}_{2a}$ (Brown and others, 1960).
long, roughly north-trending structure		~200 ft; contains both northern and Olympic glacial and nonglacial deposits. Shoreline exposures 0.3 to 1 mi east of the	Evra	<b>Rhyolite (middle Eocene?)</b> —Tan to gray, aphanitic to porphyriti
Crescent Formation basalt (unit Ev <sub>c</sub> )		map area may laterally grade into unit Qoa <sub>p</sub> , suggesting that an ancestral Elwha River may have carried sediment several miles		breccias, and possible intrusive plug; texture is trachytic to pilotaxitic with phenocrysts of sanidine(?); also includes chlorite.
ended this fault approximately 1500 ft ad terminated it.		further east than the modern Elwha. Analysis of wood fragments obtained from a sand facies 78 ft below the surface in a water well		magnetite, pyrite, zircon, garnet, and possible epidote. Whole-roc XRF analyses are listed in Table 1. Brown and others (1960) also
S		$({}^{14}C \text{ loc. 1 on map})$ yielded a conventional radiocarbon age of 37,800 ±1100 ${}^{14}C$ yr B.P. (Beta No. 187683), correlative to marine		noted garnet and epidote in silicic volcanic rocks at Striped Peak just west of the map area.
sand graval organic matter rin ran		oxygen isotope stage 3 (~ $10-18$ ka). A peat sample collected near sea level from the shoreline bluff at the west end of Ediz Hook (1 mi east of the man area) yielded a radiocarbon date of >44.620	Evc	<b>Crescent Formation (middle and lower Eocene)</b> —Marine, subalkaline, pillow dominated basaltic rocks; includes minor
vate and reshape the land surface; on-engineered fills: shown only where		<sup>14</sup> C yr B.P. (Beta No. 123218), suggesting an age correlative to marine oxygen isotope stage 3 or older for the lower part of that		aphyric basalt flows, and minor gabbroic sills and dikes; may contain thin interbeds of basaltic tuff, chert, red argillite,
extensive, sufficiently thick to be of and readily verifiable.		section. We postulate that the nonglacial deposits within unit Qu <sub>p</sub> are likely dominated by sediments of marine oxygen isotope stage		inmestone, suitstone and abundant chlorite and zeolites; inclusions of marine sedimentary rocks are mapped as subunit $Em_{1c}$ ; dark gray to dark greenish gray weathers to dark brown means in the
—Soil, sediment, or other geologic		3. The northern source sediments within the unit are undated but local stratigraphic relations suggest that they are mostly pre-late		flows, basalt breccia, massive diabasic basalt, and volcaniclastic sandstone and conglomerate all grade into each other both
es mappable sand and gravel pits s Qga and Qoa <sub>p</sub> .		Wisconsinan (that is, oxygen isotope stage 4 or earlier). Most exposures of Qu <sub>p</sub> are dominated by Olympic sediment, such that porthern sediments are generally too isolated to suggest inference		laterally and vertically. Whole-rock XRF analyses are listed in Table 1. In the map area, the unit forms a 3.5 to 4.5 mi-wide belt.
e)—Sand and cobbles, may include silt, ers; usually a mix with variable		of coherent layers, except in landslide scarps along the shoreline bluffs from the western map edge 2 mi to the east. Northern		Reported ${}^{40}$ Ar/ ${}^{39}$ Ar plateau ages range from 45.4 Ma to 56.0 Ma (Babcock and others, 1994), where the youngest age was from the
d Olympic rocks, but within 1 mi west River, dominated by Olympic rocks;		sediments may locally include late JFL advance outwash.		base of the unit, causing Babcock and others (1994) to suggest that the basalts may be part of separate extrusive centers; contains for aminiferal assemblances referable to the Depution to Lucician
ts typically well rounded and flat; except near Port Angeles landfill, where	Qoap	silt, clay, and peat; variably sorted; compact; crudely bedded; may locally include lacustrine and beach deposits; likely dominated by		Stages (Rau, 1964). Divided into:
ented by hematite and other minerals. ravel, sand, silt, clay, and peat; variably		outwash from Olympic alpine glaciation(s) (Thackray, 1996), with typically <1% northern clasts; local paleoflow directional		Em <sub>1c</sub> Marine sedimentary rocks (middle and lower   Eocene) —Flow breccia, tuff breccia, volcanic   conglomagetta, and volcanolithia sandstance lass
osited in stream beds and estuaries, and de some lacustrine and beach deposits;		indicators suggest northeast to northwest flow of an ancestral Elwha River. Unit Qoa <sub>p</sub> is stratigraphically beneath JFL till in the		commonly chert and calcareous argillite; clasts mostly basalt and diabase: lithic, calcareous, and fossiliferous
ades down into units Qoa or Qgo where		Elwha River delta fan area, where its thickness ranges from 100 to >250 ft and exposures of the unit overlie either bedrock or up to 50 ft thick sections of fining unward northern sediment (unit		gray, green, red, or black; well stratified; breccias, tuff and sandstones are normally graded; unit occurs as thi
ot 's' indicates mostly sand-size or finer		$Qu_p$ ). Unit $Qoa_p$ likely dates to marine oxygen isotope stage 3 (~70–18 ka) or earlier, but could represent an Olympic recessional		tongues and isolated lenses of sedimentary rock within unit Ev <sub>c</sub> ; Foraminifera range in age from Penutian to
ir upper end with debris slide fans (unit es historic delta deposits (prograded into		outwash pulse from the alpine glaciation that preceded the arrival of the JFL ice early in the late Wisconsinan.		Ulatisian (Rau, 1981, 2000). Blue Mountain unit of Tabor and Cady (1978a)
and organic-matter-rich mineral	Qols <sub>fp</sub>	<b>Debris slides</b> —Boulders, gravel, sand, silt, and clay in debris slide fan deposits: may include a draping of unit QqI and expose		(Eocene–Paleocene?)—Lithic sandstone, siltstone, argillite, granule or pebble conglomerate, and siltstone
sed depressions; includes peat, muck, nt to wetlands.		underlying units in head scarp and slide track areas (included only where distinct); slide material angular to rounded; unsorted;		or slate-clast breccia; gray to black; laminated and rhythmically bedded; believed to be a submarine
Boulders, gravel, sand, silt, and clay;		generally unstratified, broken and chaotic, gravel to boulder clast- supported; likely to interfinger at distal (downslope) end with		locally very thick; contains black plant material concentrated along fine-grained laminations:
ng slope-parallel planes; loose; l dry raveling along (typically steep)		coeval anuvium (interred beneath unit Qgl). Unit Qols <sub>fp</sub> is mapped on midslope benches along the Elwha valley sidewalls between about 800 and 1100 ft above MSL (>400 ft above the modern		interfingers and is in fault contact with the Crescent Formation unit $Ev_c$ ; contains foraminiferal assemblage
colluvium was noted in the field and is nick.		valley floor) and south of the apparent JFL ice limit. The benches are locally blanketed with a veneer of unit Qol. The fans appear to		of Ulatisian or older stages (Rau, 2000).
—Boulders, gravel, sand, silt, and clay; be locally stratified; typically loose;		grade to a paleovalley floor at their terminus, and dissection by modern drainages indicates that they are no longer active slide		
ium-covered slopes that appear ns exposures of underlying units and		areas. The fans are interpreted as pre-Wisconsinan debris fans on the basis of location, field relations, and geomorphic		
ould not map with confidence or are too eatures.		characteristics.		
oulders, gravel, sand, silt, and clay in ring units in head wall and head scarp				
h landslide areas, except in the LICS, all are mapped as bedrock; angular to				
iy loose, unstratified, broken, and tain primary bedding structure;		di dip and SW		
an soil creep and frost heave; typically with surrounding units. Unit includes		) strike ar lings to NE		
t') slides that cannot be age-correlated Landslides shown where scale permits.	W	A No sea		A' East
slide does not imply absence of sliding icates debris fan, which may include	600	J MNW, app. J AXIS (ap)	Wells are iden Ecology identit and others (20	tified by the Washington State Department of fication tab number or by the well ID used by Atkins 103). Bedrock structure in the area is best illustrated
Depris fans interfinger with but are		S3,37 Proxi	on a north–sou	Jth cross section (see Schasse and others, 2004).

vertical exaggeration 10X

profile of surface from lidar-based DEM

**Older alluvium (late Pleistocene)**—Gravel, sand, silt, clay, and peat; variably sorted; loose; generally bedded; deposited in stream beds and estuaries and on flood plains; may include some lacustrine and beach deposits; mostly Olympic sediments; locally grades down into and may interfinger with unit Qgo; contains isolated (typically <3%) northern clasts. Subscript 's' indicates dominantly sand-size or finer material. Subscript 'g' indicates that gravel dominates. Subscript 'f' indicates alluvial fan. Alluvial fans typically interfinger at their upper end with debris slide fans (unit

# **GEOLOGIC SYMBOLS**

		Contact—long dashed where approximately located; short dashed where inferred; queried where uncertain
		Contact—location changed to conform to base map inaccuracy
D U	.D. U	High-angle dip-slip fault—dotted where concealed; relative offset shown by U and D
		Thrust fault, sawteeth on upper plate—dashed where inferred; dotted where concealed
?		Possible fault of unknown displacement; inferred, queried
	••••	Syncline, concealed—arrow shows direction of plunge
		Boundary of Lower Indian Creek slide complex—dashed where inferred
<u></u>	Lands	lide scarp, hachures on downslope side
$\sim$	Direct	ion of landslide movement
<u></u>	Terrac	e, hachures on downhill side
60	Strike	and dip of beds
<u> </u>	Strike	of vertical beds
	Southe hachur	ern limit of late Wisconsinan continental glaciation, res toward ice, dashed where approximately located
AFL 967	Water	well
◆ 3	Geoch	emistry sample locality
$\Delta^1$	Radio	carbon ( <sup>14</sup> C) sample locality

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Figure 1. Relative sea level and time line of events in the field area from the late Wisconsinan glaciation to the present. Post-glacial sea level curve mostly after Mosher and Hewitt (2004). Age control based on previously published radiocarbon dates, except for disturbance event at LICS (see text under Large-Scale Landsliding and Structural Geology). We used CALIB REV 4.4.2 software to convert (to ka) age estimates that were previously published in <sup>14</sup>C yr B.P. Upper axis is labeled in <sup>14</sup>C yr B.P. and is a nonlinear time scale. Lower axis is labeled in ka and

		*	—— Radio	ocarbon year	s befo	ore present ( <sup>14</sup> C ky B.P.)		
17 300	7 <sup>14</sup> C ky B.P. 14	.5 1:	2.6 1 <sup>′</sup>	1.6 10	0.7 9	.4	5	0
200	Maximum rela Mathews and others (1970) report 2 — Abc at least 2	tive sea level not established in the map area. 250 ft near Victoria on Vancouver Island, B.C. ut 12,600 ±200 <sup>14</sup> C yr B.P., relative sea level 130 ft above MSL (Dethier and others, 1995)	RSLM 13,285 ka					
100		2 nourined in field area	Global seale	A (U G fr	pproxin sing C. SC-111 om the	nate timing of MSL intercept suggested by pooling ALIB, v. 4.4.2) of five 14C dates (I-3675, GSC-1130, 4, GSC-1142, GSC-1131) (Clague and others, 1982) Victoria area, B.C.	),	
MSL		2 ine sea level rise made	212,804 ka (1, 1; 2)	11,422 ka	out 10	720 ±60 <sup>14</sup> C yr B.P.,	Minor global sea-level rise continues to present; relative sea level likely near-constant (Mosher and Hewitt, 200-	ł)
-100	- as the ad esten of	relu-		eld near based	on data Moshe	from near Victoria, B.C., and Hewitt, 2004) Gold <sup>10</sup>		. 1950)
-200	Global sea level rise.	Global sea level rises due to deglaciation (	ice-cap melting	ি ?⊢ 11,127 ka and thermal expa	nsion o	10,334 ka f seawater)	Shoreline erosion causes 3000 to 5000 ft of coastal retreat,	(A.D
	Ice covers the map area	$ \rightarrow$ ? Ice sheet collapses	Major glacio-is establishmen	ostatic rebound a t of modern drain	nd rapi age pat • 10.7	d incision of steep-walled post-glacial valleys; tern ends widespread deposition of unit Qoa ka: glacio-isostatic rebound is substantially complete	establishing modern shoreline bluffs (Galster, 1989)	
	Juan de Fuca Juan de Fuca lobe ice advances into map area	←	Dead ic highest terraces along Little R	e melts	– <b>–</b> → (past 93	Chunks of dead ice may $-2 \rightarrow 2 \rightarrow$ locally persist past ~10.2 ka $80 \pm 180^{-14}$ C yr B.P., Heusser, 1973)		
		Qgo deposition (meltwater driven) ★	Qgo depositi	on drops off, then	$\stackrel{\text{ceases}}{-}$	as meltwater supply runs out 	Alluvial valley floors convey sediment downstream	
	?	? ←? ← -? ← ← Post-glacial activity on the LC	CBCF?	→ ?	Bedro	level in lower reaches of larger coastal streams ck-defended valley floors continuously deepened (ex-	without significant aggradation or degradation xdept where aggraded with Qa after 10.7 ka)	→ 
		LICS emplacement (post-glacial; may include Disturbance event at the LIG	S 12,360 ka	i11,570 ka	. 0			
	20 ka 10 18 1	7 16 15 14	12	10 44	0			
	20 Ka 19 18 1	1 10 15 14	I 3	⊐∠ 11 - Calendar v	ears h	pefore present (ka) $\longrightarrow$	b 5 4 3 2 1	0

Table 1. Geochemical analyses for the Elwha quadrangle performed by x-ray fluorescence at the Washington State University GeoAnalytical Lab. Instrumental precision is described in detail in Johnson and others (1999). Major and trace elements normalized to 100 on a volatile-free basis, with total Fe expressed as Fe; LOI%, percent loss on ignition

Loc. no.	Sample no.	Geologic unit, rock type	Chemical analysis	SiO <sub>2</sub>	т	iO <sub>2</sub>	Al <sub>2</sub> O <sub>3</sub>	Fe	0	MnO	Mg	gO	CaO	Na <sub>2</sub> O	K	<b>Z</b> <sub>2</sub> <b>O</b>	P <sub>2</sub> O <sub>5</sub>	Origi tota	1al I LOI(%
1	HS-49	Evr <sub>a</sub> , rhyolite	rhyolite	74.42	2 0.	246	12.63	3.6	57	0.077	1.9	0	0.68	5.77	0.	.31	0.060	99.2	7
2	HS-53	Evr <sub>a</sub> , rhyolite	rhyolite	69.91	0.	264	15.17	5.2	27	0.056	0.6	57	0.41	6.96	1.	.06	0.075	98.7	4
3	HS-54	Evr <sub>a</sub> , rhyolite	dacite/rhyolite	70.70	) 0.	298	13.82	4.5	57	0.090	1.6	58	2.24	5.57	0.	.65	0.048	99.6	2
4	HS-55	Ev <sub>c</sub> , diabase	basalt	48.14	1.	651	15.40	12.	05	0.202	9.4	6	8.81	3.49	0.	.49	0.151	97.2	8 6.15
5	HS-56	Evr <sub>a</sub> , rhyolite	rhyolite	77.08	<b>3</b> 0.	126	12.26	2.4	18	0.046	0.7	2	0.57	4.75	1.	.86	0.016	99.8	2 1.67
6	MP-98	Ev <sub>c</sub> , basalt	basalt	49.24	1.	036	14.51	12.	00	0.211	8.2	25	11.75	2.42	0.	.33	0.102	98.9	2
7	MP-35	Ev <sub>c</sub> , diabase	basalt	49.29	) 1.	124	13.99 12.88		88	0.271 8.53		53	10.74	2.93	0.	.03	0.088	98.1	5
TRACE	ELEMENTS-	-NORMALIZED (parts per	r million)																
Loc. no.	Sample no.	Geologic unit, rock type	Chemical analysis	Ni	Cr	Sc	V	Ba	Rb	Sr	Zr	Y	Nb	Ga	Cu	Zn	Pb	La	Ce Tł
1	HS-49	Evr <sub>a</sub> , rhyolite	rhyolite	8	4	8	4	1088	6	195	586	94	23.6	19	8	160	5	18	41 5
2	HS-53	Evr <sub>a</sub> , rhyolite	rhyolite	6	7	7	6	324	16	153	657	117	31.2	30	2	181	5	22	49 5
3	HS-54	Evr <sub>a</sub> , rhyolite	dacite/rhyolite	31	54	11	37	2187	10	245	431	124	24.5	24	21	158	4	24	59 3
4	HS-55	Ev <sub>c</sub> , diabase	basalt	91	242	44	316	73	7	235	117	33	9.0	19	136	91	2	4	24 1
5	HS-56	Evr <sub>a</sub> , rhyolite	rhyolite	6	4	3	6	192	38	43	303	77	69.8	21	10	80	2	14	32 10
6	MP-98	Ev., basalt	basalt	90	264	49	369	53	5	142	64	28	2.8	16	168	91	3	7	10 0